Final report

Dual purpose crops for lamb production in southern QLD and northern NSW

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Abstract

The project aimed to understand the financial and animal health benefits of an alternative autumn lambing time and of dual purpose crops for prime lamb production in the summer rainfall zone. The project had a modelling component considering multiple locations and a field trial component based in Armidale NSW. Although limited by circumstances (drought and Covid19), producer engagement was sought throughout the project. Model the outcomes of providing DPC grazing and of changing lambing time for financial and animal health outcomes.

Demonstrate through communications and a field trial the potential effects of providing DPC grazing and of changing lambing time on a prime lamb production enterprise.

Recruit and train a postdoctoral scientist capable of farm systems modelling research.

We demonstrated autumn-lambing as a strategy for responding to the looming issue of drench resistance. We uncovered a need for further education of producers about the options available for optimising sheep reproduction. We also identified a need for further research on feedbase optimisation considering year to year variation in an increasingly unpredictable climate and the financial realities of attempting a cropping enterprise.

Executive summary

Background

We aimed to use a formal test of the value of both autumn lambing and dual purpose crops (DPC) across the northern NSW southern QLD region using modelling followed by a field trial demonstration in the Armidale area, as a co-learning platform where researchers and producers could conduct research work together. The research output will be of use to producers and producer advisors, especially when the mix of enterprises and/or the timing of operations and/or the types and diversity of feedbase provision options on the farm are being re-considered.

Objectives

Model the outcomes of providing DPC grazing and of changing lambing time for financial and animal health outcomes.

Demonstrate through communications and a field trial the potential effects of providing DPC grazing and of changing lambing time on a prime lamb production enterprise.

Recruit and train a postdoctoral scientist capable of farm systems modelling research.

Methodology

Modelling was undertaken using multiple software platforms to analyse whole farm systems, the demand of livestock for feed and the provision of feed to meet that demand, the outcomes for gastrointestinal parasites (GIN) and blowfly control and the financial performance of farms.

A field trial was undertaken testing the combination of two lambing times (May – "Autumn" and August – "Spring") and feed regimes including pasture only ("Pasture only", or with 25% of the land area growing DPC and the remainder pasture ("DPC/Pasture"). There were two 4 ha farmlets for each of the four combinations. Each of the eight farmlets housed 20 Merino ewes, mated to White Suffolk rams, with ewes and lambs kept within the farmlets for the entire study period. Three production cycles were followed beginning in December 2018 and ending in June 2022.

Producer engagement was undertaken via an advisory committee, field days and online presentations.

Results/key findings

Modelling

Whole farm modelling predicted a benefit from DPC within lamb production systems in four locations in NSW (Armidale, Gulargambone, Goulburn and Temora). The benefit of DPC was predicted for both autumn and spring lambing across three stocking rates in Armidale, Goulburn and Temora. At Gulargambone during the 20% lowest gross margin years, dual purpose crops decreased the gross margin in spring, but not autumn lambing systems. Autumn lambing was superior to spring lambing in most circumstances except at Gulargambone at low and medium stocking rates, and at Temora when stocking rates were low. During the 20% lowest gross margin years, the benefit of

autumn lambing at high stocking rates in Temora was negated, with spring and autumn lambing having similar financial performance.

The negative effects of GIN are principally experienced through reductions in meat and wool production. Our modelling showed losses are higher at higher stocking rates because of increased transmission of infective larvae between animals. The modelling also showed that autumn lambing reduced the losses of meat and wool production caused by GIN in most circumstances. The provision of DPC increased losses from GIN somewhat, and these effects were exacerbated at lower stocking rates.

Fly strike is predominantly a summer problem in the target area. The modelling we undertook in collaboration with TIA shows that autumn lambing significantly reduces the number of lambs exposed to flystrike (Merino lambs sold for meat) and that faster lamb growth rates increase the advantage of autumn lambs. There is insufficient background data to model cross bred lambs.

It should be remembered that modelling experiments can only be used to predict outcomes in production systems, and it was necessary to conduct field trials to clarify the applicability of the modelling experiments to producers in NNSW and SQLD.

Field Trial

The field trial was conducted at CSIRO's Chiswick research station near Uralla (Northern Tablelands of NSW) over a period where there was an extreme drought, followed by two wetter than average years. All farmlets made financial losses in the first, drought year due to expenditure on drought feed (we did not have a de-stock option in the experiment). The farmlets with DPC had lower expenditure on drought feed, but this did not prevent a loss occurring. In the subsequent two production cycles all farmlets made a profit. The DPC enterprises produced useful grazing in the first and second production cycles but did not generate a grain crop in the first production cycle. In the third production cycle wet weather prevented sowing of crops until after the optimum sowing window, and these crops provided neither grazing or a grain crop. Grain crops had higher expenditure than income in the first two years, excluding the benefit of the crops to the grazing enterprise.

Production cycle one financial performance

Expenditure exceeded income for all the treatment groups during the first production cycle due to drought feeding. The autumn lambing farmlets with DPC/pasture had a less negative outcome for the lamb enterprise compared to autumn farmlets with pasture only, and similarly the spring lambing farmlets with DPC/pasture had a less negative outcome for the lamb enterprise compared to spring farmlets with pasture only. When the costs of the failed crop are included for a combined lamb and crop enterprise assessment of financial performance, this reverses the effect of the DPC/pasture treatment so that for both autumn and spring lambing the pasture only farmlets had a less negative outcome than the DPC/pasture farmlets.

In the first production cycle, when comparing between lambing seasons within feed regimes, the spring lambing farmlets had a less negative financial outcome for the lamb enterprise than the autumn lambing farmlets for the lamb enterprise. The first production cycle for the spring lambing systems extended beyond the drought, so a lower amount of drought feeding was necessary for the spring lambing compared to the autumn lambing systems.

The overall ranking of production systems considering both crop and lamb enterprises was:

1. spring lambing, pasture only
2. autumn lambing, pasture only
3. spring lambing DPC/pasture
4. autumn lambing DPC/pasture

Production cycle two financial performance

In the second production cycle income exceeded expenditure across all the farmlets. As for production cycle one, in production cycle two the autumn lambing farmlets with DPC/pasture had a higher net income for the lamb enterprise than the autumn lambing pasture farmlets for the lamb enterprise. However, the crop enterprises incurred higher expenditure than income in the second production cycle, so that when assessed together the combined net income for the autumn lambing systems was higher for the pasture only feed system.

The second production cycle for spring lambing farmlets had an outcome opposite that of the first production cycle with respect to the feeding regime. In production cycle two the spring lambing farmlets with DPC/pasture had a lower net income for the lamb enterprise than the spring lambing pasture farmlets for the lamb enterprise. The crop enterprises incurred higher expenditure than income in the second production cycle, so that when assessed together the difference in combined net income for the spring lambing systems was greater than when the lamb enterprise was considered alone.

In the second production cycle the lamb enterprises with DPC/pasture had higher net income for the autumn lambing farmlets than the spring lambing farmlets, but the opposite was the case for the pasture only farmlets. The inclusion of the crop enterprise did not change the comparison between autumn and spring lambing groups within the DPC/pasture farmlets.

The overall ranking of production systems considering both crop and lamb enterprises was:

1. spring lambing, pasture only
2. autumn lambing, pasture only
3. autumn lambing DPC/pasture
4. spring lambing DPC/pasture

Production cycle three financial performance

In the third production cycle income exceeded expenditure across all the farmlets, but the cropping enterprises did not commence due to poor sowing conditions, so only the lamb enterprise can be assessed. Despite the absence of crops, the DPC/pasture systems had higher net income than the pasture only systems for both spring and autumn lambing systems during the third production cycle. For the pasture only farmlets, the autumn lambing system had a higher net income than the spring lambing system, but the DPC/pasture systems the spring lambing systems had the higher net income.

The overall ranking of production systems considering the lamb enterprises in the absence of a crop enterprise was:

1. spring lambing, DPC/pasture
2. autumn lambing, DPC/pasture
3. autumn lambing pasture only
4. spring lambing pasture only

Accumulative net income across three production cycles

The overall ranking of production systems considering both crop and lamb enterprises was:

1. spring lambing pasture only
2. autumn lambing pasture only
3. spring lambing, DPC/pasture
4. autumn lambing, DPC/pasture

Note however, the differences in total net income between spring and autumn lambing systems are not statistically significant, whereas the differences between the two feed regime systems ($p=0.003$) and between production cycles ($p<0.001$) are significant, as is the interaction between these ($p=0.004$). The interaction is because the DPC/pasture system had a lower net income for the first two production cycles compared to pasture only systems and a higher income relative to the pasture only systems in the third year. This is purely because the cropping operation was not undertaken in the third production cycle.

Animal health

Animal health costs were lower for the autumn prime lamb enterprises in each of the three production cycles. The benefit of autumn lambing for animal health outcomes was clear across all the production cycles and feed regimes. The number of drenches necessary for autumn lambs was reduced compared to spring lambs in all three production cycles, and the number of treatments for hoof and limb issues was also lower for autumn lambing ewes. Ewes in the DPC/pasture farmlets were generally treated for lambing/lactation issues fewer times than pasture-only ewes, though during the second production cycle DPC/pasture farmlet ewes were treated more often. Contrary to the model predictions, autumn lambs experienced flystrike at a similar rate to spring lambs, although the rates of flystrike in these crossbred lambs in either season was much lower than the model predictions for merino lambs.

Feed provision

Feed provision was more often in surplus relative to DM demand throughout the trial (77% of grazing events where supply exceeded demand), however when we included an allowance for 25% pasture loss through trampling, there were many more grazing events with a deficit of DM provided (36%). The grazing events for the autumn lambing DPC/pasture animals had a higher rate of deficits (48%), compared to autumn pasture only (38%) or the spring pasture only group (32%), whilst the spring lambing DPC/pasture only group had the lowest number of grazing event deficits (27%).

Field Trial compared to model outcomes

There were multiple aspects of the field study that were either not taken into account in the model simulations or where the outcomes in the field trial differed to the predictions from the simulation model.

The growth rate of lambs can be influenced by factors other than the provision of feed, and model simulations are not always accurate.

There is not a current model of sheep reproduction which allows for the influence of melatonin implants.

The costs of various inputs, and prices received for outputs, are variable and so financial outcomes can vary significantly from model predictions, this is an inherent property of most whole farm system models.

Industry communication

The drought, and then the Covid19 pandemic had negative impacts on our ability to communicate with producers and consultants. Hand feeding during the drought meant that producers did not have time for communication activities, and Covid19 precluded any fact to face communication until December 2021. Despite these limitations communication activities were conducted and opportunities for producer feedback on the project were provided.

Surprisingly (for researchers), producers most often questioned us about the methods used to conduct autumn lambing. The melatonin implant product (Regulin®) necessary for achieving out of season mating in spring/summer was first registered in South Australia in 1988 and has been registered nationally since 2002. Despite this, many producers were unaware of the product, its effects, or the need to use strategies for achieving ovulation out of season.

Although we conducted some wool testing during the project, producers raised some questions about the effect of changing lambing season on wool quality characteristics. If pre-lambing shearing is adhered to, as in the field trial we conducted, there were no differences in wool quality between spring and autumn lambing ewes. However, producers asked if there might be effects if the same shearing time was employed for both spring and autumn lambing ewes. This issue was beyond the scope of the project.

Producers were clearly interested in the modelling and the animal health outcomes. The project addressed animal health issues only in the context of summer-dominant rainfall situations. The interactions between lambing time and animal health outcomes in other environments cannot be understood without conducting similar work in those other environments.

Benefits to industry

The future holds uncertainty for lamb production. This work has provided insights into the possible outcomes of adopting feedbase provision through DPC in future climate scenarios relative to enterprise profitability. The research has also shown a methodology for reducing reliance on drenches in a future where many drench product actives will be rendered ineffective due to drench resistance.

Future research and recommendations

Drench resistance is a national issue not limited to summer rainfall environments. Further research to establish optimal systems to avoid GIN and therefore drenching across environments is needed. The interaction of livestock system optimisation (e.g. autumn lambing) with other strategies to reduce GIN such as the use of vaccines or breeding for worm resistance is not yet understood. Given the uncertain future for GIN control via anthelmintics, researching these optimal strategies should be a high priority.

Current climate variability and future continuation of climate changes will make feedbase optimisation for prime lamb and grass-fed beef production a significant problem for producers. We explored the provision of DPC to help fill feed gaps and this had varying effects across years and (via modelling) in different regions of NSW. We observed spring and summer feed gaps in addition to winter feed gaps during the research. A far greater effort is needed to research appropriate feed gap provisions for producers.

Table of contents

Dual purpose crops for lamb production in southern QLD and northern NSW 1

Executive summary 3

1. Background 11

2. Objectives 13

3. Methodology 14

3.1 Whole Farm Systems Modelling 14

3.1.1 Lamb production and feedbase 14

3.1.2 Gastro-intestinal parasites 22

3.1.3 Fly strike 24

3.2 Field Demonstration Trial 25

3.2.1 Site set up and baseline data 25

3.2.2 Crop production 27

3.2.3 Lamb production and animal health monitoring 28

3.2.4 Statistical analysis 32

3.2.5 Gross margins 33

3.3 Producer Engagement 33

3.3.1 Northern Advisory Committee 33

3.3.2 Field days, webinars and podcast 33

3.3.3 Data use for model improvement 34

4. Results and Discussion 34

4.1 Whole Farm Systems Modelling 34

4.1.1 Lamb production and feedbase 34

4.1.2 Gastro-intestinal parasites 48

4.1.3 Fly strike 50

4.2 Field Demonstration Trial 52

4.2.1 Crop production 52

4.2.2 Lamb production 63
4.2.3 Animal health monitoring...83
4.2.4 Gross margins 89
4.3 Producer Engagement 94
4.3.1 Northern advisory committee 94
4.3.2 Field days, webinar and podcast 94
5. Conclusion.. 96
5.1 Key findings 96
5.2 Benefits to industry 97
6. Future research and recommendations 97
7. References 102
8. Appendices 105
8.1 Appendix 1 Soils and field site 105
8.1.1 Soil types at the field demonstration site 105
8.1.2 Images of the field demonstration site 111
8.2 Appendix 2 Sources of information for net income calculations.. 112
8.3 Appendix 3 Weather over the period of the field trial................. 114
8.4 Appendix 4 Rising plate meter calibration 117
8.5 Appendix 5 Reproductive performance for individual farmlets... 118
8.6 Appendix 6 Supplementary feeding.. 120
8.7 Appendix 7 Statistical analysis of lamb weight and growth parameters within and across production cycles 123

1. Background

Lamb production in the NSW/QLD summer rainfall zone is predominantly based on winter/spring lambing. In this environment, lamb mortality can be up to 30% (Allworth et al. 2017), and post-weaning conditions risk Barber's pole worm infection (Southcott et al., 1972), fly strike (Ward, 2001) and grass seed damage (Holst et al., 1996). Producers in winter and non-seasonal rainfall zones often conduct autumn lambing (Masters and Thompson, 2016). In these areas, dual purpose winter crops (DPC) have been used to fill the winter feed gap and increase whole farm income by up to $100/ha (Bell et al., 2015). The winter feed gap and insufficient experience with DPC prevents northern NSW and southern QLD producers from adopting autumn lambing, and this affects beef producers as well. In southern Queensland, the winter feed gap is especially evident from May to September in typical beef enterprises, and this feed deficit has an accumulative effect on feed availability in spring (Moore et al., 2009). In contrast the feed gap begins earlier in Wimmera region of Victoria where it occurs from January through to July. Agricultural systems modelling and recent producer experience show that DPCs can be grown in summer rainfall areas, producing forage to fill the winter feed gap, increasing lamb or beef production and providing an economic grain yield.

Although some producers have adopted autumn lambing in the NSW/QLD summer rainfall zone (~20% increase between 2004 and 2011 – Reeve & Walkden-Brown, 2014), and a few are utilising DPC, the uptake of these management changes has not peaked and most importantly, these crucial farming decisions have not been supported by rigorous field research to optimise the outcomes.

The summer rainfall zone sheep producers are located in the ABS regions of Border Rivers Maranoa Balonne (QLD), Border Rivers Gwydir (NSW) and Namoi (NSW). Additional producers in the neighbouring parts of another four regions are also part of the summer rainfall zone: Northern Rivers (NSW), Central West (NSW), Western (NSW) and Southwest (QLD). Production and enterprise data relating to these regions with comparison to the Lachlan (NSW) and North Central (VIC) regions from the winter rainfall zone are presented in Table 1.

In the key target zone for this work, there are approximately 3,700 producers already engaged in both cropping and livestock (i.e. mixed farming) who currently do not utilise the crop for assisting with livestock production. Also in the target zone are another 3,200 crop specialists and 10,000 grazing specialist producers, who could adopt dual purpose crop grazing. Better information is needed for these producers to make informed decisions about utilising dual purpose crops, and this project was designed to assist producers by providing that information.

Table 1 - Details of summer rainfall sheep production regions (2015 Agricultural data - Australian Bureau of Statistics)

Region	State	Proportion summer rainfall	Proportion Arable *	Sheep	Cattle	Cropping enterprises	Grazing enterprises	Likely number mixed businesses
Northern Rivers§	NSW	1	0.07	803,556	856,046	2,509	5,222	516
Namoi	NSW	1	0.32	917,916	664,667	1,435	2,435	1,074
Border Rivers - Gwydir	NSW	1	0.33	1,524,684	749,354	1,221	2,374	903
Border Rivers Maranoa Balonne	QLD	1	0.15	781,959	1,182,726	1,068	2,029	754
Central West	NSW	0.3	0.25	4,847,691	763,214	2,429	4,494	1,752
Western	NSW	0.3	0.01	2,563,792	132,959	117	675	36
South West	QLD	1	0.001	669,055	551,758	25	481	0
Lachlan	NSW	0	0.27	6,253,991	471,944	2,779	4,022	1,841
North Central	VIC	0	0.41	2,850,253	373,634	2,280	3,159	1,256
Total in Summer rainfall zone^	NSW and QLD	-	-	6,920,615	4,273,403	7,022	14,091	3,783

* Total area under any crop divided by total area of region - does not include land which is arable but not currently used for crops or land used for intensive improved pastures.

^ Sum of the products of ‘Proportion summer rainfall’ column and the data column

§ The ABS region “Northern Rivers”, includes the Northern Tablelands of NSW.

One aim of the project was to assist mixed farming enterprises to make a confident decision regarding their current practice compared to a more integrated approach. We estimate that perhaps 750 (20% uptake) of these businesses could integrate their cropping and livestock enterprises and increase livestock production by 20% because of the research/extension activity.

The project also aimed to engage the 3,200 crop specialists and 10,000 grazing specialist producers and assist them to make an informed decision regarding changing to a mixed operation or not. If 5% of these producers were to adopt a changed practice towards mixed production, we estimate they could increase farm profitability by on average 20% because of the research/extension activity.

The project aimed to use a formal test of the value of both autumn lambing and DPC across the northern NSW southern QLD region using modelling followed by a field trial demonstration in the Armidale area, as a co-learning platform where researchers and producers conduct research work together. Included in the research were observations of key production outcomes to explain differences between the production systems that were tested.

An additional project aim was to allow producers in other areas of the NSW/QLD summer rainfall zone to assess the relevance of the systems to their businesses including animal health, lamb production, crop production and over-all farm economic outcomes. Key to this objective was the use of animal and pasture modelling for a range of locations that could be compared to the measured, field trial results from the Armidale area.

2. Objectives

The objectives of this project were:

2.1 Predict the lamb and crop production potential of systems using DPC compared to those that do not, and also winter/spring compared to autumn lambing using the APSIM model.

2.2 With the involvement of the feed-base sub-program producer participation group, conduct a field site trial to test the APSIM predictions. Analyse the trial outcomes, involving the producers in the gathering of data, analysing and interpreting it. Producers will be invited to make use of the exercise to suggest scenarios for APSIM model runs.

2.3 Report the experimental outcomes and long-term model predictions and communicate these broadly with lamb producers throughout the summer rainfall zone. In consultation with these producers, analyse the differences between the production system outcomes and predict risk factors which might influence the advantages of each system in differing years and with differing lamb, grain and oilseed prices.

2.4 Use the additional data generated to modify and improve our models to predict the system outcomes in existing and future scenarios, across the northern NSW, southern QLD zone.

2.5 Support new postdoctoral scientist, to gain further training in agricultural systems modelling, be involved directly with producer groups and discover future research needs.

3. Methodology

3.1 Whole Farm Systems Modelling

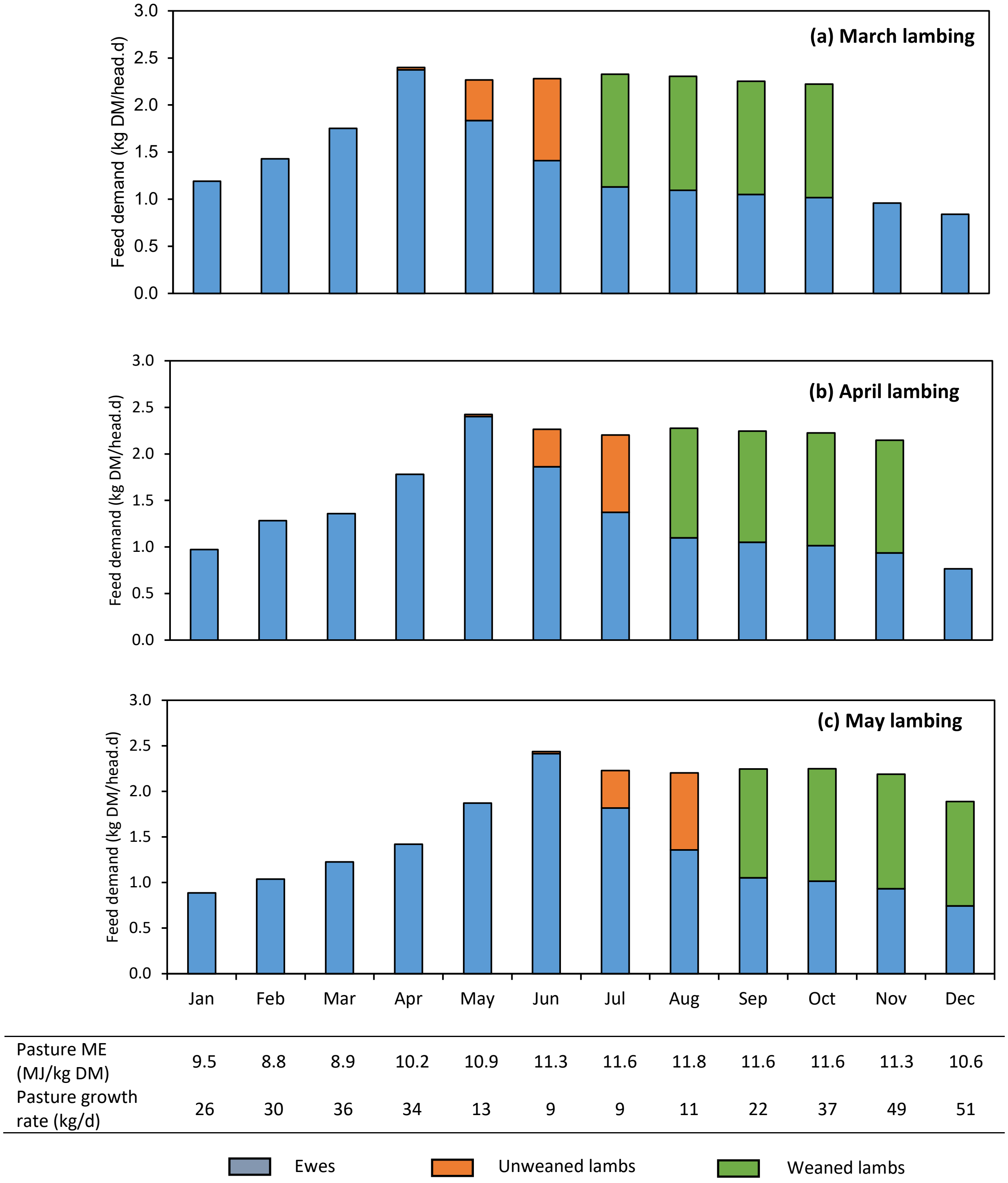
3.1.1 Lamb production and feedbase

Pre-trial feed base modelling – optimised autumn lambing time

In the Northern Tablelands, NSW in an improved pasture only (Phalaris/subterranean clover) system a feed gap exists from May to end of August due to a low rate of pasture growth (Figure 1). Based on output from the Feed Demand Calculator (FDC) (MLA, 2019) there were only marginal differences in feed supply and demand for the differing autumn lambing times. However, for the improved pasture system, late-autumn lambing had greater minimum feed on offer in both a standard and poor year (Tables 2 and 3) and lower pasture deficit using freshly grown supply and supply with carryover in a poor year (Table 3) compared to early- and mid-autumn lambing systems.

Incorporating a DPC into the feed base and allowing livestock to graze from May to end of August resulted in greater minimum FOO and lower pasture deficit of both fresh and carry over supply in a standard and poor year compared to the improved pasture only system for all autumn lambing times (Tables 2 and 3). This may also allow for higher ‘safe’ stocking rates in an improved pasture + DPC system.

Based on the FDC predictions for the improved pasture only systems, late-autumn lambing in May was recommended as the optimal lambing time in the Northern Tablelands, NSW region (and thus for the field experiment at the CSIRO Chiswick site, Armidale) to minimise the risk of feed deficits and the reliance on supplementary feeding to maintain livestock.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pasture ME (MJ/kg DM)	9.5	8.8	8.9	10.2	10.9	11.3	11.6	11.8	11.6	11.6	11.3	10.6
Pasture growth rate (kg/d)	26	30	36	34	13	9	9	11	22	37	49	51

Figure 1 - Overall daily feed demand of ewes, unweaned and weaned lambs grazing a Phalaris/subterranean clover pasture from March to August in an (a) early- (March), (b) mid- (April) and (c) late- (May) autumn lambing system in the Northern Tablelands, NSW. Values calculated using the Feed Demand Calculator based on the metabolisable energy (ME) value of the pasture for the corresponding month in a standard year.

Table 2 Yearly feed supply output from the Feed Demand Calculator for the varying autumn lambing systems in a standard year, under improved pasture or improved pasture + dual-purpose crop (DPC). Output includes minimum feed on offer (FOO), pasture deficit based on freshly grown supply and pasture deficit using supply with carryover.

	Month	Minimum FOO (kg DM/ha)	Pasture deficit, using freshly grown supply (tonnes/ha.year)	Pasture deficit, using supply with carryover (tonnes/ha.year)
Pasture	March	573	0.18	0.0
	April	596	0.16	0.0
	May	614	0.19	0.0
Pasture + DPC	March	754	0.0	0.0
	April	778	0.0	0.0
	May	798	0.0	0.0

Table 3 Yearly feed supply output from the Feed Demand Calculator for the varying autumn lambing systems in a poor year, under improved pasture or improved pasture + dual-purpose crop (DPC). Output includes minimum feed on offer (FOO), pasture deficit based on freshly grown supply and pasture deficit using supply with carryover.

	Month	Minimum FOO (kg DM/ha)	Pasture deficit, using freshly grown supply (tonnes/ha.year)	Pasture deficit, using supply with carryover (tonnes/ha.year)
Pasture	March	167	0.74	0.44
	April	167	0.74	0.38
	May	170	0.69	0.33
Pasture + DPC	March	396	0.13	0.04
	April	396	0.06	0.04
	May	396	0.07	0.04

Simulated scenario design

Twelve whole-farm systems involving a factorial of two lambing systems (autumn vs. spring lambing) by two feedbase types (100% pasture vs. 75% pasture and 25% dual-purpose crops) by three stocking densities (‘low’, ‘medium’ or ‘high’) were simulated for four locations within NSW. The locations were selected based on differences in rainfall and rainfall distribution, including Armidale (high rainfall, summer-dominant), Gulargambone (medium rainfall, summer-dominant), Goulburn (high rainfall, uniform), and Temora (medium rainfall, uniform) (Figure 2). Stocking density for each location was calculated based on annual biomass (on a dry matter (DM) basis) produced in a pasture-only system (Table 4.).

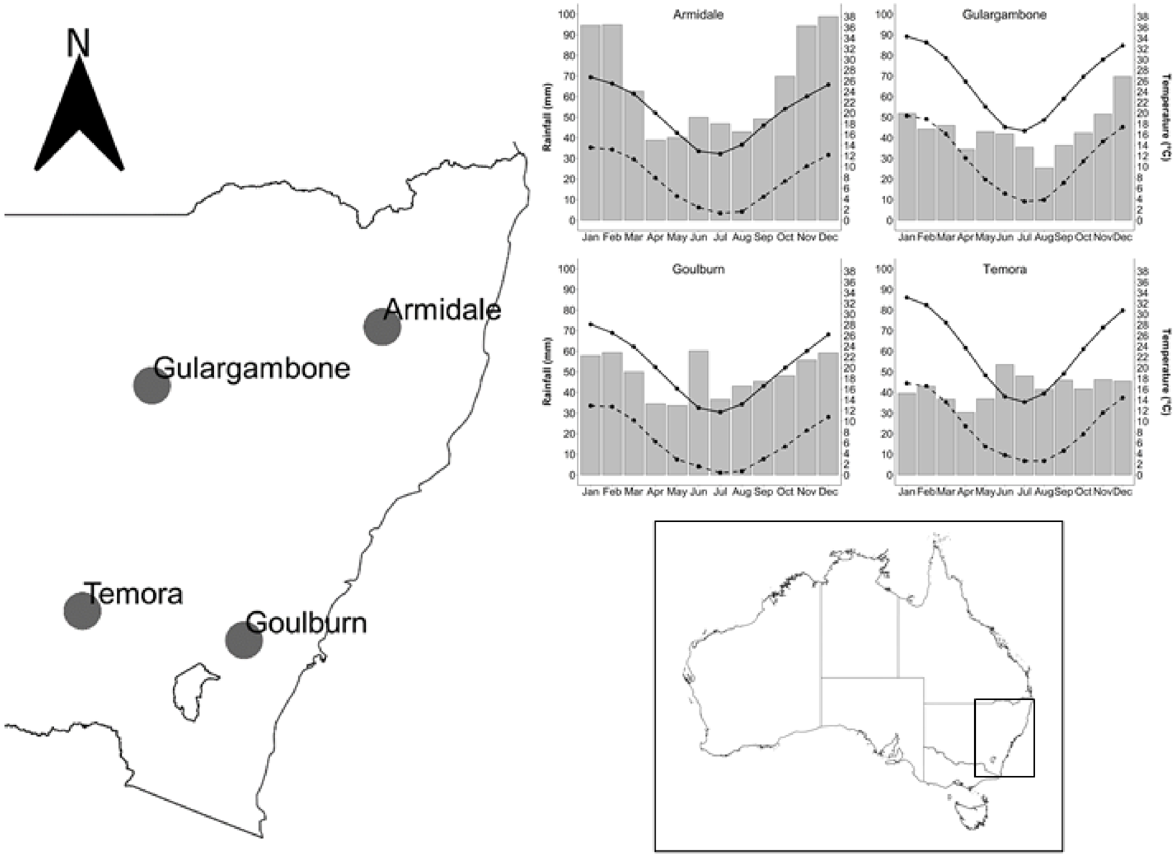


Figure 2 Map of the four locations used in the whole-farm model scenarios in APSIM, including the average monthly rainfall (bars) and minimum (dotted line) and maximum (solid line) temperature (Source Watt et al., 2022).

The whole-farm system simulations were run in APSIM (Agricultural Production Systems Simulator; Holzworth et al. 2014) using APSIM crop modules and GRAZPLAN pasture and livestock modules (Moore et al., 2007). Two paired 30-year simulations, offset by one year of each other, were run for each scenario at each location, which allowed for legacy effects to be captured from the first to second year. The livestock system was also ‘reset’ every two years allowing for 15 simulation cycles within each paired simulation.

Table 4 Stocking densities applied for the different feedbase utilisation rates for the four locations in NSW.

	Armidale	Gulargambone	Goulburn	Temora
Stocking density (ewes/ha)				
30% utilisation	5.5	5.3	3.8	4.7
40% utilisation	7.4	7.1	5.1	6.3
50% utilisation	9.2	8.9	6.4	7.9

Simulated whole-farm characteristics

All simulations were based on a 1200 ha farm with eight paddocks, each 150 ha in size. For the pasture scenarios, all paddocks had established permanent monoculture pastures, and in the pasture + dual-purpose crop scenarios, six of the paddocks were allocated to the established permanent monoculture pastures and the other two paddocks were sown annually to dual-purpose crops wheat and canola.

The Soils and Landscapes Grid of Australia (Grundy et al., 2015) and the SoilMapp iPad app (CSIRO, 2020) were used to select two or three suitable soils in the APSoil database (https://www.apsim.info/apsim-model/apsoil/) for each location and captured the variability of soils across the farm landscape. Paddocks were then allocated to different land management units (LMU) with a LMU 1 representing land with highly fertile soil suitable for cropping/improved pasture; LMU 2 representing land with moderately fertile soil suitable for improved pasture; or LMU 3 representing low fertile soils suitable for lower productivity native or naturalised pastures (Table 5).

Table 5 Land management units (LMU) contribution to farm area, associated soil types and their plant-available water-holding capacity (PAWC) at each of the four simulated locations in northern and southern NSW.

Location	LMU	% of farm area	Soil type (APSoil No.)	PAWC (mm)
Armidale, Northern NSW	1	25	Red Chromosol (236)	153
	2	25	Deep Red Podzolic (580-YP)	141
	3	50	Sandy Loam (612-YP)	87
Gulargambone, Northern NSW	1	25	Sandy-heavy Clay (247)	181
	2	37.5	Vertosol (1156)	153
	3	37.5	Grey Vertosol (1160)	126
Goulburn, Southern NSW	1	25	Sandy-clay Loam (245)	169
	2	37.5	Podosol (1037)	167
	3	37.5	Deep red Podzolic (580-YP)	141
Temora, Southern NSW	1	50	Red Chromosol - heavy (179-YP)	206
	2	50	Red Chromosol - light (913)	147

The permanent monoculture pastures for each location were selected based on literature (McDonald, 2004, 1999, 1998) and consultation with industry advisors. For both the pasture and the pasture + dual-purpose crop scenarios, pasture species and crops were allocated to paddocks based on LMU (Table 6).

Table 6 Allocation of pasture and crops to the different land management units (LMU) for the pasture, and the pasture + dual-purpose crop scenarios. Values in brackets '()' represent the percent of the farm consisting of that feedbase.

		Pasture only scenarios	**Pasture + dual-purpose crop scenarios**
Location	LMU	Permanent pasture	Permanent pasture OR Crop
Armidale	1	Phalaris (25%)	Wheat (12.5%) and canola (12.5%)
	2	Phalaris (25%)	Phalaris (25%)
	3	Phalaris (50%)	Phalaris (50%)
Gulargambone	1	Lucerne (25%)	Wheat (12.5%) and canola (12.5%)
	2	Lucerne (37.5%)	Lucerne (37.5%)
	3	Austrostipa spp. (37.5%)	Austrostipa spp. (37.5%)
Goulburn	1	Lucerne (25%)	Wheat (12.5%) and canola (12.5%)
	2	Lucerne (37.5%)	Lucerne (37.5%)
	3	Microlaena (37.5%)	Microlaena (37.5%)
Temora	1	Lucerne (50%)	Wheat (12.5%), canola (12.5%), and Lucerne (25%)
	2	Lucerne (12.5%) and Phalaris (37.5%)	Lucerne (12.5%) and Phalaris (37.5%)

Simulated dual-purpose crop management

In the pasture + dual-purpose crop scenarios, two cultivars of both dual-purpose crop wheat and canola were selected based on the location to match the optimal sowing window (Bell et al. 2015; Lilley et al. 2015; Flohr et al. 2018) (Table 7). At all locations, sowing was triggered by 25 mm of rain, falling over at least 3 days, whilst the cultivar sown was dictated by the timing of the rain event. If the sowing conditions were not met within the window, the early maturing cultivar was 'dry sown' in a forced sowing event on the last day of the sowing window.

Starting soil water and nitrogen were reset on 15 January of each simulated year at levels expected to mimic the soil water conditions following a cereal crop the previous year. Starting soil water was set at 30% of the plant-available water, for locations where summer rainfall occurs with some frequency (i.e. locations in the following agro-climatic zones: temperate, cool-season wet; wet Mediterranean; temperate, sub-humid; and sub-tropical, sub-humid). Starting soil water was set at 0% for locations with little summer rainfall (i.e. locations in dry Mediterranean climate zone). After this reset, rainfall and evaporative processes proceeded in a realistic way prior to sowing.

'Ungrazed' dual-purpose wheat and canola crops were simulated alongside the 'grazed' crops to get better estimates for grazing end dates and grain yield. APSIM poorly simulates plant growth stage post-grazing and would have resulted in non-sensible end grazing dates, harvest dates, and grain yield estimates. The critical end-grazing date in 75% of years, corresponding with floral initiation, was identified using the 'ungrazed' simulations for each crop in each location (Table 7). These dates were kept constant for each simulation and were integrated into the crop grazing rules of each crop to ensure animals were removed at a sensible time when farmers would be locking up crops for grain production.

Table 7 Wheat and canola cultivars simulated at the four locations, including sowing windows and grazing end dates.

Crop	Armidale	Gulargambone	Goulburn	Temora
Wheat				
Cultivar 1	Revenue	Wedgetail	Revenue	Wedgetail
sowing window	1-Mar – 3-May	1-Mar – 3-May	1-Feb – 22-Mar	22-Mar – 26-Apr
Cultivar 2	Wedgetail	Gregory	Wedgetail	Gregory
sowing window	3-May – 17-May	3-May – 17-May	22-Mar – 17-May	26-Apr – 31-May
Grazing end date	22-Aug	11-Aug	25-Aug	31-Aug
Canola				
Cultivar 1	Taurus	CBI406	Taurus	CBI406
sowing window	1-Mar – 22-Mar	1-Mar – 5-Apr	1-Feb – 29-Mar	1-Mar – 5-Apr
Cultivar 2	CBI406	46Y78	CBI406	46Y78
sowing window	22-Mar – 19-Apr	5-Apr – 3-May	29-Mar – 19-Apr	5-Apr – 19-Apr
Grazing end date	1-Aug	30-Jun	18-Jul	10-Jul

Livestock management

A prime lamb enterprise was simulated in all scenarios comprising of a single-aged cohort of medium-wool Merino ewes joined to a Suffolk ram. The livestock enterprise was reset at the end of each two-year simulation cycle by culling and purchasing a new cohort of ewes to avoid any confounding effects of flock age and climate. When purchased, ewes were three years old, 50 kg in liveweight with a BCS of 3, and were culled when they reached five years old. The culling and replacement of ewes occurred in early November in autumn lambing and mid-February in spring lambing systems, which coincided with the period after weaning, but before joining. After weaning, lambs were sold once they reached a target liveweight of 48 kg, but lambs that did not meet the target within five months post weaning were force sold at the end of the selling window. Details of the livestock management activities are outlined in Table 8

Table 8 Dates for the livestock management activities for the simulated autumn and spring lambing systems.

Livestock event	Autumn	Spring
Purchase ewes	01-Nov	15-Feb
Cull ewes	31-Oct	14-Feb
Ewes joined	16-Nov	01-Mar
Lambs born (average)	27-Apr	11-Aug
Lambs weaned (average)	03-Aug	17-Nov
Start selling lambs	04-Aug	18-Nov
End selling lambs	04-Jan	20-Apr
Shearing	10-Apr	25-Jul
Crutching	01-Nov	15-Feb

Animals were moved around the pasture paddocks based on available biomass with animals moving from the ‘current paddock’ when biomass reached 1 t DM/ha or less to another paddock containing the most biomass of all pasture paddocks available. Ewes and lambs were managed as a single flock until weaning where they were then managed separately but still moving around the farm based on the biomass grazing rules. In the pasture scenarios, ewes moved around six pasture paddocks (LMU 2 and 3) and the lambs moved between two pasture paddocks (LMU 1). In the pasture + dual-purpose crop scenarios, ewes moved around four pasture paddocks (LMU 2 and 3), but also had access to wheat stubble once the crop was harvested (LMU 1), whilst the lambs moved between two pasture paddocks (LMU 2). Once the lambs were sold, all paddocks became available to the ewes.

In the pasture + dual-purpose crop scenarios, animals grazed the crops over winter as dictated by a series of crop grazing rules. The wheat and canola crops could be grazed when at least 1.5 t DM/ha and 2.0 t DM/ha of biomass, respectively, were available. Animals were removed from the crops when biomass was reduced to 0.8 t DM/ha or less, or when the end grazing date of the crop was reached (Table 7; as previously described). Provided all conditions were met, crops could be grazed multiple times, which was dependant on the sowing date and season. After harvest, the wheat stubble was grazed by ewes for a maximum of 14 days where they could access spilt grain that was supplied at a rate of 3% of the average crop yield. Canola stubble was not grazed.

Ewes were offered wheat grain supplement at maintenance feeding levels when the average BCS of the flock was ≤ 2.5 or when the biomass in the ‘best paddock’ was below 1.5 t DM/ha. After weaning, lambs could be supplemented if the average daily weight gain of the cohort fell below 0.05 kg/day. The supplement demand of the livestock enterprise was calculated using Equation 1. The ME value of the wheat supplement used in the simulations was 13.8 MJ ME/kg DM (Agriculture Victoria, 2021).

(1) Supplement demand (GJ ME/farm ha/year) = supplement fed (t/farm ha/year) × 13.8

Ewes and lambs were offered supplement at a maximum rate of 1 kg/head/day as required, but the actual amount of supplement consumed by the animals varied based on the availability and nutritive value of the pasture available to them and supplement required to meet their maintenance requirements. Animals were not allowed to access supplement whilst grazing the crops.

Estimation of farm gross margins

Gross margins were calculated on a fiscal year basis (July to June) and accounted for livestock and grain sales and associated input costs. Lamb sales were based on market specifications for carcass weight (CWT) (18-22 kg CWT and 12-18 kg CWT), whilst cull ewe sales were based on a set price/kg CWT. All livestock sales had a set transport cost and skin price (Table 9) and dressing percent of 41%. Replacement ewes were also purchased at a set price (Table 9). Shearing and crutching costs were based on a ewe only basis as lambs were not shorn or crutched. Wool sales only accounted for shearing as the model could not calculate crutched wool, which typically generates low profits (typically stained wool). Lamb and sheep meat, live sheep and wool prices were based on the average price over a 10-year period (2010-2020) and were attained from the Meat and Livestock Australia market information statistics database (http://statistics.mla.com.au/Report/List) and Australian Wool Innovation (AWI, The Rocks, Sydney).

Wheat supplement had a set price (Table 9) and was calculated on an ‘as consumed’ basis. Input variable costs were applied to both the livestock and cropping systems. The livestock variable cost accounted for total input costs for animal health (drenches and vaccines) and the labour costs of these, plus general labour associated with the care and movement of livestock on farm (Table 9). A pasture and livestock infrastructure cost was also applied and accounted for the maintenance cost of fences and other livestock infrastructure, and fertiliser for pastures (Table 9).

In the pasture + dual-purpose crops scenarios, crops provided an additional income to the farm enterprise, but also had additional input costs (Table 9). Wheat and canola had a set variable cost that were based on estimates from industry advisors, that accounted for the cost of seed, fertiliser, pesticide applications, and costs of sowing and harvesting contractors. Crop grain yields from the 'ungrazed' wheat and canola simulations over the same simulated years, were adjusted to account for grain spillage and moisture content at harvest, with a 1.02 multiplier applied for canola and a 1.09 multiplier applied for wheat.

Table 9 Output and input values from livestock and grain production used for gross margin estimates.

Variable	Value
Output	
Lamb meat (18-22 kg CWT; c/kg)	587
Lamb meat (12-18 kg CWT; c/kg)	560
Sheep meat (c/kg CWT)	371
Skin price ($/head)	5
Wool price (21-22 micron wool; c/kg clean)	1424
Wheat grain sale ($/t)	255
Canola grain sale ($/t)	520
Input	
Replacement ewes ($/head)	79
Livestock transport ($/head)	4
Crutching rate ($/breeding ewe)	0.90
Shearing rate ($/breeding ewe)	3.12
Livestock variable cost ($/breeding ewe)	25
Pasture and livestock infrastructure cost ($/pasture ha)	300
Wheat supplement ($/t consumed)	255
Wheat variable cost ($/wheat crop ha)	640
Canola variable cost ($/canola crop ha)	750

3.1.2 Gastro-intestinal parasites

Scenarios

Twenty-four scenarios were modelled (Table 10) using the Risk Management Model for Nematodes (RMMN; Dobson et al. 2011) to determine the incidence, and production and economic losses associated with *Haemonchus contortus* (Barber's pole worm) infestation in autumn and spring lambing systems, with or without the integration of dual-purpose crops (DPC; wheat and canola), at varying stocking densities, and with 2 or 3 crop grazing phases. All scenarios were modelled over a 20 year period (1-Jan 2000 to 31-Dec 2019), which is the maximum simulation length for the modelling software.

Table 10 Scenarios modelled in the Risk Management Model for Nematodes.

		Breeding ewes/ha			
Lambing system	Feedbase	Experiment (Chiswick)	40% feedbase utilisation	50% feedbase utilisation	60% feedbase utilisation
Autumn	Pasture + DPC (wheat – canola – wheat)	5.0	6.7	8.3	10.0
Autumn	Pasture + DPC (wheat – canola)	5.0	6.7	8.3	10.0
Autumn	Pasture only	5.0	5.8	7.2	8.6
Spring	Pasture + DPC (wheat – canola – wheat)	5.0	6.7	8.3	10.0
Spring	Pasture + DPC (wheat – canola)	5.0	6.7	8.3	10.0
Spring	Pasture only	5.0	5.8	7.2	8.6

Unlike the flystrike model reported in MS2, the RMMN includes paddock rotations in nematode risk calculations; however, the model is limited to a maximum five paddocks with weekly rotation options. All scenarios were based on a 400 ha farm with 4 x 100 ha pasture paddocks in pasture only scenarios, and 3 x 100 ha pasture only paddocks plus 2 x 50 ha forage crop paddocks in pasture + DPC scenarios.

Preliminary modelling to calculate inputs for the RMMN were carried out using both the Agricultural Production Systems Simulation (APSIM; Holzworth et al. 2014) and the Feed Demand Calculator (MLA, 2019). Subsequent calculations from outputs obtained from this modelling software were managed using Microsoft Excel.

APSIM was used to model wheat and canola crops over a 100 year simulation for the Armidale region. Outputs from APSIM allowed for estimations of average daily biomass growth rate and metabolisable energy (ME) content of the forage crops monthly, and average dates where biomass thresholds for the commencement of grazing, and APSIM plant stage 4.9 (bud formation) were reached.

The Feed Demand Calculator (MLA, 2019) was used to output feed supply and demand to calculate stocking densities for the 40, 50 and 60% feedbase utilisation scenarios. The pasture base modelled in the FDC was a Phalaris-sub clover pasture grown in standard rainfall year conditions. In pasture + DPC scenarios, average monthly biomass growth rate and ME content of the forage crop (limited to wheat only) used output from APSIM. Monthly feed demand of ewes and lambs (kg DM/head.day) for both feedbase scenarios was outputted and used to calculate feed utilisation and subsequent stocking densities using Excel. These calculations accounted for 1.1 lambs weaned per ewe.

In the RMMN, paddock rotations for the pasture only scenarios coincided with management activities (i.e. lamb weaning, ewe joining, shearing, crutching, drenching). Paddock rotations for the pasture + DPC scenarios coincided with management activities and grazing parameters (i.e. start and end biomass thresholds and stage of plant growth) set for the forage crops, which dictated duration of each crop grazing phase, and subsequently the time spent grazing in pasture paddocks between management activities. The start and end biomass threshold for wheat were 1500 kg DM/ha and 500 kg DM/ha, respectively, and for canola were 2000 kg DM/ha and 800 kg DM/ha, respectively. Grazing ceased prior to plant stage 4.9, regardless of biomass. The average dates that start biomass and plant stage thresholds were reached are presented in Table 11.

Table 11 Average dates where thresholds for start grazing biomass and plant stage 4.9 were reached in wheat and canola crops based on 100 year simulation for the Armidale region using the Agricultural Production Systems Simulator.

Crop	Start grazing (dd-mmm)	Stage 4.9 reached (dd-mmm)
Wheat	14-May	31-Aug
Canola	10-Jun	9-Aug

Microsoft Excel was used to calculate the crop grazing windows in each scenario based on crop biomass, average daily growth rate of the crop, and daily feed demand of ewes and lambs, which dictated the paddock rotations in the RMMN for the pasture + DPC scenarios.

Lambs and ewes in all scenarios received the same number and type of drench, but the dates administered differed based on the timing of management activities, as per the field experiment at Chiswick (Table 12).

Table 12 Drench type and date administered in autumn and spring lambing scenarios, including other management activities.

	Date (dd-mmm)				
	Ewes				Lambs
	Drench 1 Activity: wean	**Drench 2** Activity: crutch	**Drench 3** Activity: management drench	**Drench 4** Activity: shear	**Drench 1** Activity: wean
Autumn lambing	1-Sep	1-Nov	5-Jan	10-Apr	1-Sep
Spring lambing	16-Dec	14-Feb	17-Apr	27-Jul	16-Dec
Drench type	Startect® (Abamectin, derquantel)	Zolvix® (Monepantel)	Combination (Benzimidazole, Levamisole, Macrocyclic lactone)	Zolvix® (Monepantel)	Startect® (Abamectin, derquantel)

3.1.3 Fly strike

The flystrike modelling was undertaken in collaboration with Brian Horton, UTAS, Launceston TAS.

The weather-based flystrike model of Wardhaugh et al. (2007) predicted flystrike for each individual day in the period, before determining an average risk of strike for each day of the year. Average risk of flystrike over all the years was used to determine the optimum preventative treatment for each scenario. The applied treatment was then tested for each year to examine the variation in flystrike and the associated costs per annum.

The model was initially set to consider the lambs to be shorn at birth, to simulate the short wool length at birth, with the risk increasing as the lambs grew and their wool length increased. Mulesed lambs were simulated because the model was developed primarily for Merino sheep. Furthermore, the breech characteristics in un-mulesed cross-bred or meat-breed lambs would be similar to mulesed Merino lambs.

The model optimises the type and timing of preventative treatment to minimise overall costs. As a result, some sheep may be flystruck at times when it is not economic to apply treatment to prevent a very small number of flystrikes. All preventative treatments accounted for in the model assumed that treatment was applied based on ‘best’ practice. In reality, poor treatment application would result in greater flystrike risk.

Flystrike costs were estimated to be $24.26 per lamb struck (Lucas and Horton 2013).

3.2 Field Demonstration Trial

3.2.1 Site set up and baseline data

During 2018 a field site was constructed for the experiment which is a two-by-two factorial experiment with two replicates. Eight farmlets (A-H) were delineated by blocks 70m wide and 560m long (3.92 ha), running approximately North/South. The facility is situated on the CSIRO Chiswick property against the Big Ridge road, and near other facilities being used for Livestock Productivity Partnership (LPP) research. The farmlets can be divided into multiple plots using electric fencing, and this is used to facilitate controlled grazing of the area by sheep. Usually, 0.49 ha blocks are utilised for grazing and/or cropping, but two adjacent blocks have been utilised where feed on offer (FOO) was low.

A soils map exists for the area (Appendix 1), and soil analyses were conducted in 2017. Before the commencement of the trial, in autumn 2018 the area was fertilised with single superphosphate and lime, and over-sowing was attempted by direct drilling annual ryegrass, white clover, subterranean clover and French Serradella. This over-sowing was mostly unsuccessful because of low rainfall in 2018.

The site has a sloping aspect with the farmlets in the Western side being much flatter than those on the Eastern side. Therefore it was decided to conduct the replicates in two blocks. The position of the farmlets is described in Table 13.

In October, 2018, two hundred Merino ewes (New England fine wool type) were selected for the trial from a mob of approximately four hundred. The animals retained had liveweights between forty and fifty-two kg. The ewes were divided into groups using a random stratified method so that all the group mean weights were within 0.8 kg. Ten groups were created, each containing 20 ewes. Five groups were assigned for autumn lambing, and five for spring lambing. In addition to these groups, there were two groups of spare ewes also designated for autumn or spring lambing. These spares were used to substitute ewes at mating each year for deaths or culls. In each experimental group at the beginning of the trial there were twelve 2014-drop and eight 2015-drop individuals. Between four and six animals in each group had been part of the AWI-funded breechstrike flock, so additional information is available for these ewes (not presented here).

Table 13 Characteristics of the eight farmlets comprising the demonstration trial.

Feed regime /Lambing season	Farmlet	Block	Cropping plots	Lambing time	Altitude range (m)	Main two soils*
DPC+Pasture| Autumn	A	Western	Yes	May/June	1076-1114	4a, 3b
DPC+Pasture| Spring	B	Western	Yes	August/September	1088-1106	4a, 2e
Pasture only| Autumn	C	Western	No	May/June	1083-1116	4e, 2e
Pasture only| Spring	D	Western	No	August/September	1046-1109	4e, 1f
DPC+Pasture| Autumn	E	Eastern	Yes	May/June	1076-1107	4e, 1f
DPC+Pasture| Spring	F	Eastern	Yes	August/September	1090-1102	4b, 1f
Pasture only| Autumn	G	Eastern	No	May/June	1084-1102	4b, 1f
Pasture only| Spring	H	Eastern	No	August/September	1091-1107	1f, 2e

* - See Appendix 1 for soil type descriptors.

Autumn lambing ewes were administered with a melatonin implant (Regulin© APVMA 38233) to induce oestrus on the day of drafting, and the ewes were kept in a single mob until the 5th of December, 2018 when they were introduced to the farmlets. Also at the time of drafting, five White Suffolk rams were administered with Regulin and kept separated from the ewes until being introduced to the plots on the 5th of December with the autumn lambing ewes. Mating proceeded until the 17th of January, 2019. The use of Regulin is necessary to stimulate oestrus during times of the year when daylength is not decreasing (Appendix 3, Figure 8.3.2).

Spring lambing ewes were kept in a single mob with the autumn lambing ewes until being placed on the farmlets on the 5th of December. These ewes were to be mated later (March 2019), also using white Suffolk rams, but we did not use Regulin in these ewes as oestrus is maximal close to the autumn equinox when daylight periods are decreasing (Appendix 3, Figure 8.3.2). The Tables 15 and 16 provide dates for mating, lambing, shearing and crutching times.

The crop plots within farmlets A, B, E and F were prepared beginning in October when they were cultivated twice using a chisel plough. After a few weeks the plots were sprayed with glyphosate and Starane following rates recommended on the label. In January, an additional spray with glyphosate was administered. Fertiliser rates were calculated according to the soil analysis data from late 2017 (Appendix 1). A pre-mixed fertiliser concentrate containing N, P, K, S and B was applied according to the recommended rates, with additional N in the form of urea, and the plots were cultivated using a disc plough to incorporate nutrients. A second application of urea was applied prior to sowing, and this was also incorporated using disc ploughing.

3.2.2 Crop production

Production Cycle 1

Wheat and Canola were sown in farmlets A, B, E and F on the 1st of April 2019. Each of these crops was sown on one of the eight plots in the farmlet, so that each of these farmlets had 0.98 ha of crop and 2.94 ha of pasture, compared to 3.92 ha of pasture in farmlets C, D, G and H.

From November 2018 until sowing the crop plots were kept weed free using a combination of tilling and herbicide sprays (first Starane 625 mL/ha, dicamba 625 mL/ha, glyphosate 4L/ha and second glyphosate 4L/ha). These plots had never been used for cropping before and contained many different weed species, so site preparation was more rigorous for the initial planting. Prior to sowing fertiliser was applied including a custom blend (monoammonium phosphate 80 kg/ha, potassium sulphate 200 kg/ha, Solubor 12 kg/ha) and urea (applied separately at 100 kg/ha). Cropmasta 13 was also applied with seed at the time of sowing at 120 kg/ha.

Wheat variety Manning, which is a winter wheat with barley yellow dwarf virus resistance was sown at 90 kg/ha, and the long season, hybrid clear fields Canola variety Edimax was sown at 12.5 kg/ha.

In summary, the plots were cultivated four times including twice to incorporate pre-sowing fertiliser, they were sprayed with herbicides twice prior to sowing and so including sowing there were seven passes of implements across the field.

After germination a post-emergent herbicide application was conducted on both crop types (Canola, Clethodim 120g/ha, Clopyralid 75 g/ha and wheat 50.4 g/ha clodinafop-propargyl with cloquintocet, 350 g/ha 2,4D, 138.75 g/ha dicamba).

Costs (Appendix 2) for implement passes were calculated from $220/ha based on actual prices charged by a local contractor, and these eight operations comprised 65% for the Canola and 69% for the wheat of the total expenses. Fertiliser comprised 20% of the total costs for Canola and 22% of total costs for wheat. Seed was the next largest cost for the cropping enterprises at 12% for Canola and 6% for wheat. The remaining costs were herbicides.

No grain was harvested from these crops in the 2019 season. The Canola crops did flower and set seed (Figure 8), and the estimates of yield are provided in Table 25. None of the four quadrats had a commercial yield (500 kg/ ha), and the seed quality was variable (Figure 8), so the crops were used for sacrificial grazing.

Production Cycle 2

Wheat was sown in farmlets A, B, E and F on the 1st of April 2020. Canola was sown in farmlets A and B on the 16th of April and farmlets E and F on the 27th of April. Cropmasta 13 was applied with seed at the time of sowing at 100 kg/ha. Wheat variety Manning, which is a winter wheat with barley yellow dwarf virus resistance was sown at 90 kg/ha, and the long season, hybrid clear fields Canola variety Edimax was sown at 12.5 kg/ha. Each of these crops was sown on one of the eight plots in the farmlet, so that each of these farmlets had 0.98 ha of crop and 2.94 ha of pasture, compared to 3.92 ha of pasture in farmlets C, D, G and H.

Sowing had been delayed due to wet weather, and there were difficulties with large amounts of trash from weeds, especially in the Canola plots, where the failed wheat crop from the previous year had left bare ground readily colonised by weeds. Wet weather had precluded adequate weed control during the summer; however all plots were treated with herbicide (glyphosate 4L/ha) on the

16th of January and again on the 17th of March. A flail mower was used to mulch dead weed material prior to sowing the Canola with a tine type seeder, this had not been necessary for the wheat as a disc seeder could be used. After germination a post-emergent herbicide application was conducted for the wheat (340 g/ha MCPA, 80 g/ha dicamba). We also top dressed the wheat plots with urea (100 kg/ha) in early spring.

In summary, all plots were sprayed twice to control fallow weeds, the Canola plots had an additional weed mulching treatment so that there were five field passes for each plot (including sowing and harvest), and the wheat had a post-emergent herbicide spray and a fertiliser treatment so that there were six field passes for each plot (including sowing and harvest).

Costs (Appendix 2) for implement passes were calculated from $220/ha based on actual prices charged by a local contractor, and these eight operations comprised 76% for the Canola and 83% for the wheat of the total expenses.

In production cycle 2, both wheat and Canola crops were harvested. The harvest took place on the 27th of January 2021, delayed by some weeks because of wet weather.

Production Cycle 3

The third production cycle began during an extremely wet 2020/21 summer. Soil moisture levels were too high to safely operate farming equipment from January through to May, resulting in our inability to sow crops for this third production cycle.

3.2.3 Lamb production and animal health monitoring

Ewes were inspected on the plots three times each week to fulfil animal ethics obligations, to monitor their health and condition and to ensure fences, water troughs and other infrastructure was sound and functional. During lambing, ewes were inspected twice daily, new lambs were captured and the liveweight, dam identification and condition of the lamb recorded. Lambs were administered electronic and visual ear tags for identification at this time. More detailed examination of ewes was undertaken at regular intervals when the animals were mustered and taken to nearby stock yards. Ewe and lamb weights, ewe body condition score and health issues were noted and recorded at these times.

Treatment of animals for any issues identified in field or yard inspections was recorded on an individual basis. Mobs of ewes and lambs were monitored for internal parasites by undertaking flock monitors from fresh faeces collected within the plots. Three replicate counts of faecal eggs were undertaken using the modified McMaster salt flotation/microscopy method from each mixed flock monitor sample. Where egg counts were high enough, mobs were brought to the yards for individual rectal sampling and drenching. Drenching decisions were based on the egg count, animal condition and feed availability following the WormBoss recommendations (http://www.wormboss.com.au). Drenches were rotated according to best practice to slow the development of anthelmintic resistance. During autumn, 2020, resistance arose against “triple” products (containing a macrocyclic lactone and benzimidazole active with levamisole). As a result, the rotation changed from triple/monepantel/naphthalophos to abamectin+derquantel/monepantel/naphthalophos. Proprietary names of products containing these actives are listed on WormBoss.

Preventative application of products to reduce the risk of fly strike was undertaken where it was likely to be needed according to Table 14. Crutching and shearing was also undertaken at strategic times to prevent fly strike (Table 15).

Table 14 Preventative flystrike treatments administered through the field demonstration trial

Stock group	Date	Active	Production cycle
Autumn ewes	8/11/2019	dicyclanil	1
	6/12/2021	cyromazine	3
Spring ewes	8/10/2019	dicyclanil	1
	5/10/2021	cyromazine	3
	24/02/2022	cyromazine	3
Spring lambs	8/10/2019	dicyclanil	1
	1/10/2020	imidacloprid	2
	5/10/2021	cyromazine	3

NB: No treatments were administered to autumn lambs

Table 15 Shearing and crutching through the field demonstration trial

Stock class	Production Cycle	date	operation
Autumn ewes	1	7/03/2019	shearing
	1	8/11/2019	crutching
	2	19/02/2020	shearing
	2	30/09/2020	crutching
	3	3/03/2021	shearing
	3	13/09/2021	crutching
	4	31/01/2022	shearing
Autumn lambs	1	8/11/2019	crutching
	2	15/12/2020	crutching
	3	24/11/2021	shearing
Spring ewes	0	7/03/2019	crutching
	1	2/07/2019	shearing
	1	19/02/2020	crutching
	2	6/07/2020	shearing
	2	17/12/2020	crutching
	2	2/03/2021	crutching
	3	5/07/2021	shearing
	3	17/12/2021	crutching
Spring lambs	1	19/02/2020	crutching
	2	2/03/2021	crutching
	3	6/02/2022	shearing

NB: All ewes were shorn on the 24th of October 2018, prior to entering the trial

Mating and lambing times are provided in Table 16. Autumn lambing ewes were mated in early December after Regulin treatment according to the manufacturer's instructions. Spring lambing ewes were mated in late March without Regulin treatment which is not necessary to induce oestrus during autumn. Autumn lambs were born in May and June, and the spring lambs in August, September and October.

Table 16 Mating and lambing dates through the field demonstration trial

Season	Farmlet	Production cycle	1st lamb	last lamb	mating start	mating end
Autumn	A	1	4/05/2019	7/06/2019	5/12/2018	17/01/2019
		2	6/05/2020	31/05/2020	9/12/2019	19/01/2020
		3	6/05/2021	25/05/2021	7/12/2020	21/01/2021
	C	1	1/05/2019	7/06/2019	5/12/2018	17/01/2019
		2	6/05/2020	8/06/2020	9/12/2019	19/01/2020
		3	5/05/2021	6/06/2021	7/12/2020	21/01/2021
	E	1	6/05/2019	28/05/2019	5/12/2018	17/01/2019
		2	6/05/2020	1/06/2020	9/12/2019	19/01/2020
		3	5/05/2021	23/05/2021	7/12/2020	21/01/2021
	G	1	8/05/2019	6/06/2019	5/12/2018	17/01/2019
		2	6/05/2020	29/05/2020	9/12/2019	19/01/2020
		3	6/05/2021	2/06/2021	7/12/2020	21/01/2021
Spring	B	1	22/08/2019	10/09/2019	25/03/2019	6/05/2019
		2	20/08/2020	10/09/2020	24/03/2020	28/04/2020
		3	18/08/2021	10/09/2021	25/03/2021	29/04/2021
	D	1	19/08/2019	25/09/2019	25/03/2019	6/05/2019
		2	20/08/2020	22/09/2020	24/03/2020	28/04/2020
		3	21/08/2021	24/09/2021	25/03/2021	29/04/2021
	F	1	22/08/2019	1/10/2019	25/03/2019	6/05/2019
		2	20/08/2020	6/09/2020	24/03/2020	28/04/2020
		3	21/08/2021	7/09/2021	25/03/2021	29/04/2021
	H	1	21/08/2019	25/09/2019	25/03/2019	6/05/2019
		2	21/08/2020	17/09/2020	24/03/2020	28/04/2020
		3	26/08/2021	15/09/2021	25/03/2021	29/04/2021

Lambs were marked 25 to 44 days after the mid-point of lambing and weaned 84 to 100 days after the mid-point of lambing, and the dates are provided in Table 17. After marking weaners were grazed in plots within the farmlets until sale, or until feed available was insufficient in which case they were grain finished in a makeshift feedlot adjacent to the farmlets. Feedlot finishing was necessary for the first production cycle only. Lambs were weighed between 5 and 8 times after weaning. Sale of lambs was organised to coincide with a predicted 90% of lambs exceeding 44.5 kg live weight. This target weight was chosen to achieve 18 kg carcase weights, the minimum required by the abattoir for slaughter groups. These predictions were based on growth rates experienced by the lambs after weaning in each production cycle. The lambs were sold directly to the abattoir and their carcases were individually weighed on the production line to enable calculation of income for each farmlet.

Table 17 Marking, Weaning and Sale dates for autumn and spring lambs through the field demonstration trial

Season	Production cycle	marking	weaning	sale
Autumn	1	27/06/2019	13/08/2019	3/03/2020
	2	1/07/2020	20/08/2020	10/01/2021
	3	21/06/2021	17/08/2021	14/02/2022
Spring	1	8/10/2019	9/12/2019	8/06/2020
	2	1/10/2020	7/12/2020	14/06/2021
	3	5/10/2021	1/12/2021	27/05/2022

Animal ethics was approved for this trial under New South Wales (Australia) legislation by the CSIRO FD McMaster Laboratory Animal Ethics Committee under animal research authorities 18/13, 19/14, 20/13 and 21/16.

Supplementary feeding was undertaken with groups of lambs and/or ewes as necessary when feed was insufficient. During the drought year (2019) the use of supplements was across all the groups for an extended period, however other supplementation was provided in the other years mostly as wet cold weather limited pasture growth immediately prior to increased feed demand. Feeding was always supplementary (to achieve adequate nutrition) and never to achieve production above the level of adequate pasture/crop grazing.

The quantity of pasture and crop forage was assessed using a rising plate meter (RPM). We conducted some preliminary work to evaluate the green seeker, CDAX and RPM methods of pasture quantification relative to quadrat cuts. The RPM performed best in these tests (Appendix 4), and the built-in calculation of dry matter quantity per ha was very similar to the regression we performed using the height measurement as an explanatory variable for quadrat cuts. Therefore pasture quantity estimates were recorded using the RPM with its built in calculation of dry matter. We used more than one RPM instrument and checked to make sure they were calibrated to give the same results. To calculate whether a feed deficit occurred, we first measured the pasture quantity on the first (Q_1) and last (Q_2) days of each grazing event, converting these data to kg DM rather than kg DM/ha (plots were 0.49 ha in area). Second, we used the feed demand calculator for Phalaris dominant pastures in combination with the weather records for the grazing period to calculate the amount of feed growth which would have occurred during the period in the absence of grazing (Q_M). The DSE stocking rate of the pasture during the grazing event was calculated using the values in Table 18.

Table 18 Dry sheep equivalents for various classes of livestock

Status Description	DSE
Ewes after mid-point of mating	1.3
Single bearing Ewes before lambing (6 wks.)	1.5
Twin bearing ewes before lambing (6 wks.)	1.9
Single rearing Ewes after lambing	3.0
Twin rearing ewes after lambing	3.2
Ewes after weaning	1.0
Lambs after marking	1.3
Lambs after weaning	1.7

Where the stocking rate changed during the grazing event due to deaths or changes to status, the increase or decrease in DSE was calculated as a linear increase or decrease through the grazing event. We used the “Evergraze rule of thumb” (Evergraze, 2010) to estimate DM intake requirements (feed demand) as 1 kg/day required for each DSE (Q_R). We multiplied the feed demand by a factor (1.25) to account for losses of pasture due to trampling (De Leeuw and Bakker, 1986). The evaluation of feed provision (FP) therefore was undertaken using the formula:

$(Q_1 + Q_M) – (Q_R \times 1.25) = FP$

Where FP was less than zero, we defined this as a feed deficit, and where FP was greater than zero, as a feed surplus. We then evaluated whether our estimates of FP were in accordance with Q_2, by subtracting FP from Q_2. We reasoned that if this method were accurate that Q_2 – FP would usually not be less than zero, when FP was greater than zero. Of 270 grazing events where FP was greater than zero, only four yielded a negative answer when FP was subtracted from Q_2.

To analyse results, surplus and deficit FP data were expressed relative to feed demand by dividing FP by ($Q_R \times 1.25$) and binned according to quartiles to create four categories S1-S4 corresponding to the four quartiles of data from the lowest positive FP values to the highest, and D1-D4 corresponding to the four quartiles of data from the highest negative (i.e. closest to zero) FP values to the lowest.

The number of grazing events in each category was compared between farmlets and between feed regime and lambing season factors using Chi squared tests (α=0.05). The number of grazing events evaluated using this methodology was 424 across the eight farmlets in the study.

3.2.4 Statistical analysis

Genstat (19th edition) Version 19.1.0.21390 was used for statistical analysis.

Repeated measures (REML) analysis was used to characterise lamb growth data. Feed regime, lambing season, replicate, age, parity of birth, sex, and year of birth (drop) were included individually in the model to estimate significance of effects. All effects were significant (α=0.05), so a model was constructed to test the effects of feed regime, lambing season and drop, with age, sex, parity of birth and replicate in the random model. Drop was considered separately because of the differences in the outcomes of the dual purpose cropping enterprise in the three production cycles.

Analysis of variance using the unbalanced design tool was utilised in the analysis of lamb weights and carcase weights, faecal worm egg count data, animal health treatments. Analysis of variance using the general model was used to compare farmlet outputs mass of carcase per hectare, income per hectare, lambs produced per hectare, net income per hectare, expenses per hectare and the per ewe equivalents.

Lamb and carcase weights at specific times (birth, marking, weaning, final weight and carcase weight), growth rates from birth till final and from weaning till final, and dollar value of carcases were compared using analysis of variance. For the effects of Feed regime, lambing season, parity of birth, sex, and drop, replicate was included in the model as a fixed term. Age at time of measurement was included as a co-variate when analysing marking, weaning, final and carcase weights and carcase value. Age at final weighing was included as a co-variate for analysing growth rate data.

3.2.5 Gross margins

Costs were calculated based on records (livestock treatments, livestock numbers, cropping operations) and costs as listed (Appendix 2).

Income from lamb was from actual sales and individual animal carcase weights. Where multiple lambs had the same carcase weight, but differing price based on fat depth, it was assumed those with the lightest liveweight had the lowest fat depth.

Income from wool for the 2020 and 2021 shearing of ewes was based on individual fleece weights. Income for the 2022 shearing was based on the mean fleece weights for the two previous years as ewes were removed from the experiment before shearing had occurred. Lambs were shorn in 2021/2, and income was based on the total amount of baled fleece divided by the number of lambs. Wool prices were obtained from AWI's wool indicator price website (https://www.wool.com/market-intelligence/weekly-price-reports/); we chose the 17 micron price ex-Sydney on the first week following shearing (or predicted shearing) for ewe wool and the 28 micron price for lamb's wools.

3.3 Producer Engagement

3.3.1 Northern Advisory Committee

In combination with NSW DPI we set up a Northern Advisory committee to review progress and comment on projects in program 1 which were concerning summer rainfall zone agriculture in northern NSW and southern QLD. The committee was organised by Suzanne Boschma (NSW DPI) and Peter Hunt (CSIRO), who took turns chairing the meetings. Three consultant agronomist representatives were appointed Robert Freebairn (Coonabarabran), Lester McCormick (Manilla) and Michael Duncan (Armidale). At each meeting of the NAC we attempted to have additional producer representatives attend, but this was difficult to achieve due to increased drought workloads on producers and the Covid19 pandemic.

We had three NAC meetings on the 19th of December 2018, 7th of November 2019 and the 3rd of November 2020. At the first meeting we had apologies from two producers who were unable to attend on the day, at the second meeting we were able to host Aidan Rodstrom (Boggabri, NSW) and at the third meeting (conducted by video conference) we hosted Aidan Rodstrom (Boggabri, NSW), Jared Doyle (Nundle, NSW) and Brett Smith (St George, QLD).

3.3.2 Field days, webinars and podcast

With others in the LPP program 1 team, we organised a webinar event showcasing the LPP projects on the 3rd of November 2020. On the 25th of November 2021 a presentation was made to producers via the NSW Sheep connects program, in the following week a podcast about the project was also released via Sheep connects. On the 3rd of December 2021 the project was presented to producers in Tamworth at a NSW DPI field day. On the 16th of March 2022 a field day was conducted at CSIRO Armidale where Armidale-based projects in the LPP were presented to producers. Comments and responses to survey questions were collected at all these events. The project outcomes were also presented in a webinar presented as part of an MLA series on the 12th of October, 2022.

3.3.3 Data use for model improvement

A goal in the project was to see if we could use the data generated to modify and improve models for predicting system outcomes in the summer rainfall zone. Although the data generated will be useful for future improvements, it suffers from first, being generated across three very unusual seasons and second across a relatively small sample size (32 ha, 160 ewes, three seasons). Further efforts to continue data collection and add to that obtained in this project may be useful. Aspects of the model which do not appear to adequately represent the observations in the field trial include:

Lamb growth rates were much lower than predicted for a Phalaris-based pasture. We have gathered data on pasture composition and quantity, with some limited data on pasture quality (pasture quality data collection was discontinued due to Covid restrictions). A more comprehensive analysis is needed over multiple years, and given the differences in Merino type, the model would be best improved if multiple strains of Merino could be compared within sites.

Fly strike rates in first cross lambs were much lower than predicted for Merino ewes, but many more animals would need to be monitored over multiple years to generate data to improve the flystrike model.

Autumn lambing reproduction rates were much higher than predicted in the model simulation. The use of Regulin may have been a factor, but there are conflicting opinions regarding the efficacy of Regulin in the literature. The field trial was conducted without a contrast of with- and without-Regulin, as this would have doubled the size and cost of the work. Given the observation that Regulin may have achieved an effect greater than reparative for autumn lambing, further observations would be needed to test this with greater scientific rigour and gather sufficient data to adjust model predictions.

4. Results and Discussion

4.1 Whole Farm Systems Modelling

4.1.1 Lamb production and feedbase

Pre-trial modelling

Based on the results from the FDC for the improved pasture only systems, late-autumn lambing in May was recommended as the optimal lambing time in the Northern Tablelands, NSW region (thus for the field experiment at the CSIRO Chiswick site, Armidale) to minimise the risk of feed deficits and the reliance on supplementary feeding to maintain livestock.

Multiple location modelling[1]

Feedbase deficits and supplement demand

At all locations, in a pasture only system, shifting from spring to autumn lambing increased the supplement demand during late autumn and winter, while for spring lambing systems supplement

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[1] This section is based on the publication (Watt et al., 2022)

demand was higher in spring, summer, and autumn (Figure 3). In autumn lambing systems, dual-purpose crops significantly improved winter feed supply and reduced supplement demand in all simulated locations (Table 19; Figure 3). For example, at Goulburn, the location that benefited most from dual-purpose crops, the supplement required to meet livestock demand was reduced by ~60% compared to a system relying on pasture only. In contrast, the integration of dual-purpose crops with a spring lambing system was less beneficial and at some locations and sometimes resulted in higher supplement demand compared to the pasture only system, especially at Gulargambone (Table 19). This was because of a 'crop penalty' that arose due to the displacement of pastures with dual-purpose crops. This meant there was a summer feed gap at some locations, as there was less pasture available over the summer months, coupled with the need to support ewes and spring born lambs at this time (Table 19; Figure 3).

Compared to the current pasture only spring lambing system, on average autumn lambing systems with dual-purpose crops had ~28% less supplement demand. This effect was most apparent at medium and high stocking densities (Table 19). The was not the case at Gulargambone, where at low and medium stocking densities the pasture only spring lambing system had a lower supplement demand than the autumn lambing system with dual-purpose crops (Table 19). This was because the displacement of pasture with dual-purpose crops induced more frequent feed deficits in summer (January and February). However, at high stocking density, the autumn lambing system that integrated dual-purpose crops performed more favourably (5% less supplement demand), because dual-purpose crops were still able to mitigate some of the winter feed gap in this system, whilst in the spring lambing system with pasture only, the higher stocking density created a much larger feed deficit in the summer due to insufficient pasture to support the high feed demand of growing lambs and dry ewes (Table 19).

The impact of dual-purpose crop integration on the frequency and amount of supplement demand varied across the different locations and altered the potential benefit in shifting lambing time to autumn. Autumn lambing systems with dual-purpose crops were most favourable in the higher rainfall cooler environments of Armidale and Goulburn. At these two locations, the autumn lambing system with dual-purpose crops had a less severe winter feed gap (Figure 3a-h) and the supplement required was on average around one third of that for the other scenarios tested (Table 19). At Goulburn in particular, the frequency and amount of supplement demand for the autumn lambing system with dual-purpose crops was considerably less across all seasonal conditions and across all three stocking densities (Figure 4b). At Armidale, the effect of dual-purpose crops was less with a similar frequency in supplement demand between all scenarios tested; although the supplement demand of the autumn lambing system with dual-purpose crops was still marginally lower, especially at high stocking density (Table 19; Figure 4a).

The positive impact of dual-purpose crop integration in both autumn and spring lambing systems was less consistent in lower rainfall warmer environments of Gulargambone and Temora. At Temora, the frequency and amount of supplement demand at low stocking density was marginally less for spring lambing systems with dual-purpose crops, but as stocking density increased to medium, and high stocking densities the benefit of dual-purpose crops was similar for both autumn and spring lambing systems across all different seasonal conditions (Table 19; Figure 4d). At this location, the spring lambing system with pasture only had the highest supplement demand of all scenarios tested (Table 19; Figure 4d), with the greatest demand during the spring (Figure 2m-p) when ewe demand was peak due to lambing and lactation. Dual-purpose crops reduced the frequency and amount of supplement demand in spring lambing systems during spring, and in autumn lambing systems in late summer-early autumn, despite the crops not being available for grazing in these seasonal windows (Figure 3m-p). The benefit of dual-purpose crops at Temora was most apparent at medium and high stocking densities (Figure 4d). At Gulargambone, dual-purpose crops improved winter feed supply, although there were still considerable deficits from May to July that would not allow for autumn lambing systems (Figure 3k-l). In spring lambing systems, at this location, the displacement of pasture for cropping negatively impacted feed supply in summer and early autumn, as the crops were not available to graze and the reduced pasture area meant there was insufficient feed to adequately support the demands of the growing lambs and dry ewes (Figure 3i-j). Hence, spring lambing systems with pasture only were most favoured at this location, especially at low and medium stocking densities when the frequency of supplement demand was lower across all seasonal conditions, whilst the value of dual-purpose crops was significantly less (Figure 4c).

The different lambing systems also shifted the supplement demand of the different livestock classes. Because autumn born lambs were sold in early summer, very little supplement was fed to lambs, and this was further reduced with the integration of dual-purpose crops (Table 19). In contrast, a high proportion of supplement was required by spring lambs over the late summer and early autumn (February-March), particularly at Goulburn and Armidale (Table 19; Figure 3a-h). At Armidale and Goulburn, the percent of supplement fed to autumn born lambs rather than ewes was very low (lambs received < 6% of the supplement) compared to spring born lambs (lambs received > 32% of the supplement) because forage quantity and nutritive value was lower at these locations over summer (Table 19; Figure 3a-h) and hence the supplement demand of spring lambs was higher over the summer months. The use of lucerne pasture that is summer-active, at Gulargambone and Temora, offset supplement demand over summer (Figure 3i-p).

At all locations, the stocking density employed to achieve different feedbase utilisation rates interacted with the potential benefits of dual-purpose crop integration. The frequency of supplement demand of each system in the different seasonal conditions increased as stocking density increased (Figure 4). At high stocking density at all locations, integrating dual-purpose crops led to a lower relative increase in supplement demand compared to the pasture only systems but especially for autumn lambing systems (Table 19). This is because the pasture only systems were unable to adequately support livestock demand at high stocking density resulting in a higher frequency and amount of supplement demand, whilst the dual-purpose crops were able to help fill some of those feed deficits in late autumn and winter (Figure 4). At low stocking density at all locations, systems that integrated dual-purpose crops had lower supplement demand compared to the pasture only systems, but differences in the frequency of supplement demand under the different seasonal conditions were more marginal between the scenarios tested (Figure 4).

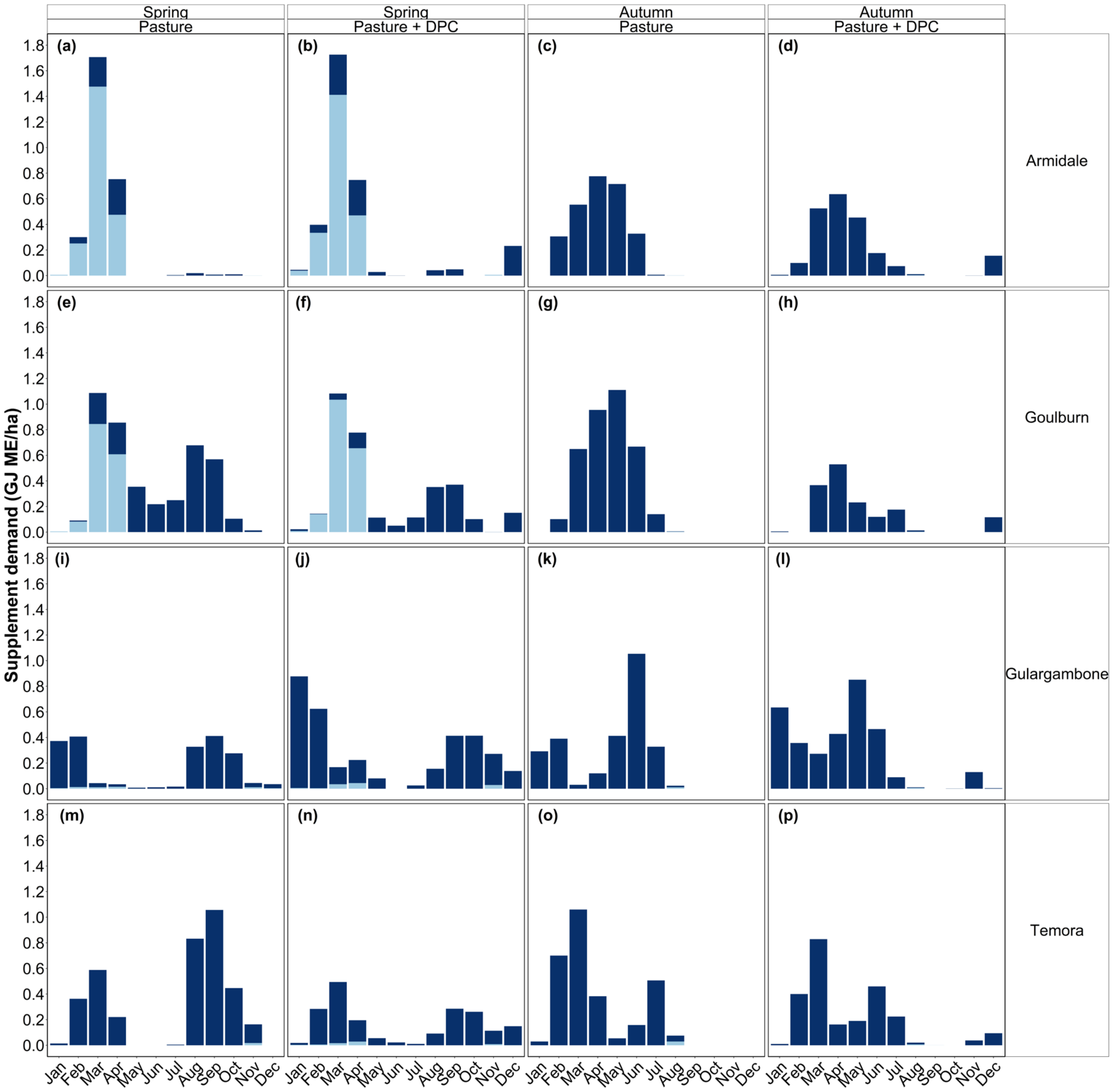

Figure 3 Number of Average monthly supplement demand (GJ ME/ha) at Armidale, Goulburn, Gulargambone, and Temora NSW based on the supplementary feed requirements of ewes (dark blue) and lambs (light blue) in spring and autumn lambing systems, with or without the integration of dual-purpose crops at 'medium' stocking density (i.e., 40% feedbase utilisation rates).

Table 19 Simulated supplement required to meet livestock demand, and the percentage of that supplement fed to lambs under an autumn or spring lambing system with a pasture only or pasture + dual-purpose crop feedbase stocked at ‘low’, ‘medium’, and ‘high’ stocking densities (i.e., 30%, 40% and 50% feedbase utilisation rates, respectively) at four locations spanning northern and southern NSW.

(Utilisation rates calculated using average monthly pasture produced in the pasture only feedbase system. Supplement demand based on supplement fed for maintenance requirements multiplied by 13.8 MJ ME/kg DM (metabolisable energy content of wheat supplement fed)).

Location	**Lambing system**	**Feedbase utilisation rates and feedbase type**					
		30%		40%		50%	
		Pasture	+ DPC	Pasture	+ DPC	Pasture	+ DPC
		Supplement demand (GJ ME/farm ha/year)					
Armidale	Spring	1.3	1.3	2.8	3.0	4.8	5.1
	Autumn	1.7	1.2	3.3	2.5	4.8	4.0
Goulburn	Spring	2.2	1.3	4.9	3.6	8.3	5.8
	Autumn	2.5	1.1	4.5	1.8	5.9	2.6
Gulargambone	Spring	0.8	1.8	2.5	4.1	6.5	8.7
	Autumn	3.0	1.7	3.6	3.8	6.8	6.2
Temora	Spring	2.6	1.5	4.7	2.2	6.7	4.1
	Autumn	2.2	2.1	3.7	2.9	5.7	4.7
		Supplement fed to lambs (% of years)					
Armidale	Spring	86	78	77	73	73	64
	Autumn	0	0	6	2	4	0
Goulburn	Spring	35	67	32	57	38	59
	Autumn	2	1	2	2	0	3
Gulargambone	Spring	15	5	6	7	2	7
	Autumn	0	0	2	0	0	0
Temora	Spring	3	13	0	14	1	10
	Autumn	17	0	0	0	0	3

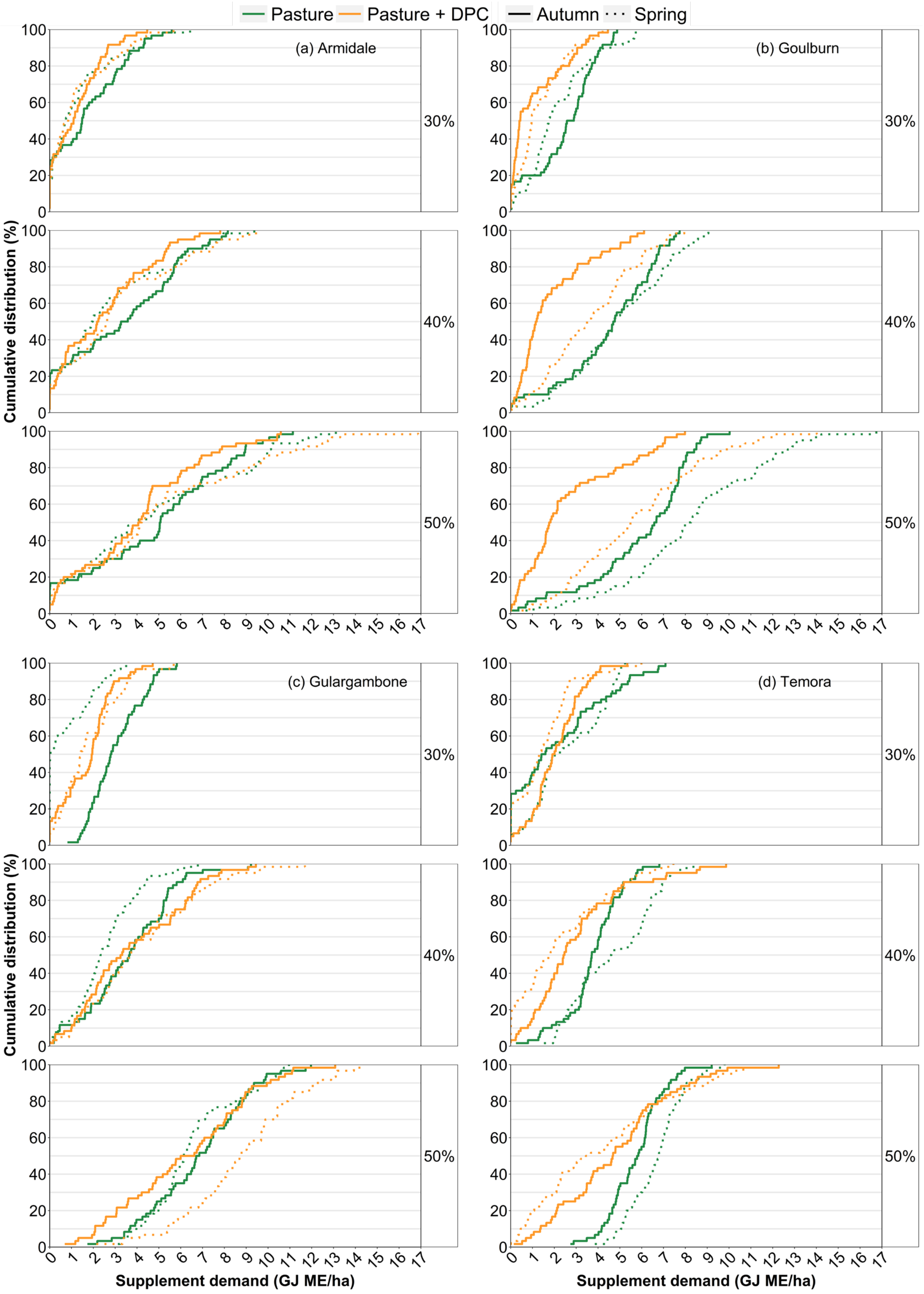

Figure 4 Cumulative distribution of annual supplement to meet livestock demand for autumn and spring lambing systems with pasture only or integrated with dual-purpose crops and stocked at ‘low’, ‘medium’, and ‘high’ stocking densities (i.e., 30%, 40% and 50% feedbase utilisation rates, respectively) at four locations.

Livestock production

Although the modelling study showed that dual-purpose crops help fill the winter feed gap in autumn lambing systems (and in two environments therefore also reduced the amount of supplement fed), this did not always result in higher livestock production metrics compared to autumn lambing systems with access to pasture only. They also provided no additional benefit to livestock production metrics in spring lambing systems (Table 20). Because animals were supplemented when feed could not meet maintenance requirements, the addition of supplement is likely to have masked any potential benefits of dual-purpose crops on livestock productivity that may have otherwise occurred. Integration of dual-purpose crops is also likely to have brought about some challenges, especially to lamb production, as lambs ultimately had limited to no access to the grazing of dual-purpose crops (DPC grazing was only available for ewes pre-lambing in the model) and the displacement of the most productive pastures to crops (i.e., grown on the most productive soil types; LMU1) meant lambs from those systems had access to lower productivity pastures from spring-early autumn. As a result, in some instances, lamb production metrics were marginally lower for the systems that integrated dual-purpose crops compared to those with access to pasture only for the same lambing time (Table 20). However, this was not the case for ewe body condition at joining and reproduction (i.e., based on lamb weaning rates) in their second lambing cycle (i.e., legacy effect) as these metrics were generally the same for the two feedbase systems for the same lambing time (Table 21).

At all locations, regardless of feedbase, the modelling experiment showed that shifting from a spring to an autumn lambing system on average reduced lamb weaning rates by ~13% (data not shown). This reflects the seasonality of ewe ovulation and oestrus that peaks in autumn when joining is scheduled for spring lambing. Autumn born lambs were also ~5% lighter at weaning (data not shown). However, shifting from a spring to an autumn lambing system also bought about livestock production benefits, particularly for individual lamb production. On average, autumn born lambs reached target LW ~16 days sooner, 32% more lambs reached target LW, and carcass weights were 9% higher than spring born lambs; although the lower weaning rates meant total lamb production/ha was ~4% less (Table 20). Even though lamb production metrics were often lower for systems that integrated dual-purpose crops, compared to the current pasture only spring lambing system, autumn born lambs from the system with dual-purpose crops still reached target LW ~10 days sooner, had ~26% more lambs that reached target LW, and ~8% higher carcass weights, although total lamb production/ha was ~7% less (Table 20).

As for lamb production, shifting from a spring to autumn lambing system significantly improved model predictions for ewe body condition at joining and reproduction in their second lambing cycle. On average, autumn lambing ewes had improved body condition (0.8) after their first lambing, compared to spring lambing ewes that more often lost body condition (-0.1) (Table 21). The effect of lambing time on change in lamb weaning rates in the second lambing cycle was much more significant, with weaning rates in autumn lambing systems increasing on average by 7.5% compared to only 0.1% in spring lambing systems, with weaning rates in spring lambing systems decreasing up to 6% at some locations (Table 21).

Differences in livestock production between the two modelled feedbase systems for spring and autumn lambing systems varied across most locations, largely due to feedbase deficits limiting individual lamb production, and ewe body condition and reproduction in the second lambing cycle. At Armidale and Goulburn, autumn lambing systems with pasture only had the highest percent of lambs sold at target LW, and lambs were sold sooner, compared to the other scenarios tested. These differences were greatest when compared to the spring lambing systems as spring born lambs required significant supplementation over summer and early-autumn (Figure 3) that limited lamb production. At higher stocking density the difference in these livestock production metrics were marginal between the two autumn lambing systems (Table 20). At these two locations, the carcass weights of autumn born lambs was always higher than spring born lambs at all stocking densities, but carcass weights were similar for the two autumn lambing systems (Table 20). Total lamb production was marginally higher for the lambing systems with pasture only, regardless of stocking density (Table 20) as these lambs had access to more productive pastures. Despite the higher weaning rates in the spring lambing system (data not shown), total lamb production at medium and high stocking density at these two locations was marginally higher for autumn lambing systems because of the much higher carcass weights (Table 20).

At Gulargambone, at low and medium stocking density, integrating dual-purpose crops allowed autumn born lambs to reach target LW sooner compared to the other scenarios tested, but at high stocking density, there was no difference between the two autumn lambing systems (Table 20). In general, the percent of lambs that reached target LW, and carcass weights were better for autumn lambing systems compared to spring lambing systems. These differences were marginal at low stocking density, but as stocking density increased, the percent of lambs that reached target LW declined significantly in the spring lambing systems (Table 20). At this location, total lamb production was highest for the spring lambing system with pasture only, especially compared to the autumn lambing systems. This was because spring lambing systems had higher lamb weaning rates compared to the autumn lambing systems (data not shown) as carcass weights did not vary significantly (Table 20). However, compared to the spring lambing system with dual-purpose crops, total lamb production was better because the displacement of pasture by crops led to greater feed deficits in autumn, and hence, lower production, especially at higher stocking density.

At Temora, at low and medium stocking density, the number of days to reach target LW, percent of lambs that met target LW, and carcass weights were similar for the two autumn lambing systems and the spring lambing system with pasture only. However, at high stocking density, these lamb production metrics were marginally better for the autumn lambing system with pasture only (Table 20). In general, ewe body condition at joining and lamb weaning rates in the second lambing cycle were significantly better in the autumn lambing systems compared to the spring lambing systems, but these metrics were greatest in the autumn lambing system with dual-purpose crops than all other scenarios tested (Table 21). At Temora, total lamb production was highest for the spring lambing systems compared to the autumn lambing systems due to the higher lamb weaning rates (data not shown) as carcass weights were marginally higher for autumn lambing systems (Table 20). At this location, integrating dual-purpose crops into spring lambing systems benefitted total lamb production at low and medium stocking density, but at high stocking density the pasture only system was better as feed deficits in summer-early autumn in the dual-purpose crop system limited individual lamb production (Table 20).

Generally, as stocking density increased in the modelling experiments, lamb production metrics including number of days to reach target LW, percent of lambs sold at target LW, and carcass weight decreased, but total lamb production/ha increased (Table 20). Ewe condition at joining and reproduction in their second lambing cycle also declined as stocking density increased (Table 21). This was because the on farm feedbase was unable to sufficiently support livestock demand at higher stocking densities and the maintenance level supplementation provided was inadequate to support high growth rates. Spring lambing systems were especially sensitive to increased stocking density due to the much higher feed deficits (thus supplement demand) over summer-early autumn compared to the autumn lambing systems. Although total lamb production increased because of the higher lamb numbers per hectare, the relative increase in total lamb production was marginally lower for spring lambing systems compared to autumn lambing systems (17% vs. 21%) (Table 20).

Table 20 Simulated lamb production outputs for autumn and spring lambing systems with a pasture only or pasture + dual-purpose crop feedbase.

Location	**Lambing system**	**Feedbase utilisation rates and feedbase type**					
		30%		40%		50%	
		Pasture	+ DPC	Pasture	+ DPC	Pasture	+ DPC
		Total lamb production (kg meat/farm ha)					
Armidale	Spring	247	244	307	297	354	339
	Autumn	245	238	326	318	399	392
Goulburn	Spring	164	161	203	199	235	221
	Autumn	159	150	208	201	256	247
Gulargambone	Spring	280	271	366	350	424	402
	Autumn	233	234	312	302	371	361
Temora	Spring	223	228	277	297	370	358
	Autumn	203	204	267	268	329	315
		Average days to reach target liveweight[1]					
Armidale	Spring	151	152	154	154	154	154
	Autumn	125	134	133	134	135	136
Goulburn	Spring	154	154	154	154	154	154
	Autumn	134	143	141	145	148	151
Gulargambone	Spring	115	122	132	144	141	151
	Autumn	108	98	119	111	124	126
Temora	Spring	108	127	119	139	135	146
	Autumn	105	108	117	122	123	139
		Lambs sold at target liveweight (%)					
Armidale	Spring	31	33	18	16	12	12
	Autumn	74	71	72	70	69	69
Goulburn	Spring	25	24	15	11	8	4
	Autumn	70	63	66	61	60	56
Gulargambone	Spring	75	74	67	55	58	36
	Autumn	82	83	77	80	73	73
Temora	Spring	79	72	75	60	61	44
	Autumn	82	82	80	76	75	57
		Average lamb carcass weight (kg)					
Armidale	Spring	16.7	16.8	15.7	15.4	14.8	14.5
	Autumn	18.6	18.5	18.5	18.5	18.4	18.4
Goulburn	Spring	16.4	16.3	15.5	15.1	14.5	13.5
	Autumn	18.5	18.2	18.3	18.2	18.1	18.0
Gulargambone	Spring	18.6	18.6	18.3	17.8	17.9	16.8
	Autumn	18.9	18.9	18.7	18.8	18.6	18.6
Temora	Spring	18.8	18.5	18.7	18.0	18.0	17.1
	Autumn	18.9	18.9	18.9	18.7	18.7	17.9

Table 21 Simulated difference in ewe body condition and reproductive performance (based on lamb weaning rates) in their second lambing cycle compared to those in their first year (i.e., legacy effect) for autumn and spring lambing systems with a pasture only or pasture + dual-purpose crop feedbase stocked at ‘low’, ‘medium’, and ‘high’ stocking densities (30%, 40% and 50% feedbase utilisation rates, respectively) at four locations spanning northern and southern NSW.

Utilisation rates calculated using average monthly pasture production in the pasture only feedbase system

Location	**Lambing system**	**Feedbase utilisation rates and feedbase type**					
		30%		40%		50%	
		Pasture	+ DPC	Pasture	+ DPC	Pasture	+ DPC
		Difference in ewe body condition score at joining (%)					
Armidale	Spring	0.3	0.2	-0.2	-0.2	-0.3	-0.3
	Autumn	1.2	1.0	1.1	1.0	0.9	0.9
Goulburn	Spring	0.3	0.5	-0.1	0.2	-0.4	-0.1
	Autumn	1.1	0.8	0.8	0.6	0.6	0.5
Gulargambone	Spring	1.1	-0.4	0.4	-0.2	0.0	0.0
	Autumn	1.2	0.9	1.0	0.6	0.3	0.0
Temora	Spring	-0.1	-0.4	-0.5	-0.5	-0.4	-0.4
	Autumn	1.1	1.1	0.5	0.8	0.5	0.6
		Difference in lamb weaning rates (%)					
Armidale	Spring	3	2	0	0	1	1
	Autumn	11	9	10	9	8	7
Goulburn	Spring	3	5	-1	2	-2	0
	Autumn	9	6	7	6	5	6
Gulargambone	Spring	12	-2	3	0	0	1
	Autumn	11	11	11	8	3	2
Temora	Spring	-2	-4	-5	-6	-5	-3
	Autumn	8	10	4	7	5	6

Gross margins

At all locations, the modelling experiments showed that systems with dual-purpose crops generally had higher gross margins than the pasture only systems, for the different stocking densities and seasonal conditions. However, the degree of these differences varied between locations (Figure 5). When compared to the standard spring lambing system with pasture only, average median gross margins of autumn and spring lambing systems with dual-purpose crops were AU$284/ha and AU$260/ha higher, respectively (Table 22). These differences were mostly attributable to the economic grain yield from the dual-purpose crops, and the generally lower supplement demand of these systems, especially when autumn lambing, as lamb production was generally similar between the two feedbase systems for the same lambing time (Table 19; Figure 4).

The optimal lambing time and feedbase system that returned the greatest gross margins differed between locations and stocking densities. In higher rainfall cooler environments of Armidale and Goulburn, there was significant benefit to integrating dual-purpose crops compared to pasture only systems. However, the difference in gross margins was greatest for autumn lambing systems with dual-purpose crops, especially at high stocking density (Table 22; Figure 5a and b). This was due to the much lower supplement demand of this system compared to all other scenarios tested (Table 2) in addition to the economic grain yield. At these two locations, the autumn lambing system with dual-purpose crops also carried significantly less risk compared to the other scenarios tested, returning AU$386/ha in the lowest 20% of years (i.e., poorest seasons) compared to the spring lambing system with dual-purpose crops that returned AU$315/ha, and the pasture only lambing systems that returned on average ~AU$183/ha and were often negative at Goulburn (Table 22).

At lower rainfall warmer environments of Gulargambone and Temora, lambing systems with dual-purpose crops returned the highest gross margins, but especially spring lambing systems with dual-purpose crops (Table 22; Figure 5c and d) although differences were variable. At Temora, spring lambing systems with dual-purpose crops always returned the highest gross margins, regardless of stocking density due to a combination of lower supplement demand (Table 19) and the economic grain yield. At Gulargambone, spring lambing systems with dual-purpose crops returned higher gross margins at low and medium stocking density, but at high stocking density, there were only marginal differences in gross margins between the two lambing systems with dual-purpose crops (Table 22; Figure 5c) because the autumn lambing system had much lower supplement demand than the spring lambing system (Table 19). At Temora, lambing systems with dual-purpose crops always carried significantly less risk in the lowest 20% of years compared to the pasture only systems, especially at low and medium stocking density, returning on average ~AUD$77/ha more (Figure 5d). However, at Gulargambone, lambing systems with dual-purpose crops, and the spring lambing with pasture only carried relatively similar risk in the lowest 20% of years, returning on average ~AUD$338/ha and AUD$372/ha, respectively, and this was consistent for the different stocking densities (Table 22; Figure 5c). This was likely due to failed crops limiting winter feed and economic grain yield at this location reducing the profitability of the lambing systems with dual-purpose crops under poor seasonal conditions.

Overall, the modelling experiments showed that dual-purpose crops allowed for an increase in stocking density, without risk of loss to gross margin returns, especially in autumn lambing systems in higher rainfall locations.

Table 22 Simulated gross margins for autumn and spring lambing systems with a pasture only or pasture + dual-purpose crop feedbase stocked at ‘low’, ‘medium’, and ‘high’ stocking densities (30%, 40% and 50% feedbase utilisation rates, respectively) at four locations.

Location	**Lambing system**	**Feedbase utilisation rates and feedbase type**					
		30%		40%		50%	
		Pasture	+ DPC	Pasture	+ DPC	Pasture	+ DPC
		Median gross margin ($/farm ha)					
Armidale	Spring	228	580	295	648	323	639
	Autumn	237	592	382	763	512	889
Goulburn	Spring	3	323	22	347	-4	323
	Autumn	20	330	80	427	150	503
Gulargambone	Spring	339	434	475	580	492	551
	Autumn	179	392	373	513	416	565
Temora	Spring	150	390	204	560	372	646
	Autumn	132	338	233	475	339	526
		Average gross margin in lowest 20% of years or less ($/farm ha)					
Armidale	Spring	125	440	148	452	128	444
	Autumn	201	500	332	652	443	766
Goulburn	Spring	-47	192	-64	192	-96	170
	Autumn	-13	232	43	316	115	378
Gulargambone	Spring	283	282	410	398	424	388
	Autumn	157	264	310	347	343	391
Temora	Spring	96	211	156	289	287	327
	Autumn	107	176	213	301	289	304

Utilisation rates calculated using average monthly pasture production in the pasture only feedbase system. Results reported as average gross margin for each two-yearly cycle

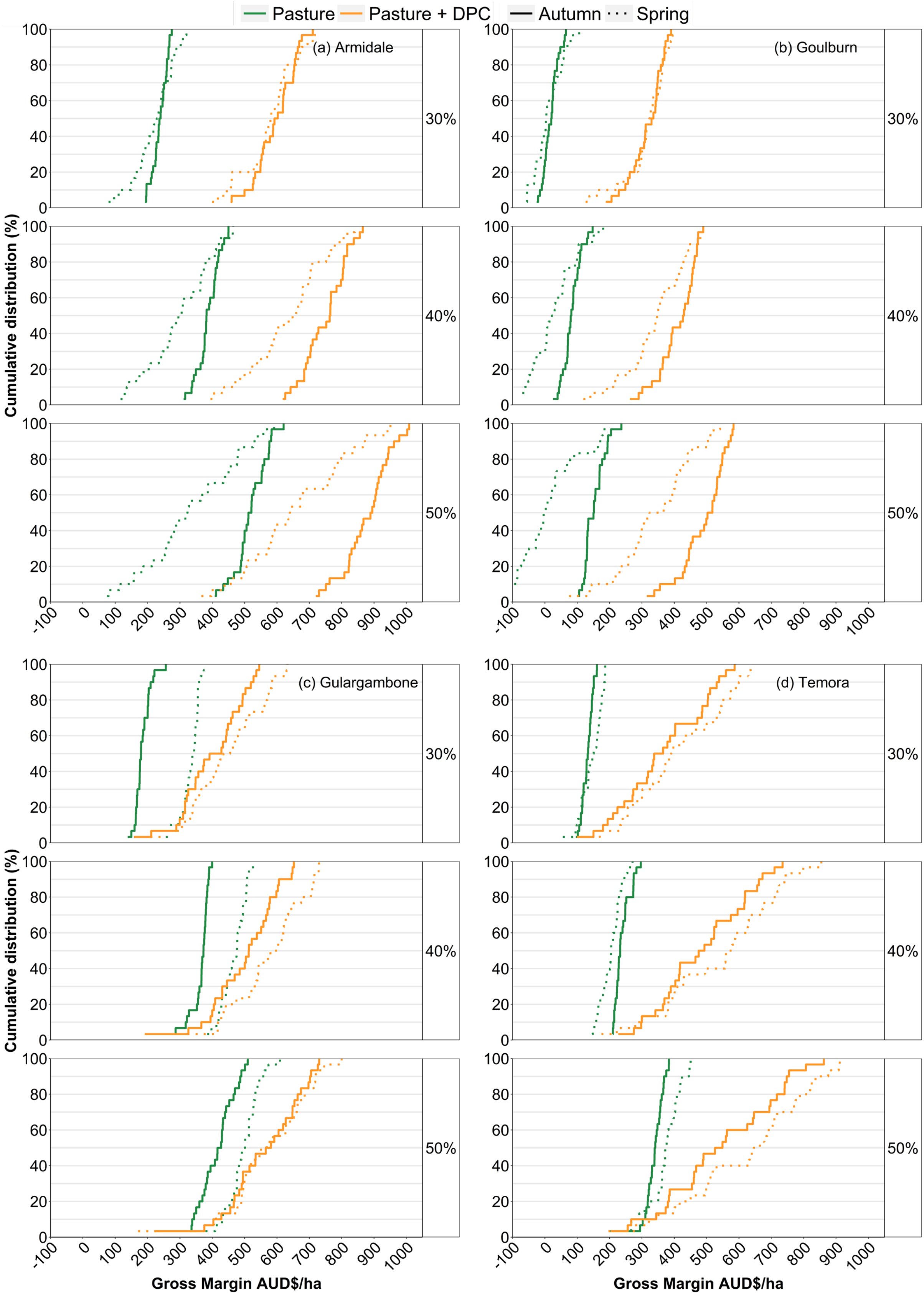

Figure 5 Cumulative distribution of farm gross margins for autumn and spring lambing systems with pasture only or integrated with dual-purpose crops and stocked at different stocking rates (30%, 40% and 50% feedbase utilisation) at four locations. Results represent the average yearly gross margin based on each two-year simulation cycle.

4.1.2 Gastro-intestinal parasites

Total cost of drench treatments and associated labour costs in all modelled scenarios were $6880/1000 sheep (Appendix 2).

Regardless of stocking density, the modelling experiments showed that the autumn lambing system had lower risk of nematode infestation, and thus lower production losses compared to the spring lambing system.

In autumn lambing scenarios where the stocking densities modelled were between five and ten breeding ewes per ha, grazing the crop in 3 phases resulted in lower nematode risk than grazing the crop in only 2 phases. This was attributable to the short crop grazing phases in combination with more frequent paddock rotations. Conversely, when stocked at 5 breeding ewes/ha (i.e. below 40% feedbase utilisation), the longer time animals spent grazing a crop within a single grazing phase, in conjunction with higher stocking rates/ha due to smaller paddock size, resulted in a higher risk of infection, particularly in young lambs as demonstrated from greater lamb meat losses (Table 23). In autumn lambing scenarios, the pasture only system stocked at 5, 5.8 or 8.6 breeding ewes/ha resulted in lower incidence of nematodes compared to the integration of DPC for grazing at 5, 6.7 and 10 breeding ewes/ha. This is likely to be associated with differences in stocking rates between the pasture only and pasture + DPC systems. When the pasture only paddocks in the autumn system were stocked at 7.2 breeding ewes/ha there was only a marginal difference in nematode infectivity compared to the pasture + DPC system with 3 crop grazing phases, stocked at 8.3 breeding ewes/ha (50% feedbase utilisation). In an autumn lambing system, stocked at 5 breeding ewes/ha, grazing of the DPC in only 2 phases or the pasture only system resulted in the lowest incidence of nematodes than any other scenario modelled for both autumn and spring lambing systems.

In a spring lambing scenario, the pasture only systems resulted in lower incidence of nematode infestations, and thus lower production losses, compared to the integration of DPC grazing in either 2 or 3 grazing phases, regardless of stocking density. For the spring lambing, pasture + DPC grazing scenarios, grazing of the DPC in 3 grazing phases, resulted in lower nematode incidence compared to 2 crop grazing phases.

Table 23 Lamb meat and animal wool losses from the modelling experiments associated with infestations of the nematode *Haemonchus contortus* in an autumn or spring lambing system run at varying stocking rates, with or without the integration of dual-purpose crops (wheat and canola). Lamb meat and wool loss costs are based on average prices from 1-Jan 2017 to 1-Apr 2020 (Appendix 2)

Lambing system	Feedbase	Stocking rate (breeding ewes/ha)	Lamb meat loss (kg/1000 lambs)	Lamb meat loss ($ lost/1000 lambs)	Wool loss (kg/1000 animals)	Wool loss ($ lost/1000 animals)
Autumn	Pasture + DPC (wheat – canola – wheat)	5	131	910	4	1180
Autumn	Pasture + DPC (wheat – canola)	5	0	0	9	240
Autumn	Pasture only	5	0	0	2	60
Spring	Pasture + DPC (wheat – canola – wheat)	5	149	1040	52	1320
Spring	Pasture + DPC (wheat – canola)	5	179	1250	74	1870
Spring	Pasture only	5	136	950	47	1200
Autumn	Pasture + DPC (wheat – canola – wheat)	6.7	19	130	28	700
Autumn	Pasture + DPC (wheat – canola)	6.7	80	560	26	670
Autumn	Pasture only	5.8	6	40	9	220
Spring	Pasture + DPC (wheat – canola – wheat)	6.7	323	2250	138	3500
Spring	Pasture + DPC (wheat – canola)	6.7	267	1860	65	1640
Spring	Pasture only	5.8	174	1210	43	1080
Autumn	Pasture + DPC (wheat – canola – wheat)	8.3	37	260	32	810
Autumn	Pasture + DPC (wheat – canola)	8.3	123	860	42	1050
Autumn	Pasture only	7.2	43	300	19	490
Spring	Pasture + DPC (wheat – canola – wheat)	8.3	422	2940	102	2580
Spring	Pasture + DPC (wheat – canola)	8.3	539	3760	123	3110
Spring	Pasture only	7.2	409	2850	68	1720
Autumn	Pasture + DPC (wheat – canola – wheat)	10	99	690	55	1400
Autumn	Pasture + DPC (wheat – canola)	10	254	1770	61	1550
Autumn	Pasture only	8.6	86	600	18	450
Spring	Pasture + DPC (wheat – canola – wheat)	10	551	3840	104	2630
Spring	Pasture + DPC (wheat – canola)	10	478	3330	69	1740
Spring	Pasture only	8.6	297	2070	55	1380

4.1.3 Fly strike

Flystrike risk is much higher from October to March, than May to September due to the cooler winter conditions of the latter period when flies are not active. The risk of flystrike in the modelling experiments over the 30-year period (as indicated by the flystrike rate in untreated sheep; Table 24) was much higher when the lambs were born in late-winter/spring (September) than in late-autumn (May) by a factor of 6 to 15. A longer period lambs spent on farm before sale due to lower growth rates, always increased the incidence of flystrike.

Table 24 Average flystrike incidence (number of lambs) and costs ($) per 1000 lambs weaned over a 30-year period (1988-2018).

Scenario	Born	Sold	Strike Untreated	Strike Treated	Strike Costs
1	23 May	30 October	20.7	20.7	$539
2	23 May	9 December	87.1	13.9	$1,131
3	8 September	15 February	312.4	25.0	$1,598
4	8 September	27 March	495.5	17.8	$1,999

Late-winter/spring born lambs on a property with an average risk of flystrike would require preventive treatment, with the cost depending on the time of sale. Lambs born in May might not require preventive treatment unless growth was slow resulting in their sale later than October.

More preventative treatment would need to be applied to late-winter/spring born lambs compared to late-autumn born lambs. In both late-winter/spring lambing scenarios the model recommended the application of the preventative treatment dicyclanil, a more expensive long-acting product. This may result in higher concentrations of pesticide in the wool at sale that could become an issue during skin processing, or in wool scouring if the wool is harvested from the skins. There was no cost-benefit of preventative treatment for late-autumn born lambs sold 30 October (due to higher growth rates), but the slower growing late-autumn lambing group benefitted from treatment of cyromazine, an inexpensive treatment of a chemical specific for Dipterans (flies and mosquitoes), with little effect on non-target species. As a result of preventative treatment, the number of flystruck lambs would only be slightly higher in the late-winter/spring born group, but the cost of preventative treatment would be 2 to 3 times higher this group of lambs (Table 24).

Despite the variation in the incidence of flystrike on a year to year basis, as driven by weather conditions, in all years simulated in this model the number of lambs at risk (Figure 5) and the total costs (Figure 6) associated with flystrike were always lower in the lambs born in late-autumn, even if the lambs grew slower than those born in late-winter/spring.

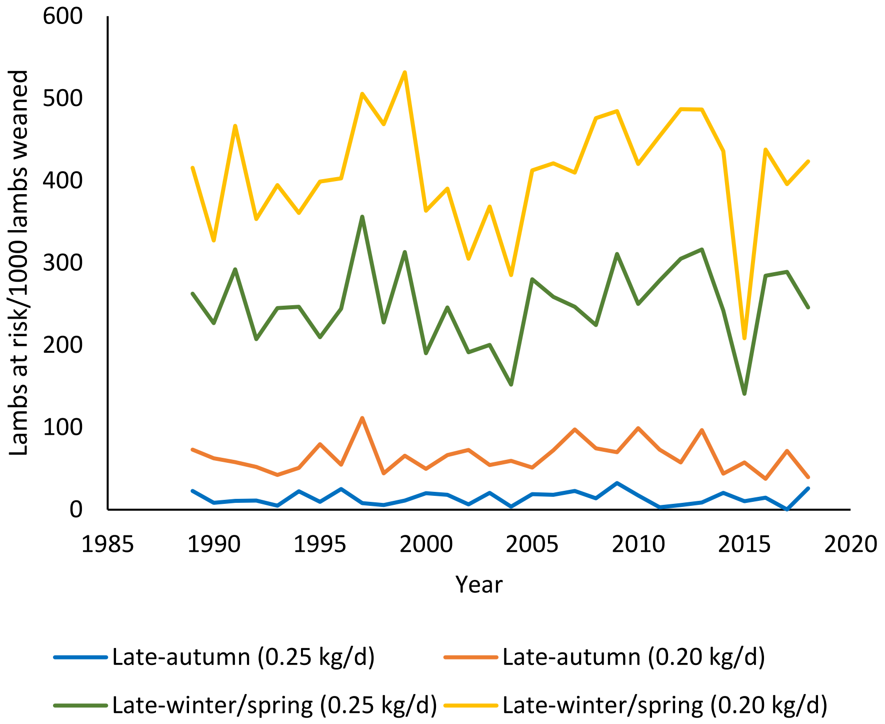

Figure 5 Number of lambs at risk of flystrike per 1000 lambs weaned (no preventative treatment) for simulated late-autumn and late-winter/spring lambing systems at two differing growth rates of 0.25 kg/d or 0.20 kg/d LW gain.

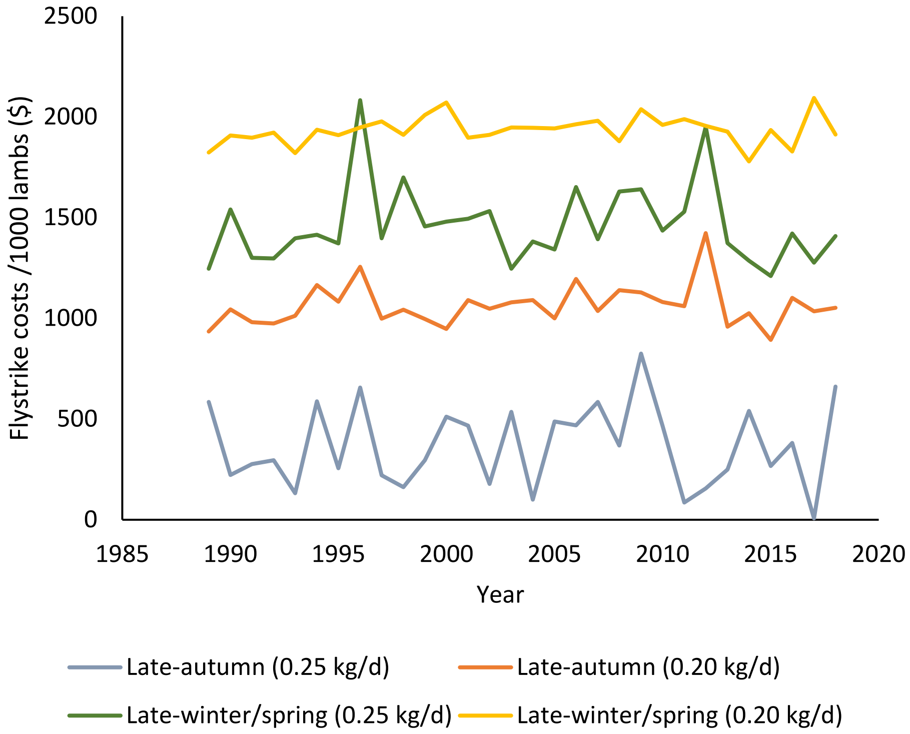

Figure 6 Number of lambs at risk of flystrike per 1000 lambs weaned for simulated late-autumn and late-winter/spring lambing systems at two differing growth rates of 0.25 kg/d or 0.20 kg/d LW gain.

4.2 Field Demonstration Trial

It should be remembered that modelling experiments can only be used to predict outcomes in production systems, and it was necessary to conduct field trials to clarify the applicability of the modelling experiments to producers in NNSW and SQLD.

4.2.1 Crop production

Production cycle 1 – sown April 2019

Wheat and Canola were sown in farmlets A, B, E and F on the 1st of April 2019. Each of these crops was sown on one of the eight plots in the farmlet, so that each of these farmlets had 0.98 ha of crop and 2.94 ha of pasture, compared to 3.92 ha of pasture in farmlets C, D, G and H.

From November 2018 until sowing the crop plots were kept weed free using a combination of tilling and herbicide sprays (first Starane 625 mL/ha, dicamba 625 mL/ha, glyphosate 4L/ha and second glyphosate 4L/ha). These plots had never been used for cropping before and contained many different weed species, so site preparation was more rigorous for the initial planting. Prior to sowing fertiliser was applied including a custom blend (monoammonium phosphate 80 kg/ha, potassium sulphate 200 kg/ha, Solubor 12 kg/ha) and urea (applied separately at 100 kg/ha). Cropmasta 13 was also applied with seed at the time of sowing at 120 kg/ha.

Wheat variety Manning, which is a winter wheat with barley yellow dwarf virus resistance was sown at 90 kg/ha, and the long season, hybrid clear fields Canola variety Edimax was sown at 12.5 kg/ha.

In summary, the plots were cultivated four times including twice to incorporate pre-sowing fertiliser, they were sprayed with herbicides twice prior to sowing and so including sowing there were seven passes of implements across the field.

After germination a post-emergent herbicide application was conducted on both crop types (Canola, Clethodim 120g/ha, Clopyralid 75 g/ha and wheat 50.4 g/ha clodinafop-propargyl with cloquintocet, 350 g/ha 2,4D, 138.75 g/ha dicamba).

Costs (Appendix 2) for implement passes were calculated from $220/ha based on actual prices charged by a local contractor (LA and RA Cameron), and these eight operations comprised 65% for the Canola and 69% for the wheat of the total expenses. Fertiliser comprised 20% of the total costs for Canola and 22% of total costs for wheat. Seed was the next largest cost for the cropping enterprises at 12% for Canola and 6% for wheat. The remaining costs were herbicides.

No grain was harvested from these crops in the 2019 season. The Canola crops did flower and set seed (Figure 7), and the estimates of yield are provided in Table 25. None of the four quadrats had a commercial yield (500 kg/ ha), and the seed quality was variable (Figure 8), so the crops were used for sacrificial grazing.

The wheat crops died during the early spring before there was evidence of heads appearing. Some plants within the grazing exclusion cages did flower and produce heads, but no grain was present within these. The wheat was very short after it died and was not able to be utilised for sacrificial grazing.

Table 25 Estimated grain yield for the four Canola plots grown in 2019

Farmlet	Total grain from 10 quadrats (g)	Predicted yield (kg/ha)*
A	0.1	0.0
B	24.1	51.6
E	52.1	5.4
F	16.3	32.9

* Yield estimated based on the median quadrat's weight of seed collected

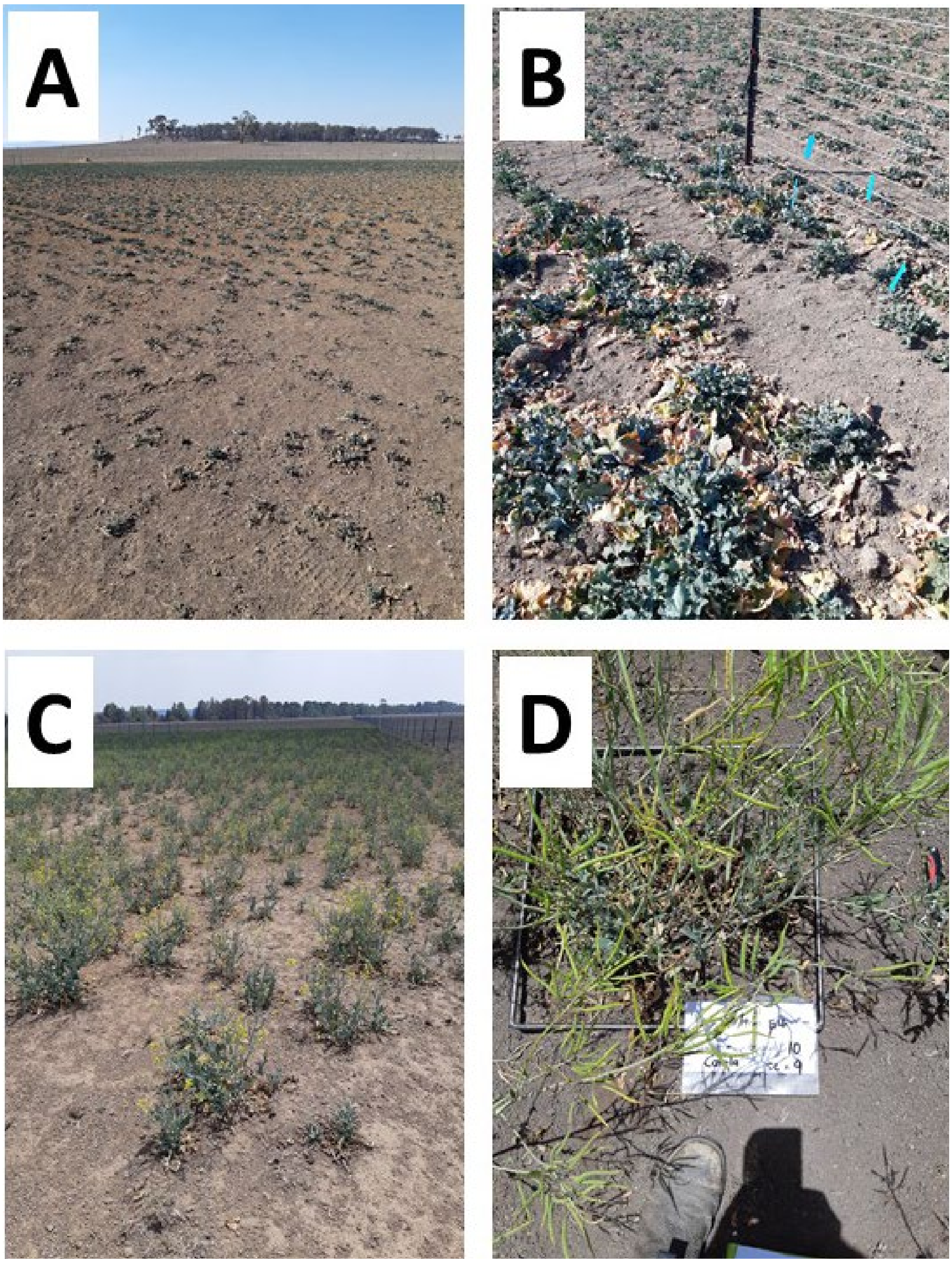

Figure 7 Photographs of (A) the Canola crop in farmlet A on the 11th of September 2019, 15 days after grazing by the autumn lambs and (B) a close up on the exclusion cage showing the ungrazed crop. (C) the Canola crop in farmlet A on the 1st of November, 2019 showing recovery from grazing and flowering, and (D) a quadrat from the Canola crop in E on the 27th of November, 2019 about to be harvested for dry matter and seed yield estimation prior to sacrificial grazing.

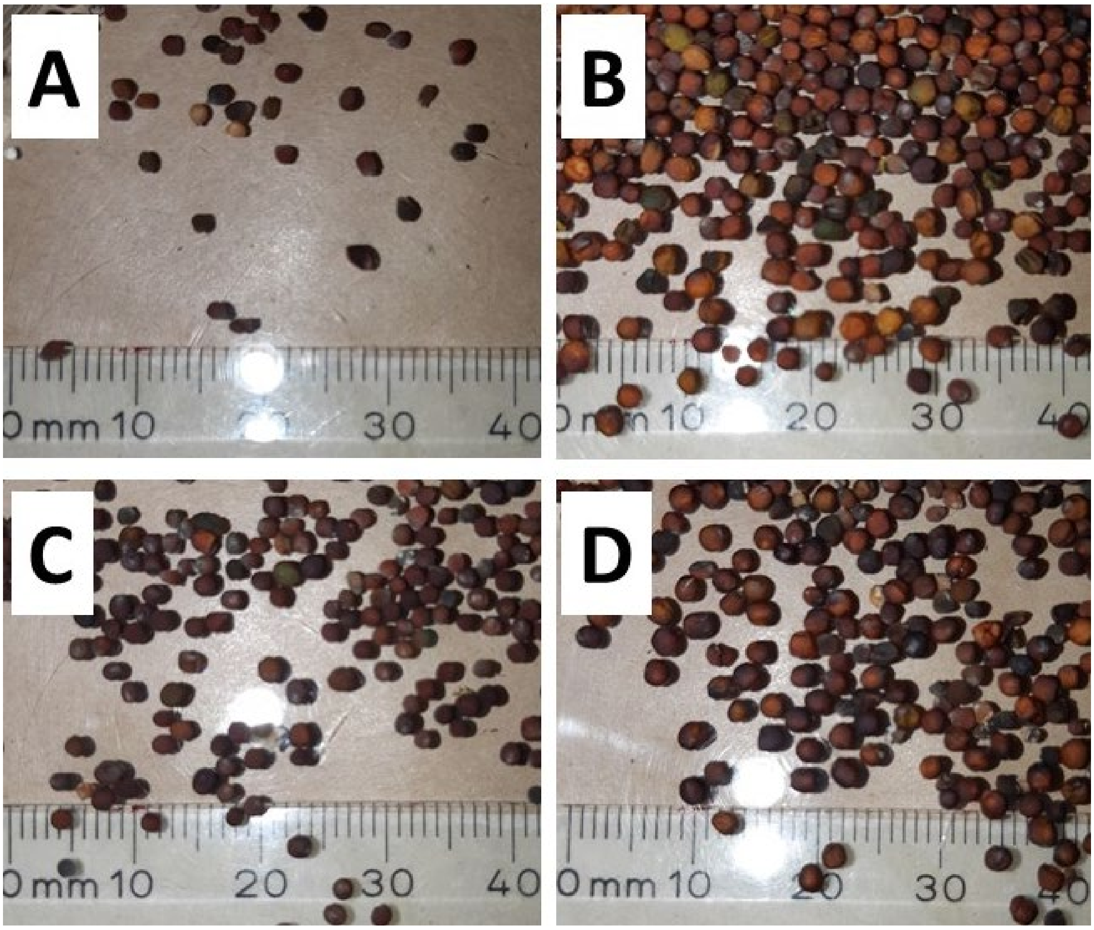

Figure 8 Photographs of seed harvested from Canola plots on the 26th of November, 2019. Seed from farmlet A (A), B (B), E (C) and F (D) is shown. Some of the seed was immature at the time of harvest and has not filled, especially the seed from farmlet A.

The feed provided by the crop grazing events likely had a positive impact on the lamb production outcomes as outlined in section 4.2.2 below. Figure 9 depicts the dry matter estimates before and after grazing for 12 crop grazing events. The difference in dry matter estimates can be expressed as the amount per head or the amount per head per grazing day (Table 26). When analysed in this way it is clear the Canola provided three-fold more dry matter for grazing than the wheat during the winter/spring grazing events (3.06 and 3.12 times for the lambs and the ewes respectively, averaging across replicate farmlets). The other feature of the data is the larger amount of dry matter disappearance during the grazing of gestating ewes compared to weaned lambs, in line with the known difference in energy requirements between these two classes of sheep. For the flowering and seed setting Canola plants, estimates of dry matter per hectare had much greater errors of measurement. Nevertheless, an estimate of dry matter disappearance during these sacrificial crop grazing events was obtained. Consistent with stocking rate and energy requirements, there was a larger dry matter disappearance for the lactating ewes with spring lambs at foot compared to the autumn lambing ewes which had weaned their lambs 104 days prior to the grazing event.

Samples of the Canola and wheat forage were sent for analysis at the NSW DPI feed analysis laboratory in Wagga Wagga. The results are presented in Table 27, including comparisons with pasture samples from November 2018 and February/March 2019 and with feed supplement samples from across the period when supplementary feeding was undertaken. The quality of both the Canola and wheat forage is superior to all pasture samples taken from across the eight farmlets, and the hay samples we analysed. Metabolisable energy levels in the wheat sample were particularly high, exceeding by a small margin the values for grain (corn) and peas. Water soluble carbohydrate (WSC) content was 25.2 % for the wheat forage sample, and this value exceeded that of all other samples. Canola forage had a lower WSC at 13.0 %, similar to samples from pasture in November 2018 (13.1% ± 8.1 %), but superior to pasture samples from March 2019 (3.9 ± 2.0 %). The crude protein estimate for the Canola forage (26.4%) exceeds even that of the peas fed as supplementary feed, however this may be a combination of protein and non-protein nitrogen as the nitrate level in the Canola fodder was 2370 mg/kg DM. The wheat sample had a lower nitrate level at 699 mg/kg DM. Neither of these nitrate levels were high enough to be of concern for animal health. Dry matter digestibility (DMD) for the wheat and Canola forage was higher than for pasture samples and hay. The DMD for wheat forage exceeded that of the corn and peas, perhaps a function of the high level of WSC.

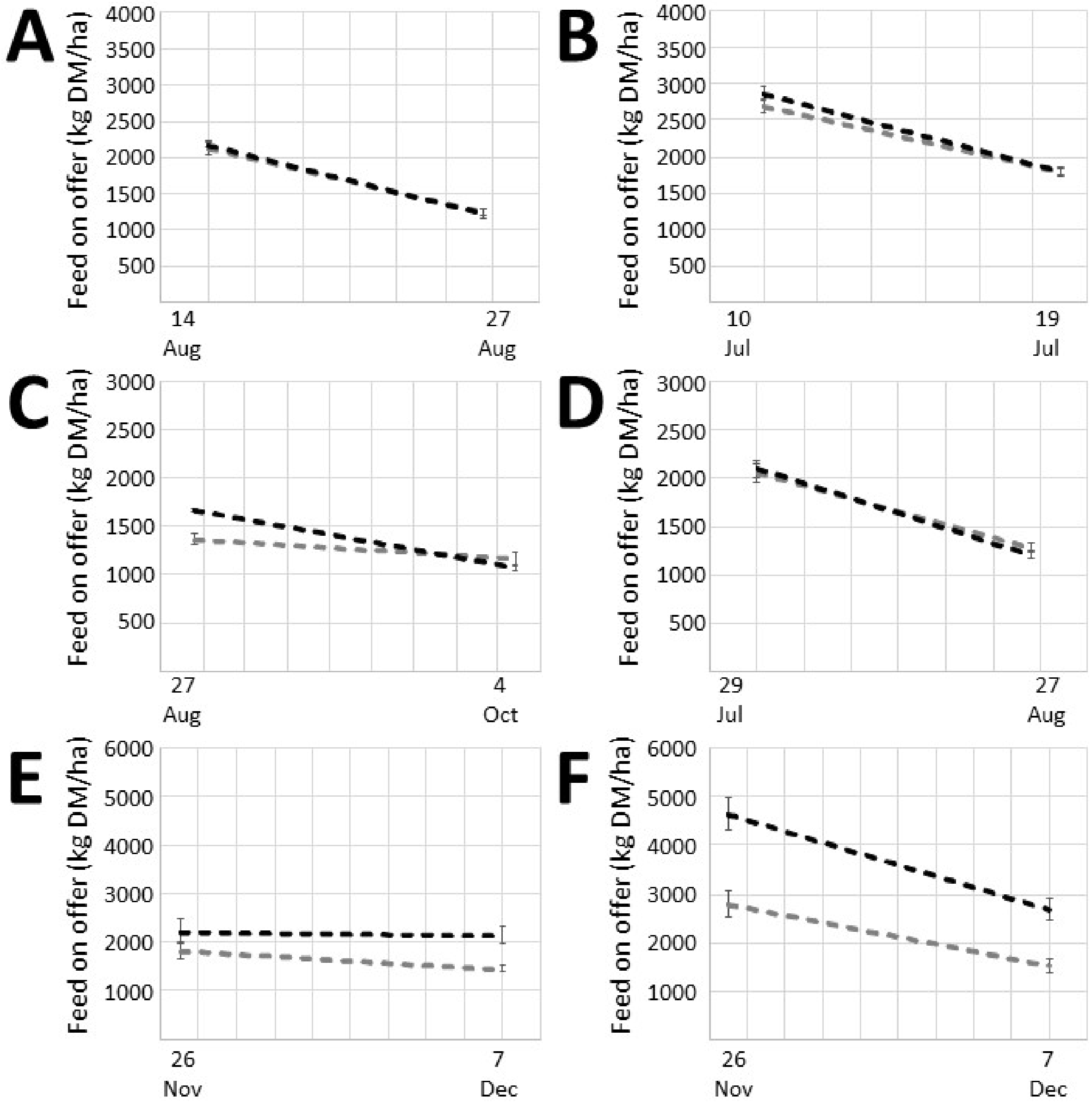

Figure 9 Graphs illustrating the dry matter on offer before and after grazing events on the crop plots during production cycle 1. Autumn drop lambs grazed Canola (A) after weaning, then wheat (C). Spring lambing ewes grazed Canola (B) and then wheat (D) in late gestation leading up to lambing. The Canola crop was sacrificed for grazing by the autumn lambing ewes (E) leading up to mating for production cycle 2, and the spring lambing ewes grazed the Canola with their lambs at foot during the same period. The grey and black dotted lines show the decline in FOO between the before-grazing and the after-grazing measurements. The grey lines represent one of the replicate plots in each graph and the black lines the other. For Figures A, C and E the grey line is for farmlet A and the black line for farmlet E; and for Figures B, D and F the grey line is for farmlet B, and the black line is for farmlet F.

Table 26 Estimated feed on offer before and after crop grazing events[#]

Crop	Farmlet	Estimated FOO (kg/ha)		Difference in FOO			Sheep	
		Pre- grazing	Post-grazing	kg/ha	kg/hd	kg/hd/day	n	Class
Canola	A	2122 ± 79	1239 ± 42	883	38.4	1.32	23	lambs
	E	2178 ± 78	1223 ± 50	955	39.8	1.37	24	lambs
	B	2689 ± 86	*	900	45.0	4.09	20	ewes
	F	2858 ± 106	1790 ± 65	1068	53.4	4.86	20	ewes
Wheat	A	1366 ± 59	1168 ± 28	198	8.6	0.23	23	lambs
	E	1668 ± 66	1071 ± 25	597	24.9	0.65	24	lambs
	B	2048 ± 93	1278 ± 52	770	38.5	1.33	20	ewes
	F	2097 ± 91	1207 ± 37	890	44.5	1.54	20	ewes
Canola (sacrificed)	A	1838 ± 178	1454 ± 59	384	19.2	1.13	20	ewes
	E	2227 ± 268	2138 ± 181	89	4.4	0.26	20	ewes
	B	2792 ± 270	1521 ± 146	1271	33.4	1.97	38	ewes & lambs
	F	4650 ± 325	2685 ± 211	1965	53.1	3.12	37	ewes & lambs

* post grazing estimation data not obtained. Data from farmlet F used to calculate difference in FOO (feed on offer)

Error estimates provided are the standard error of the mean (SEM)

We were constrained to start the wheat and Canola production cycles in 2019, but a rational producer would probably have chosen not to plant the crops due to the poor rainfall outlook. The advantages in feed supply, especially from the Canola crop were significant despite the drought conditions. However, the financial burden of livestock feeding eclipsed the value of increased lamb income due to the crop feeding. It would be attractive to do further analysis of the trade-off between these two aspects of drought management.

In addition, we had increased costs to set up the crop plots as this was a site where cropping had not been undertaken before. In the 2020 season, our costs for establishing crops were much reduced with fewer tractor operations and reduced herbicide use.

After sacrificial grazing, the Canola crops were scheduled for herbicide treatments to achieve the summer fallow. At the time sheep were removed the plots were quite bare, no rain had fallen, and it seemed unnecessary to spray. In late January, a heavy downpour occurred, and the plot soils quickly became waterlogged. At the same time runoff damaged fences so that we could not re-introduce stock. The wet soil conditions persisted for some time, and the Canola recovered, flowered and began to set seed (Figure 10). The option for either another grazing event or retention and harvest of the crop was presented to the three consultants engaged in the NAC. Two of the three advocated for grazing followed by herbicide sprays and one was in favour of seeing if a grain yield could be achieved. The persistent waterlogging issue prevented both these approaches, we could not move machinery in to repair fences, so grazing could not occur, and we also could not move machinery onto the plots for spraying or harvesting. The result was a late sowing for the second production cycle crops and a delayed return of the ewes to the system.

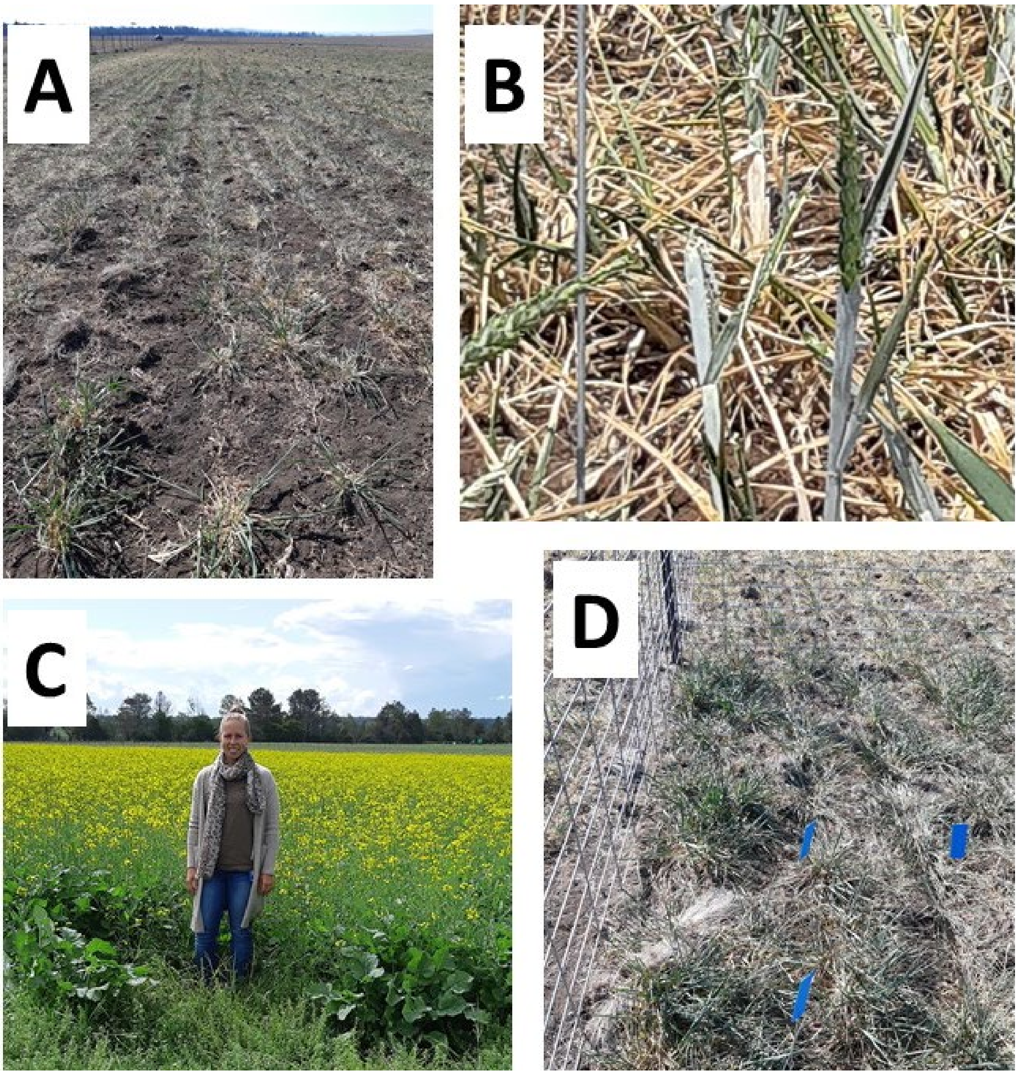

Figure 10 Photographs of (A) the wheat crop in farmlet B on the 11th of September 15 days after grazing by the spring lambing ewes and (B) a close up on wheat plants in the exclusion cage on the 1st of November showing occasional heads. When examined, these heads did not have any grain. showing the ungrazed crop. A picture of some of these plants is provided (D). Rain in late January and early February prevented the removal of the Canola crops using herbicides and the plants recovered and flowered (C). Lucy Watt is present in the photo.

Table 27 Feed quality data comparing forage samples from the Canola and wheat crops to pasture samples and samples of supplementary feed provided[#]

Sample	Date	n	Dry Matter %	Crude Protein %	Metabolisable energy (MJ/ kg DM)	Dry matter digestibility %
Pasture	Nov-18	8	92.8 ± 0.04	8.8 ± 0.62	8.5 ± 0.37	59.1 ± 2.16
	Mar-19	8	92.9 ± 0.35	5.5 ± 0.36	5.9 ± 0.14	43.5 ± 0.83
Canola*	Jul-19	1	92.9	26.4	12.0	79.0
Wheat*	Jul-19	1	94.5	21.7	13.8	89.0
Hay		4	91.3 ± 0.22	7.6 ± 0.12	9.4 ± 0.74	64.1 ± 4.2
Peas		3	93.1 ± 0.3	23.6 ± 0.43	12.9 ± 0.04	86.8 ± 0.33
Corn		3	92.8 ± 0.28	11.1 ± 0.04	13.1 ± 0.04	83.7 ± 0.29

* A single bulk sample was sent for analysis, so no error estimates are provided

Error estimates provided are the standard error of the mean (SEM)

Production cycle 2 – sown April 2020

Wheat was sown in farmlets A, B, E and F on the 1st of April 2020. Canola was sown in farmlets A and B on the 16th of April and farmlets E and F on the 27th of April. Cropmasta 13 was applied with seed at the time of sowing at 100 kg/ha. Wheat variety Manning, which is a winter wheat with barley yellow dwarf virus resistance was sown at 90 kg/ha, and the long season, hybrid clear fields Canola variety Edimax was sown at 12.5 kg/ha. Each of these crops was sown on one of the eight plots in the farmlet, so that each of these farmlets had 0.98 ha of crop and 2.94 ha of pasture, compared to 3.92 ha of pasture in farmlets C, D, G and H.

Sowing had been delayed due to wet weather, and there were difficulties with large amounts of trash from weeds, especially in the Canola plots, where the failed wheat crop from the previous year had left bare ground readily colonised by weeds. Wet weather had precluded adequate weed control during the summer; however all plots were treated with herbicide (glyphosate 4L/ha) on the 16th of January and again on the 17th of March. A flail mower was used to mulch dead weed material prior to sowing the Canola with a tine type seeder, this had not been necessary for the wheat as a disc seeder could be used. After germination a post-emergent herbicide application was conducted for the wheat (340 g/ha MCPA, 80 g/ha dicamba). We also top dressed the wheat plots with urea (100 kg/ha) in early spring.

In summary, all plots were sprayed twice to control fallow weeds, the Canola plots had an additional weed mulching treatment so that there were five field passes for each plot (including sowing and harvest), and the wheat had a post-emergent herbicide spray and a fertiliser treatment so that there were six field passes for each plot (including sowing and harvest).

Costs for implement passes were calculated from $220/ha based on actual prices charged by a local contractor, and these eight operations comprised 76% for the Canola and 83% for the wheat of the total expenses.

In production cycle 2, both wheat and Canola crops were harvested. The harvest took place on the 27th of January 2021, delayed by some weeks because of wet weather. Some lodging of the wheat crops was observed due to heavy rainfall, and the rain also likely resulted in loss of seed from the Canola which had ripened by early January. By January, the mouse plague was also evident at the site, possibly also reducing yield in both crops. In December, we collected quadrat cuts through both the Canola and wheat crops, aiming to estimate yield from these. Unfortunately, mouse infestation destroyed these samples before they could be analysed. Grain yields therefore are based on the grain harvested, collected in “bulka” bags and weighed using load cells. Yields were adjusted to allow for trash present at a higher than usual level because of the rain damage to crops. A 100 g sample was taken from one Canola and one wheat bulka bag, cleaned by hand and re-weighed to estimate clean seed yield. Canola samples were 96.3% clean seed and wheat samples were 94.9% clean seed. The yields provided in Table 28 are adjusted for clean seed content.

Harvested grain quality was assessed by the NSW DPI laboratory at Wagga Wagga (Table 29). The yields and a visual assessment showed that the plots in replicate one (A and B) were more similar to one another than the plots in replicate two (E and F), so the samples submitted were from combined samples representing the replicate one or replicate two plots. There are known soil and topographical differences between the replicates (Appendix 1, Table 13).

Table 28 Grain yield for the Canola and wheat plots

Farmlet	Canola (kg/ha)	wheat (kg/ha)
A	1691	2193
B	766	2080
E	997	1814
F	843	1700

The Canola grain was within the minimum quality parameters set by oilseeds Australia, but only by a small margin. The wheat variety Manning is only suitable for livestock feed, the metabolizable energy results from the analysis meet the expectations for feed quality wheat (NSW DPI – Primefact 339). The prices used to estimate income from the wheat and Canola were from agricultural press articles published soon after the harvest (wheat delivered to Darling Downs, $330/t Queensland Country Life 9/02/2021; Canola for export, $600/t The Land 11/3/2021). Grain handling and delivery charges were estimated at $45/t.

Table 29 Grain quality for the Canola and wheat plots

Measurement	**Canola**		**Wheat**	
	Rep1	**Rep2**	**Rep1**	**Rep2**
Crude Fat (%)	37.2	42.5	1.7	1.6
Starch (%)	nd	nd	67	67.5
Acid Detergent Fibre (%)	26	26	5	5
Metabolisable Energy (MJ/kg)	21.9	23.2	13.5	13.6
Crude Protein (%)	21.8	18.9	11.2	12.3
Neutral Detergent Fibre (%)	38	39	16	16
DMD (%)	80	79	90	91
DOMD (%)	79	78	88	89
Dry matter (%)	94.9	93.4	90.1	90.4
Moisture (%)	5.1	6.6	9.9	9.6
Inorganic Ash (%)	4	4	3	3
Organic matter (%)	96	96	97	97

All the farmlets grain production cycles had a net negative income due to high input costs, especially the number of field passes, and low yields. In December, a local agronomist estimated the yield for both crops at higher levels than were achieved. The wet weather and rodent damage are presumably the reason for the difference. The break-even yield for Canola given the cost of local contractors for small fields would have been 4.01 t/ha and for wheat it would have been 4.80 t/ha.

The feed provided by the crop grazing events likely had a positive impact on the lamb production outcomes. Figure 11 depicts the dry matter estimates before and after grazing for eight crop grazing events. The Canola provided more dry matter for grazing than the wheat in farmlets A and B (replicate 1 farmlets), but not farmlets E and F (replicate 2 farmlets). The replicate 2 farmlet's Canola was sown later than for the replicate 1 farmlets. Ewes during lactation were grazed on the Canola in farmlets A and E, and dry matter disappearance was marked. Their lambs after weaning grazed the wheat and dry matter disappearance was less, in line with the lower stocking density. The spring lambing ewes with lambs at foot grazed the Canola and wheat in farmlets B and F. The onset of grazing in F had to be delayed as too little dry matter was present. Nevertheless, there was no dry matter decline in these plots due to grazing pressure. The grazing events were terminated when crop phenology indicated that a risk to grain yield would have resulted from further grazing.

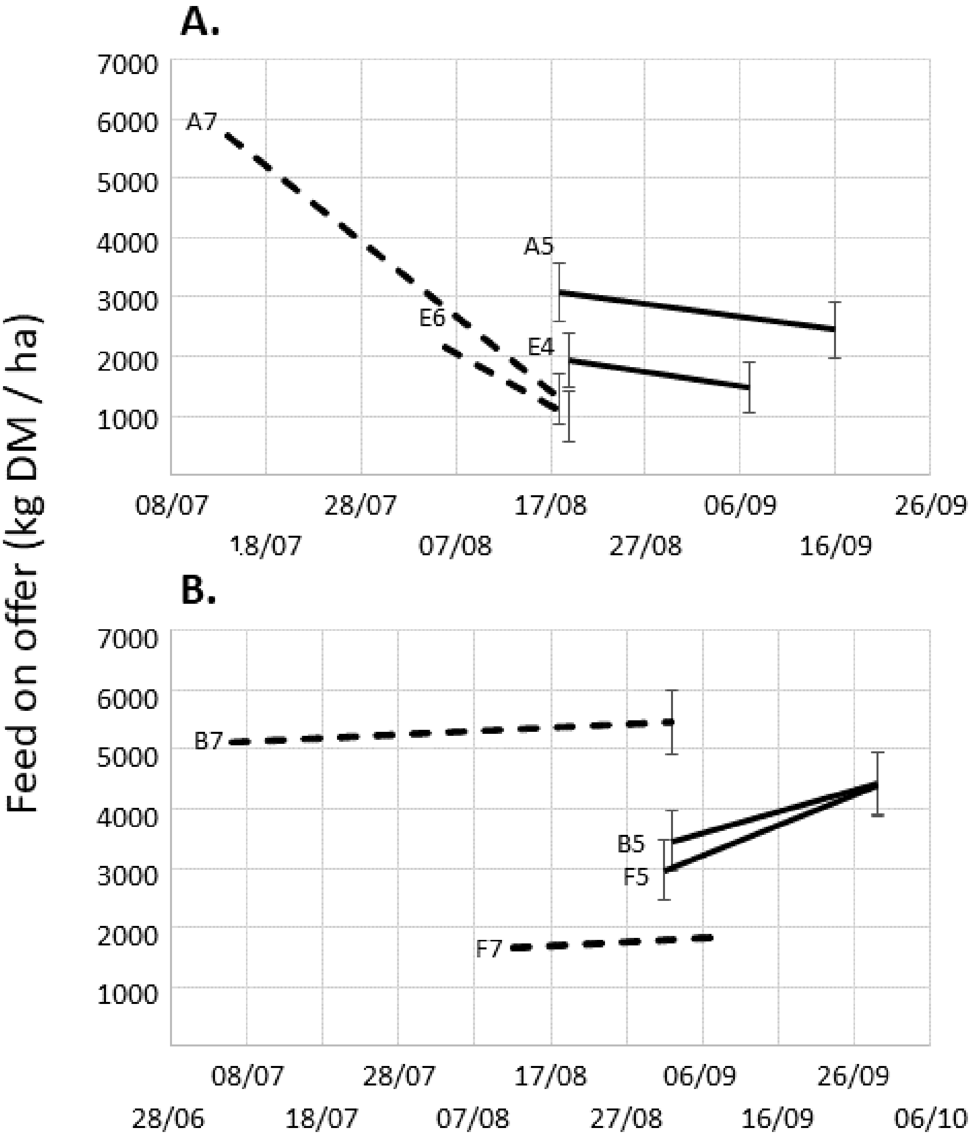

Figure 11 Graphs illustrating the dry matter on offer before and after grazing events on the crop plots during production cycle 2. Autumn lambing ewes with lambs at foot (A) grazed Canola (dotted lines), and their lambs after weaning grazed wheat (solid lines). Spring lambing ewes (B) grazed Canola (dotted lines) and then wheat (solid lines) during the lambing period and early lactation. Each line has beside it the plot (number) and farmlet (letter) indicated. The x-axis shows dates (in 2020) when the grazing events occurred. The level of FOO for the second data point in F7 has been estimated using the daily change in B7 and the starting FOO; a measurement was not possible because of equipment failure. Error bars represent twice the standard error of the mean; where these are absent equipment failure prevented us obtaining the variance of height measurements as a mean measurement only could be gathered using the backup equipment.

Samples of the Canola and wheat forage were sent for analysis at the NSW DPI feed analysis laboratory in Wagga Wagga. The results are presented in Table 30. The quality of both the Canola and wheat forage is high compared to typical pasture sample analyses, but the Canola is superior for protein, whereas the wheat contains higher amounts of water soluble carbohydrates. Pictures of harvested grain (Figure 12) illustrate the higher quality of the 2020 Canola compared to 2019, and also show some of the water damage, especially in the wheat.

Table 30 Analysis of Canola and wheat forage

Measurement	Wheat (R1*)	Wheat (R2)	Canola (R1)	Canola (R2)
Neutral Detergent Fibre %	47	46	29	32
Acid Detergent Fibre %	26	25	20	21
Crude Protein %	15	16	23.4	19.8
Inorganic Ash %	8	9	12	12
DMD %	85	86	87	87
Metabolisable Energy MJ/kg	13	13.2	13.3	13.4
*Water Soluble Carbohydrate %	31.8	31.5	22.1	23.9
Organic Matter % 75	92	91	88	88
DOMD % 38	79	80	80	81
Dry Matter %	88.6	88.6	85.2	86.1
Moisture %	11.4	11.4	14.8	14

* replicates 1 are farmlets A and B, replicates 2 are farmlets E and F

Figure 12 Photographs of the grain harvested in 2020, the wheat (upper) and the Canola (lower).

Production cycle 3 – failed crop

The third production cycle began during an extremely wet 2020/21 summer. Soil moisture levels were too high to safely operate farming equipment from January through to May, resulting in our inability to sow crops for this third production cycle.

4.2.2 Lamb production

4.2.2.1. Reproductive performance

After three production cycles of lambing, some consistent patterns have emerged in lambing outcomes when autumn is compared to spring lambing, or when dual purpose crops are included in the feedbase compared to pasture only systems. Table 31 shows a break-down of the outcomes by feed regime, lambing season and production cycle. The data separated by farmlet and into two and three factor comparisons is presented in Appendix 5.

Our trial did not aim to test any individual farm management options, but rather to contrast typical/best industry practice systems across the four treatment groups. In that respect, we used melatonin implants (Regulin®) in the ewes and rams according to the manufacturer's instructions in preparation for the December mating of autumn-lambing ewes. We did not use melatonin implants for the March mating of spring-lambing ewes, as March is an optimum month for mating, and ovulation rates should not be influenced by exogenous melatonin at that time. Spring-lambing operations do not usually utilise melatonin implants in their production system, whilst the use of melatonin implants for autumn lambing is best practice.

Compared to spring lambing, autumn lambing consistently produced more twins (ANOVA p=0.032), fewer singles (ANOVA p=0.029), more surviving lambs (ANOVA p=0.016) and a greater number of lamb mortalities (ANOVA p=0.038). This is also reflected in higher scanning (ANOVA p=0.002), lambing (ANOVA p<0.001) and lamb marking (ANOVA p=0.016) percentages and there were less than half the number of dry ewes recorded in autumn lambing compared to spring lambing (ANOVA p=0.033). Because of the greater number of twins and lamb mortalities, the category of ewes which lost one twin but raised the other is also more predominant in autumn lambing ewes (ANOVA p=0.041).

Providing dual purpose crop grazing compared to pasture only systems had little effect on lambing outcomes and this factor was not significant for any of the lamb outcome categories or ratios. The effect of year of birth might have been expected to be significant given the extreme environmental differences between years, however only one measure, scanning percentage was significantly different between years (ANOVA p=0.03). Ewes lambing in 2021 had a higher mean scanning percentage than those lambing in 2019, with 2020 ewes not significantly different to either of the flanking years.

Table 31 – Reproductive performance over three production cycles.

Year	Lambing season	Feed Regime	**Lambs dead**	**Lambs alive**	**Scan%**	**Lambing %**	**Marking %**	**Dry**	**LAL**	**LAL***	**S**	**T**
ALL	Autumn	ALL	78	314	159	163	131	12	23	32	65	108
ALL	Spring	ALL	47	269	138	132	112	28	25	17	90	80
p value			0.038	0.016	0.002	<0.001	0.016	0.033	ns	0.041	0.029	0.032
ALL	ALL	DPC	75	277	149	147	115	22	29	29	74	86
ALL	ALL	pasture	50	306	148	148	128	18	19	20	81	102
p value			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
2019	ALL	ALL	40	182	140	139	114	14	18	17	58	53
2020	ALL	ALL	41	196	147	148	123	15	13	14	54	64
2021	ALL	ALL	44	205	159	156	128	11	17	18	43	71
p value			ns	ns	0.030	ns	ns	ns	ns	ns	ns	ns

* No crops planted in DPC plots in 2021

Scan, Lambing and Marking % expressed as lambs/100 ewes

LAL Lambed and lost all lambs

LAL* Lambed and lost one twin lamb, or lambed and lost one or two triplet lambs, raising the survivor(s)

S gave birth to, and raised a single lamb

M gave birth to, and raised twin lambs or triplets (no triplets in cycle 1)

In the lower three panels, underlined numbers indicate where significant differences (by ANOVA) were observed (α=0.05).

p values for analysis by ANOVA, α=0.05.

ns = not significant

4.2.2.2. Supplementary feeding

Production cycle 1 - 2019

Due to drought conditions the autumn lambs from pasture only farmlets were confined and fed grain (maize and pulse mix 50/50) and hay to finish them for market. The lambs with access to DPC grazed these before being introduced to confinement feeding, and they received a limited grain ration during the DPC grazing to prepare them for the subsequent confinement feeding. This DPC grazing resulted in a saving of 12 kg of grain per head and 29 kg of hay per head when compared to the lambs from the pasture only feed regime farmlets. Spring lambs were weaned in January 2020 and did not have access to any standing feed, so all the lambs were raised under confinement feeding for the whole of the post weaning period. The onset of rainfall and subsequent pasture recovery in February meant the total grain fed to the spring lambs could be reduced, so these lambs were able to be finished using 35 kg less grain and 57 kg less hay per head than the autumn lamb pasture feed regime group. Table 32 shows the feed provided to both ewes and lambs in the four treatment groups (see Appendix 6 for data by farmlet). For the spring lambing groups, DPC grazing was available for the ewes in late gestation and because of the failed crop, sacrificial grazing of the Canola also occurred while these ewes had lambs at foot. Together these DPC grazing events enabled a saving of 35 kg of grain and 4 kg of hay per ewe for the spring ewes in the DPC feed regime group compared to the spring lambing pasture only group. The spring lambing ewes were also able to go onto a reduced grain and hay ration towards the end of the period leading up to mating in March 2020, due to recovery of pasture in their agistment grazing area. The autumn and spring ewes share 9 months of their production cycles (March till December). In this first production cycle, the autumn lambing ewes did not require supplementary feeding at the beginning, and supplementary feeding was phased out at the end of the production cycle for the spring lambing ewes. A comparison of supplementary feeding is therefore not straight forward, but the autumn ewes received 29 g/hd/day greater grain ration than the spring ewes and 3 kg/hd more hay.

Table 32 Supplementary feeding of lambs and ewes in production cycle 1

Animal class	Lambing season	Feed regime	Animals	Start	End	Hay (t)	Grain (t)	Days on feed	Average grain/hd/day (kg/hd/day)
Ewes	Autumn	DPC+Pasture	40	18/03/2019	6/12/2019	14.71	4.72	235	0.449
		Pasture	40	18/03/2019	6/12/2019	15.88	4.72	263	0.449
	Spring	DPC+Pasture	40	25/03/2019	23/03/2020	9.88	5.62	207	0.385
		Pasture	40	25/03/2019	23/03/2020	13.45	6.1	357	0.42
Lambs	Autumn	DPC+Pasture	46	14/08/2019	5/03/2020	1.91	5.83	178	0.621
		Pasture	52	14/08/2019	5/03/2020	3.66	7.21	203	0.68
	Spring	DPC+Pasture	35	6/01/2020	10/06/2020	0.46	3.64	156	0.668
		Pasture	47	6/01/2020	10/06/2020	0.62	4.9	156	0.668

Production cycle 2 - 2020

All the autumn lambing ewes, and one group of autumn lambs were provided with strategic supplementary feed in the second production cycle (2020 lambing) (Table 33 - see Appendix 6 for data by farmlet). The level of supplementation depended on feed availability. During mating of the autumn lambing ewes, the 2019 drought was still underway, and the ewes were fed Canola hay during December and in early January. The spring ewes were fed at this same time, but this was accounted for within the first production cycle for those groups. No supplementary feeding occurred for spring lambing ewes or lambs in production cycle two. For the autumn lambing ewes and one group of autumn lambs, feeding was again undertaken during September and October where cotton seed meal pellets were provided. A feed gap was evident at this time, but with warming temperatures pasture growth accelerated resolving the shortage of feed.

Table 33 Supplementary feeding of lambs and ewes from the Autumn lambing treatments in production cycle 2

Treatment group	Supplement	Mean days on feed	Daily quantity (kg/farmlet)	per head (g/day)	Cost/ farmlet
DPC+pasture	Canola hay	28	5.1	255	$80.00
	cotton seed meal pellets	26.5	4.3	67	$203.02
					$283.02 Total cost
Pasture	Canola hay	28	5.1	255	$80.00
	cotton seed meal pellets	40	4.3	110	$273.78
					$273.78 Total cost

Production cycle 3 - 2021

All the autumn lambing ewes, and their lambs subsequent to weaning were provided with strategic supplementary feed in the third production cycle (Table 34 - see Appendix 6 for data by farmlet). There was no provision of supplementary feed for the spring lambing groups in the third production cycle.

The level of supplementation depended on feed availability. The late spring, summer and early autumn pasture growing periods were cooler for 2020/21 than for previous years with average monthly temperatures lower than the other years for December, January and February in particular. Feed on offer was reduced in the winter and supplementary feeding became necessary. This winter feed gap was more evident within the farmlets A and E where crop sowing had been attempted and the cropping plots were withheld from grazing until it was evident that sowing had failed.

Table 34 Supplementary feeding of lambs and ewes in production cycle 3

Farmlet	Supplement	Cost/ farmlet ($)	Total amount fed (kg)
*DPC + pasture	cotton seed pellets	70.51	138
	lucerne based pellets	505.50	506
	lucerne hay	255.42	198
	wheaten hay	300.30	715
	Total	1,131.73	
	Days on feed (ewes**)	39	
	Days on feed (lambs)	84	
*Pasture	cotton seed pellets	24.23	48
	lucerne based pellets	475.00	475
	lucerne hay	227.04	176
	wheaten hay	-	
	Total	726.27	
	Days on feed (ewes**)	39.5	
	Days on feed (lambs)	84	

* Mean per farmlet

** Mean days on feed for ewes, farmlets varied (Appendix 6)

4.2.2.3. Lamb growth and carcase

Whole of life analysis

After three production cycles of lambing, consistent patterns emerged in lambing system outputs when autumn was compared to spring lambing, or when dual purpose crops were included in the feedbase compared to pasture only systems. Table 35 shows a complete break-down of the outcomes by feed regime, lambing season and production cycle (drop). The known effects of sex and parity of birth were also examined.

The data were analysed with parity of birth and sex as fixed effects and age at measurement as a co-variate. The effects of year of birth (drop), lambing season and feed regime on growth from birth were examined. There was a three way interaction between feed regime, lambing season and year of birth ($p<0.001$), with lamb production responding differently to the different management regimes depending on season.

Growth curves of group averages are shown in Figure 11. In 2019, the drought affected year, the dual purpose crop with pasture feed regime produced heavier lambs across time than the pasture only system, and this was seen for both autumn and spring lambs. In 2020 the dual purpose crop with pasture feed regime produced heavier autumn lambs than the pasture-only system, but the spring lambs from the two feed regimes were not significantly different to each other. In 2021 the largest difference was between autumn and spring born lambs, with spring born lambs performing better. There was also an interaction with feed regime in 2021, with the DPC/pasture system performing better for spring born lambs but slightly worse for autumn born lambs. These whole of life effects are important, however analysis of lamb weight at defined points in the production cycle is of interest (Table 35), especially the final weight and subsequent carcase weight data.

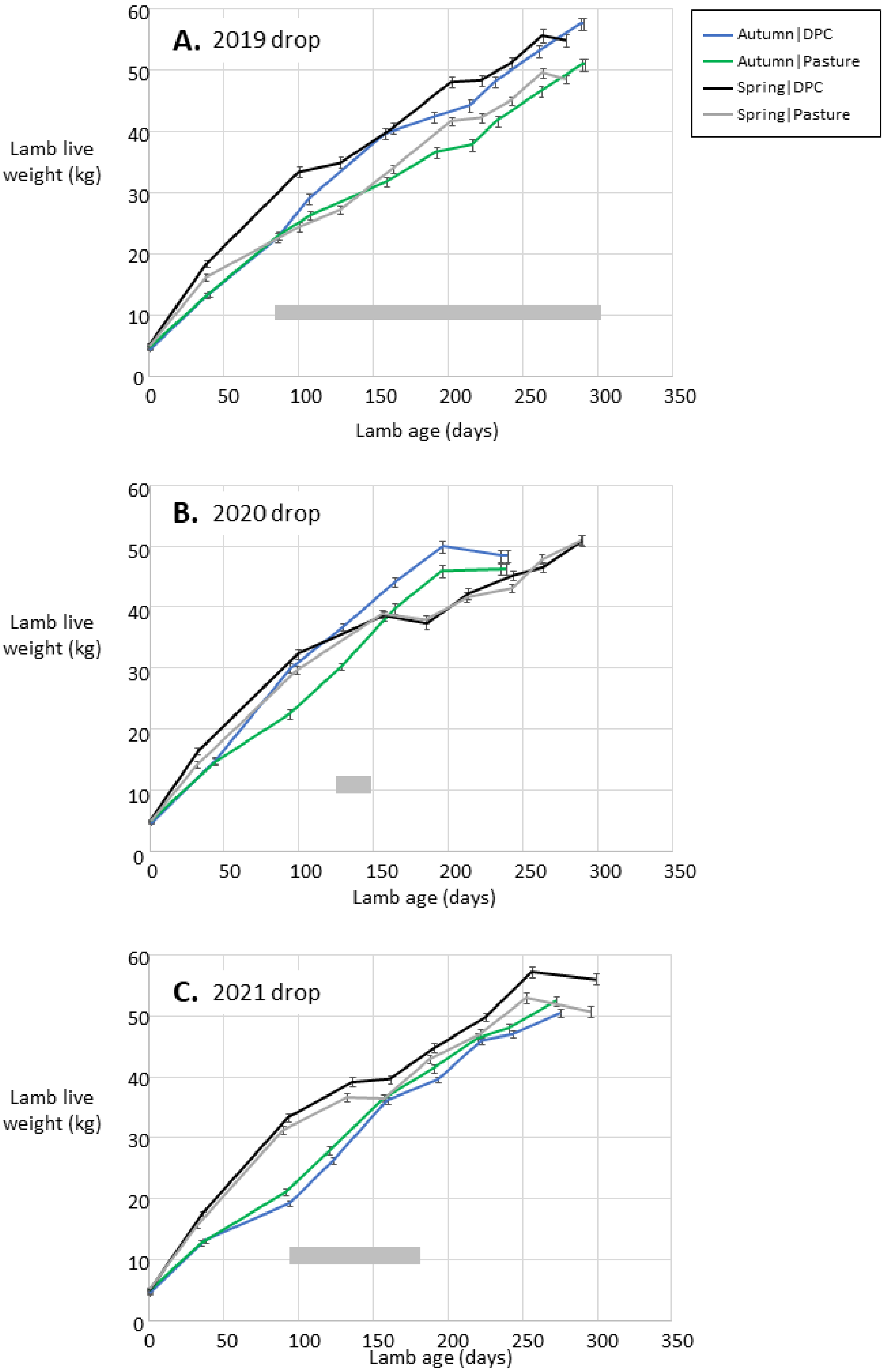

Figure 13 Lamb growth curves for 2019 (A), 2020 (B) and 2021 (C) drops, from production cycles 1, 2 and 3 respectively. The mean weight for each group (y-axis) is graphed against the mean age of the group at each time of weighing (x-axis). Error bars represent twice the standard error of the mean. The black and grey lines show data from spring born lambs and the green and blue lines represent autumn born lambs. The black and blue lines show data for lambs born and raised in the DPC/pasture feed regime farmlets and the grey and green lines are for lambs born and raised in the pasture-only farmlets. Grey bars depict the approximate periods when supplementary feeding was supplied to lambs; for all groups in (A), for one of the two autumn-lambing, DPC/pasture groups in (B) and for the autumn born lambs in (C).

Analysis of growth and weight (Table 35, Appendix 7)

Four of the five factors considered had significant effects on birth weight. Birth weights were higher in single born lambs (+1.09 kg), spring born lambs (+0.42 kg), male lambs (+0.30 kg), lambs born in pasture only systems (+0.26 kg), and lambs born in 2021 were heavier than those born in 2019 (+0.15 kg) and 2020 (+0.05 kg). The effect of drought may explain the slight but non-significant difference between the 2019 drop and the other two years. The other differences were all expected based on prior studies except for the effect of feed regime, where we may have expected a positive influence of the dual purpose crop provision which did not eventuate. Interpretation of the feed regime analysis is complicated by the differing outcomes of the cropping enterprise in the three years. There was a significant interaction between production cycle and feed regime (p=0.021, Appendix 7), which occurred because the difference in birth weight between the two feed regime treatments was most marked for the 2021 drop of lambs. When production cycles were considered separately (Appendix 7), birth weight was significantly affected by feed regime in 2021 (pasture-only +0.51 kg, p<0.001), but not in 2020 (pasture-only +0.19 kg) or 2019 (pasture-only +0.09 kg).

Four of the five factors considered had significant effects on lamb weight at marking (Table 35). Lamb weights at marking (global mean age 38 days) favoured single born lambs (+4.72 kg), lambs born in spring (+2.72 kg) and male lambs (+0.39 kg) as for birth weight. However, lambs born in the dual purpose crop/pasture system had higher marking weights (+0.89 kg), and lambs from the 2019 drop had higher marking weights than 2020 (0.06 kg) and 2021 (+0.36 kg). As for birth weight, the differences in marking weight between years of birth were not statistically significant. The two-way interactions between lambing season and parity of birth, feed regime and parity of birth and the three-way interaction between production cycle, lambing season and parity of birth were significant (p<0.001, p=0.002, p=0.007 respectively – Appendix 7). Although single born lamb marking weight means were higher than for multiple birth lambs every year, and spring born lambs had higher marking weights than autumn born lambs every year, the three-way interaction was significant because the differences between single born lambs from the spring and autumn lambings was negligible for the 2020 drop. The observation of higher marking weights in the dual purpose crop/pasture system is interesting, but the interpretation of the feed regime analysis is complicated by the differing outcomes of the cropping enterprise in the three years. When production cycles were considered separately (Appendix 7), marking weight was significantly affected by feed regime in both 2019 (DPC +0.70 kg, p=0.002) and 2020 (DPC +1.09 kg, p=0.003), but not in 2021 (DPC +0.89 kg).

All the factors considered had a significant effect on lamb weight at weaning (Table 35). Lamb weights at weaning (global mean age 98 days) were highest in single born lambs compared to multiples (+7.93 kg), lambs born in the dual purpose crop/pasture system compared to pasture only (+2.43 kg) and male lambs compared to female lambs (+0.35 kg) as for the marking weights. Autumn born lambs had higher weights (+8.38 kg) than the spring born lambs at weaning, which implies a greater growth rate of autumn born lambs than spring born lambs from marking to weaning. The differences between drops were significant for weaning weight with the 2020 born lambs heavier than 2019 (+2.09 kg) and 2021 (+2.64 kg) lambs. Multiple interactions between factors were significant for weaning weight (see Appendix 7). The effect of feed regime differed across time and within season of birth (p<0.001). Whilst spring and autumn born lambs within the DPC/pasture treatment had similar weaning weights in 2019 and 2020, the autumn lambs had much lower (-13.5 kg) mean weaning weights compared to spring born lambs in 2021. The autumn born lambs within the pasture only group had declining weaning weights over the three production cycles whereas the

Table 35 Lamb weight and carcase measurements across the three years of the field demonstration trial analysed for factor effects.

Contrast	Factors	n	Birth weight kg	Marking weight kg	Weaning weight kg	Final weight kg	Hot carcase weight kg	Ratio kg/kg	Growth rate from birth g/day	Growth rate from weaning g/day	Value $/lamb
Feed Regime	**DPC**	271	4.61 ± 0.05	15.27 ± 0.24 (a=38)	28.01 ± 0.46 (a=98)	52.75 ± 0.41 (a=278)	23.05 ± 0.23	0.44 ± 0.002	173.5 ± 1.3	137.4 ± 2.2	182 ± 2.08
	Pasture	299	4.87 ± 0.05 (p<.001)	14.38 ± 0.22 (a=37) (p<.001)	25.58 ± 0.35 (a=98) (p<.001)	49.84 ± 0.36 (a=278) (p<.001)	21.37 ± 0.2 (p<.001)	0.43 ± 0.002 (p<.001)	162.5 ± 1.3 (p<.001)	137.5 ± 2.1 (p=0.31)	167 ± 2.05 (p<.001)
Lambing season	**Autumn**	307	4.55 ± 0.05	13.55 ± 0.20 (a=40)	22.87 ± 0.34 (a=92)	50.79 ± 0.41 (a=268)	21.91 ± 0.21	0.43 ± 0.001	173.0 ± 1.3	157.9 ± 1.7	175 ± 2.28
	Spring	263	4.97 ± 0.05 (p<.001)	16.27 ± 0.23 (a=35) (p<.001)	31.25 ± 0.32 (a=106) (p<.001)	51.73 ± 0.38 (a=289) (p=0.024)	22.47 ± 0.22 (p=0.77)	0.43 ± 0.002 (p=0.002)	161.7 ± 1.2 (p<.001)	113.6 ± 1.7 (p<.001)	172 ± 1.85 (p<.001)
Parity of birth	**Multiple**	415	4.45 ± 0.03	13.52 ± 0.16 (a=38)	24.58 ± 0.31 (a=97)	49.93 ± 0.31 (a=278)	21.54 ± 0.17	0.43 ± 0.001	164.1 ± 1.0	141.7 ± 1.8	169 ± 1.75
	Single	155	5.54 ± 0.06 (p<.001)	18.24 ± 0.27 (a=37) (p<.001)	32.51 ± 0.44 (a=101) (p<.001)	54.70 ± 0.52 (a=278) (p<.001)	23.86 ± 0.3 (p<.001)	0.44 ± 0.002 (p=0.002)	177.5 ± 1.9 (p<.001)	126.1 ± 2.7 (p<.001)	188 ± 2.57 (p<.001)
Sex	**Female**	272	4.59 ± 0.05	14.6 ± 0.22 (a=38)	26.55 ± 0.42 (a=99)	49.73 ± 0.38 (a=280)	21.44 ± 0.21	0.43 ± 0.002	161.4 ± 1.3	128.6 ± 2.1	167 ± 2.17
	Male	298	4.89 ± 0.05 (p<.001)	14.99 ± 0.23 (a=38) (p<.001)	26.9 ± 0.41 (a=98) (p<.001)	52.59 ± 0.39 (a=275) (p<.001)	22.83 ± 0.22 (p<.001)	0.43 ± 0.002 (p=0.108)	173.5 ± 1.3 (p<.001)	145.6 ± 2.1 (p<.001)	180 ± 1.99 (p<.001)

Table 35 Continues from previous page

Contrast	Factors	n	Birth weight kg	Marking weight kg	Weaning weight kg	Final weight kg	Hot carcase weight kg	Ratio kg/kg	Growth rate from birth g/day	Growth rate from weaning g/day	Value $/lamb

Year of birth (drop)	**PC1 (2019)**	179	4.66 ± 0.06	14.95 ± 0.30 (a=39)	26.24 ± 0.5 (a=106)	52.70 ± 0.54 (a=285)	22.72 ± 0.27	0.43 ± 0.001	168.5 ± 1.8	146.5 ± 2.1	187 ± 2.68
	PC2 (2020)	189	4.76 ± 0.06	14.89 ± 0.27 (a=39)	28.33 ± 0.46 (a=97)	48.84 ± 0.46 (a=263)	20.27 ± 0.22	0.41 ± 0.002	168.8 ± 1.7	126.4 ± 2.4	151 ± 2.26
	PC3 (2021)	202	4.81 ± 0.06	14.59 ± 0.27 (a=36)	25.69 ± 0.53 (a=93)	52.16 ± 0.42 (a=285)	23.47 ± 0.25	0.45 ± 0.002	166.1 ± 1.4	139.8 ± 3.0	184 ± 1.97
			(p=0.066)	(p=0.369)	(p<.001)	(p=0.002)	(p<.001)	(p<.001)	(p=0.001)	(p<.001)	(p<.001)

Notes - Mean values (from raw data) are shown plus or minus the standard error of the mean. In parentheses, the mean age of groups is provided (a=x), and the level of significance of the differences between means is provided (p=x). No mean age is reported for birth, mean ages for Hot carcase weight, Ratio and Value are the same as for Final weight. PC means production cycle (the cycle is not completed until the year after birth in all cases).

spring born groups under both feed regimes had increasing weaning weights over the three production cycles. The observation of higher weaning weights in the dual purpose crop/pasture system is interesting, but the interpretation of the feed regime analysis is complicated by the differing outcomes of the cropping enterprise in the three years. When production cycles were considered separately (Appendix 7), weaning weight was significantly affected by feed regime in both 2019 (DPC +3.05 kg, p<0.001) and 2020 (DPC +5.13 kg, p<0.001), but not in 2021 (DPC -0.49 kg).

All the factors considered had a significant effect on the final lamb live weight (Table 35). Lamb final weights (global mean age 278 days) favoured lambs born in the dual purpose crop/pasture system (+7.91 kg), single born lambs (+4.77 kg), male lambs (+2.86 kg) and lambs born in autumn (+0.94 kg), similarly to for weaning weights, but with different rankings in magnitude of effect. Final lamb live weight was highest in 2019, greater than for 2020 (+3.86 kg) and marginally greater than for 2021 (+0.54 kg). Even though they remained significant, the advantage of autumn born lambs seen at weaning had waned to almost equivalence with spring born lambs when final weights were considered. In contrast, the difference between lambs born in the dual purpose crop/pasture system compared to the pasture only system was more marked at final weighing than at the other weighing times. There was a significant interaction (p=0.012, Appendix 7) between lambing season and parity of birth for final weight where the difference between single and multiple birth lambs was greater for autumn born lambs than it was for spring born lambs. There were also significant interactions between production cycle and feed regime where the higher weights of lambs from the DPC/pasture group were most marked for the first production cycle (2019 drop), were less for the second and negligible for the third (p<0.001), and for production cycle, feed regime and lambing season (p<0.001) where the autumn pasture only group had increasing final weights over the three years, whereas the DPC+pasture autumn group had decreasing final weights over the three years whereas the spring lambing groups had negligible differences in final weight between the feed regimes in the second production cycle whilst the DPC/pasture group had higher weights in both the first and the third production cycle. Interpretation of the feed regime analysis is complicated by the differing outcomes of the cropping enterprise in the three years, and the differences in supplementary feeding between groups in various years (Section 4.2.2.2.). When within-year effects were analysed separately (Appendix 7), feed regime was significant for final weight data in the 2019 (DPC group +6.71 kg, p<0.001), but not the 2020 (DPC group +0.99 kg) or 2021 (DPC group +1.38 kg) drops.

Four of the five factors considered had significant effects on the hot carcase weight at slaughter (Table 35). Carcase weights were higher for single born lambs (+2.32 kg compared to twins/triplets), lambs from in the DPC/pasture system (+1.68 kg compared to pasture only), male lambs (+1.39 kg compared to females) and lambs born in 2021 had significantly higher carcase weights compared to 2019 (+0.75 kg) or 2020 (+3.20 kg). The differences in final liveweight for lambing season were not evident in carcase weight, for which autumn and spring born lambs were not significantly different. There was a significant interaction between lambing season and parity of birth for carcase weight (p=0.041, Appendix 7), similar to the effect seen for final liveweight where the difference between single and multiple birth lambs was greater for autumn born lambs than it was for spring born lambs. There were also significant interactions between production cycle and feed regime (p<0.001) and with lambing season (p<0.001). The higher carcase weights of lambs from the DPC/pasture group were most marked for the first production cycle (2019 drop), were less for the second and negligible for the third (p<0.001). For season of birth a similar picture was evident with higher carcase weights from autumn lambs compared to spring lambs in the first two production cycles, whereas the spring lambs had the higher carcase weights in the final production cycle. Three-way interactions were also significant in the analysis. The feed regime, lambing season and production cycle interaction (p<0.001) is characterised by a declining carcase weight for autumn born lambs under the DPC/pasture regime, but stable carcase weights for autumn lambs fed pasture only. In contrast the spring lambs under the DPC/pasture regime had higher carcase weights than the pasture only group in the first and third production cycles but not the second. The feed regime, parity of birth and production cycle interaction (p=0.009) is indicative of the significantly high carcase weight for singles born in the DPC/pasture feed regime compared to singles born in the pasture only system for the first production cycle only. In the subsequent production cycles, the single born lambs had similar carcase weights irrespective of feed regime, and the multiple birth lambs had similar carcase weights irrespective of feed regime throughout the three production cycles. Interpretation of the feed regime analysis is complicated by the differing outcomes of the cropping enterprise in the three years. When within-year effects were analysed separately (Appendix 7), feed regime was significant for carcase weight data in the 2019 (DPC group +3.47 kg, p<0.001), but not the 2020 or 2021 drops.

Lamb growth rate (g/day) from birth till final weighing was calculated for each lamb. When the data was analysed the five factors considered were all significant (Table 35). Single lambs had a higher growth rate (+13.4 g/day) than lambs from multiple births, male lambs grew faster (+12.1 g/day) than females, autumn born lambs grew faster (+11.3 g/day) than spring born lambs and lambs from the dual purpose crop/pasture system grew faster (+11.0 g/day) than those from the pasture-only system. Smaller, but significant growth rate differences were observed between years and lambs born in 2020 grew faster than lambs born in 2019 (+0.3 g/day) and 2021 (+2.7 g/day). The interaction between lambing season and parity of birth was significant (p=0.005, Appendix 7) for growth rate from birth as the difference between singles and multiple birth lambs was greater for the autumn groups than for the spring groups. The interaction between production cycle and feed regime was significant (p<0.001) because the lambs from the DPC+Pasture regime grew faster than those fed pasture only in the first production cycle, but the difference was far less in the following two production cycles. The feed regime, lambing season and production cycle interaction (p<0.001) is characterised by a declining growth rate for autumn born lambs under the DPC/pasture regime but increasing growth rates weights for autumn lambs fed pasture only. In contrast the spring lambs under the DPC/pasture regime had higher growth rates than the pasture only group in the first and third production cycles but not the second. When within-year effects were analysed separately (Appendix 7), feed regime was significant for growth rate for every year, and the lambs from dual purpose crop/pasture systems grew faster than their counterparts in the pasture-only systems for the 2020 (+5.62 g/day, p=0.044) and 2019 (+23.99 g/day, p<0.001) drops but not the 2021 drop.

Lamb growth rate (g/day) from weaning till final weighing was calculated for each lamb. Although this may seem a similar measurement to growth rate from birth till final weighing, there are two important differences. First, the measurement of growth from weaning till final weighing excludes the maternal influence and is therefore different biologically and second the measurement is one that can be more practically implemented on farms as it does not need information gathered at lambing rounds. When the growth rate from weaning data was analysed four of the five factors considered were significant (Table 35). Autumn born lambs grew faster from weaning than spring born lambs (+44 g/day), male lambs grew faster than females (+17 g/day) and single born lambs grew faster than lambs from multiple births (+15.6 g/day). Lambs born in 2019 grew faster from weaning than in the other years, exceeding the growth rate of 2020 drop lambs (20.1 g/day) and 2021 drop lambs (6.1 g/day). The difference between years is not unexpected as the lambs in 2019 were grain finished due to the severe drought conditions experienced. There was almost no effect of feed regime on lamb growth post weaning, which is surprising as the autumn lambs grazed dual purpose crops post weaning in two of the three years. When the data is analysed as a whole, there is also no significant interaction in the effects of lambing season and feed regime on growth post weaning. However, production cycle interactions with both lambing season (p<0.001) and feed regime (p<0.001) were significant (Appendix 7). Although autumn born lambs had higher post-weaning growth rates in every production cycle, the magnitude of the difference was much greater for the third production cycle than the other two. Although feed regime had no significant effect on post-weaning growth rate over all production cycles, there was a significant interaction because in the second production cycle lambs with DPC+pasture had lower growth rates than lambs fed pasture, but the converse occurred in the first and third production cycles. The three-way interaction between feed regime, lambing season and production cycle was also significant (p<0.001). Within the pasture fed groups, the autumn born lambs had increasing growth rates each year from the first to the third production cycle, but in contrast the spring born lambs had decreasing growth rates across the production cycles. Within the groups fed DPC+pasture, the autumn lambs had a comparable growth rate to the spring lambs in the second production cycle whereas the autumn lambs had clearly higher growth rates than spring lambs in both the first and third production cycles.

The three-way interaction between parity of birth, lambing season and production cycle was also significant (p=0.004) (Appendix 7). In the first production cycle, multiple born lambs grew faster post-weaning than single birth lambs by a clear margin for those born in spring, but the growth rates were comparable between singles and multiples for the autumn born lambs. In the second and third production cycles, multiple born lambs had higher mean post-weaning growth rates than singles for both autumn and spring drops, but in the third production cycle the difference between the autumn and spring lambing season groups was larger than the other years.

Analysis of the data for growth rate post-weaning within production cycles reveals some interesting outcomes (Table 35). For the 2019 drop, lambs from the dual purpose crop/pasture system grew faster than their pasture-only counterparts (+15.8 g/day, p<0.001) and consumed less grain (see previous section). However the 2020 drop lambs from the pasture-only system grew faster than the DPC/pasture system lambs (+25.4 g/day, p<0.001) despite the use of dual purpose crop grazing for the DPC/pasture system lambs. The 2021 drop lambs had no access to dual purpose crop grazing as the crops failed to germinate, however there was a small advantage in post-weaning growth rate for DPC/pasture system lambs over pasture-only lambs (+9.9 g/day, p=0.028). There had been some supplementary feeding of the autumn lambs in the third production cycle, however the interaction between lambing season and feed regime within production cycle three (p<0.001) reveals that for the main effect of feed regime was seen within the spring lambs, where the model mean post-weaning growth rate was 12.1 g/day higher for spring-born DPC+pasture lambs compared to spring-born pasture fed lambs. The changing value of the DPC system across the years negates the effect of feed regime when the data is analysed together.

The ratio of hot carcase weight to liveweight is of interest as it is a crude measure of carcase yield. These ratios were calculated and analysed for effects similarly to the weight and growth rate data presented above. Although many effects were statistically significant for carcase ratio, the magnitude of differences between means is very small, and was less than 2% for sex, parity of birth, feed regime and lambing season (Table 35), Appendix 7). Differences between years were slightly larger, with a 4% difference between 2020 and 2021 drop lambs.

The value of carcases is a combination of price per kg received, the skin price and the weight of the carcase. Prices differed across the six slaughter dates during the trial, and multiple effects were observed on carcase weight as described above. Therefore, an analysis of carcase value (including skin value) was undertaken considering the five factors similarly to that undertaken for other measures of lamb production Table 35, Appendix 7). All factors considered had a significant effect on the value of carcases. The value of single lambs was greater than for lambs from multiple births (+$19), the value of lambs from the DPC/pasture system was greater than for pasture only lambs (+$15), male lamb carcases had a higher value than female lambs (+$13) and autumn born lambs had higher carcase value than spring born lambs (+$3). The lambs born in 2019 had the highest carcase value, exceeding that of the 2020 drop lambs (+$36) and the 2021 drop lambs (+$3). Some interactions between factors were also significant. The effect of feed regime was not consistent over the three production cycles such that the higher value of carcases for lambs in the DPC+pasture group was observed only in the first two production cycles (p<0.001). This may have been expected as the DPC crops were not present in the third production cycle. The effect of lambing season was also not consistent over the three production cycles such that the higher value of carcases for autumn-born lambs was observed only in the first two production cycles (p<0.001). This perhaps suggests that autumn lambs are more reliant on DPC grazing to achieve higher value. A three-way interaction between feed regime, lambing season and production cycle was also significant (p<0.001). Autumn lambs fed DPC+pasture had higher value carcases in the first and second production cycles compared to pasture fed autumn lambs. Spring born lambs fed DPC+pasture had higher value carcases in the first and third production cycle compared to pasture fed spring lambs. When analysed separately for each year, the effect of feed regime was significant in each year, with the DPC/pasture lambs having higher carcase value in 2019 (+$32, p<0.001), 2020 (+$8, p<0.001) and 2021 (+$8, p=0.028). Carcase value and production are considered in the whole farm context (per ha and per ewe) in section 4.2.4.

4.2.2.4. Ewe body condition

Ewe body condition scoring was undertaken throughout the trial. The body condition scores (BCS) were analysed using either the days before lambing (for measurements up to 180 days prior to the mid-point of lambing) or the days after lambing (for measurements up to 180 days after to the mid-point of lambing) as a co-variate, and the factors of lambing season, feed regime and production cycle were assessed. Data are shown in Table 36, including the maximum and minimum values for each group at each time, and means are shown graphically in Figure 12. In the periods before lambing, lambing-season (p=0.007), feed regime (p<0.001) and production cycle (p<0.001) were significant, and in the periods after lambing, lambing- season (p<0.001), feed regime (p<0.001) and production cycle (p<0.001) were significant.

In 2019, the period leading up to lambing coincided with the onset of the drought for the autumn lambing ewes. These ewes had decreasing BCS during this period as supplementary feeding was being ramped up. In contrast, the spring lambing ewes had the benefit of supplementary feeding for a longer period before lambing, and the BCS values rose in the period leading up to lambing (Figure 14). In the period following lambing, the spring ewes fed dual purpose crops sustained their BCS for longer than the spring ewes from the pasture-only treatment. Both groups of autumn lambing ewes had a more dramatic rise in BCS after lambing than their spring lambing counterparts.

In 2020, three of the four treatment groups sustained an increasing or stable mean BCS in the period leading up to lambing. The spring lambing ewes from the pasture-only treatment had a slight decline in mean BCS leading up to lambing in 2020. After lambing, both autumn lambing groups had a greater decline in BCS than the spring lambing groups, although the autumn group from the dual purpose crop/pasture feed regime had BCS values returning to pre-lambing levels much earlier than for the autumn lambing pasture-only group. The spring lambing groups had slower declines in BCS following lambing compared to the autumn lambing groups in 2020. The lower BCS values for the autumn lambing ewes post-lambing necessitated supplementary feeding in 2020.

In 2021, all the ewes had lower BCS compared to the previous years in the period leading up to lambing. As in other years, the period after lambing saw a decline in BCS, followed by a recovery. No supplementary feeding was given during this period in 2021, and no DPC grazing was available in this year. The autumn lambing, pasture only group's BCS began to rise earlier in 2021 compared to 2020. This third year (2021) saw the lowest BCS values of any year. The failure of the DPC crops may have been suspected to play a role, however, the pasture-only farmlets experienced a similar fate. The minimum scores observed (score of 1.5) were more common in the 2021 assessments and the lowest maximum scores of 3.5 were also more common in 2021. (Table 36.).

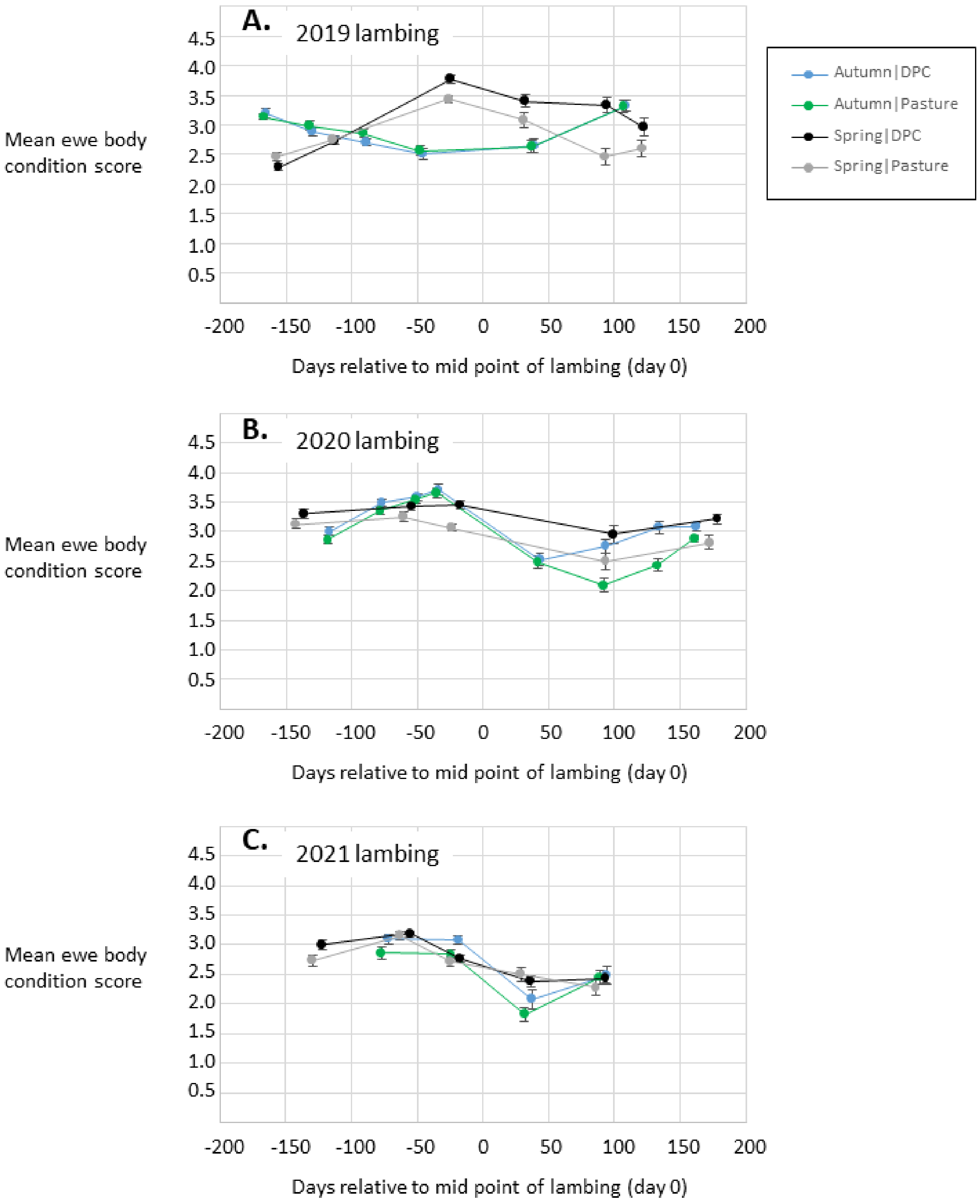

Figure 14 Body condition scores for ewes relative to lambing time in production cycles 1 (A), 2 (B) and 3 (C). The day of scoring relative to the mid-point of lambing for each group (0) is plotted on the x-axis and the mean body condition score on the y-axis. Error bars represent twice the standard error of the mean. The black and grey lines show data from ewes lambing in spring and the green and blue lines represent ewes lambing in autumn. The black and blue lines show data for ewes in the DPC/pasture feed regime farmlets, and the grey and green lines are for ewes in the pasture-only farmlets.

Table 36 Ewe body condition scores relative to lambing time

Lambing year	Lambing group	Feed group	Days relative to Lambing	Ewe body condition score		
				maximum	minimum	mean
2019	Autumn	DPC/Pasture	-165	4.0	2.5	3.20
			-130	3.5	2.5	2.89
			-89	3.5	2.0	2.70
			-46	3.0	1.5	2.51
			39	4.0	1.5	2.65
			109	4.0	2.5	3.33
			204	3.5	2.5	3.03
2019	Autumn	Pasture	-167	4.0	2.5	3.14
			-132	4.0	2.5	2.99
			-91	3.5	2.0	2.86
			-48	3.0	2.0	2.56
			37	4.0	2.0	2.64
			107	4.0	2.5	3.31
			202	3.0	2.0	2.76
2019	Spring	DPC	-156	3.0	1.5	2.29
			-113	3.5	2.0	2.74
			-25	4.0	3.0	3.78
			32	4.0	2.5	3.40
			94	4.5	2.5	3.34
			122	4.0	1.5	2.96
2019	Spring	Pasture	-157	3.5	1.5	2.46
			-114	3.5	2.0	2.75
			-26	4.0	3.0	3.44
			31	4.5	2.0	3.09
			93	4.0	1.5	2.46
			121	4.0	1.5	2.60
2020	Autumn	DPC	-117	4.0	2.0	3.00
			-77	4.0	3.0	3.49
			-50	4.0	3.0	3.59
			-34	4.0	3.0	3.70
			43	4.0	2.0	2.53
			93	4.0	2.0	2.76
			134	4.0	2.5	3.08
			162	4.0	2.5	3.08
2020	Autumn	Pasture	-118	3.5	2.0	2.86
			-78	4.0	3.0	3.35
			-51	4.0	3.0	3.54
			-35	4.0	3.0	3.65
			42	4.0	2.0	2.48
			92	3.5	1.5	2.09
			133	3.5	1.5	2.42
			161	3.5	2.0	2.88

Table 36. continues from previous page

Lambing year	Lambing group	Feed group	Days relative to Lambing	Ewe body condition score		
				maximum	minimum	mean
2020	Spring	DPC	-137	4.0	2.5	3.30
			-55	4.0	3.0	3.43
			-18	4.0	2.5	3.45
			100	4.0	2.0	2.95
			179	4.0	2.5	3.21
2020	Spring	Pasture	-143	3.5	2.5	3.13
			-61	4.0	2.5	3.25
			-24	4.0	2.0	3.06
			94	4.0	1.5	2.50
			173	4.0	1.5	2.81
2021	Autumn	DPC	-72	4.0	2.5	3.10
			-19	3.5	2.0	3.08
			37	4.0	1.5	2.09
			94	4.0	1.5	2.49
2021	Autumn	Pasture	-77	3.5	2.0	2.86
			-24	4.0	1.5	2.84
			32	3.5	1.5	1.83
			89	4.0	1.5	2.45
2021	Spring	DPC	-123	3.5	2.0	3.00
			-56	3.5	2.5	3.19
			-18	3.5	1.5	2.77
			37	3.5	1.5	2.38
			94	3.5	1.5	2.43
			192	3.5	2.0	2.45
2021	Spring	Pasture	-130	3.5	2.0	2.74
			-63	3.5	2.5	3.16
			-25	3.5	2.0	2.73
			29	3.5	1.5	2.50
			86	3.5	1.5	2.28

4.2.2.5. Pasture provision and crop grazing

In our calculations we used an equivalence of DSE/day to kg DM/day to calculate feed demand. The Figures (15 and 16) show how feed demand varied over time during the field experiment. In each Figure the spring lambing feed demand is compared to the autumn lambing feed demand, showing how the peaks of maximum feed demand occur earlier in each year for the autumn lambing, compared to the spring lambing systems. The graphs also illustrate how the peak demand was typically higher in the autumn lambing systems due to the increased number of lambs raised in these.

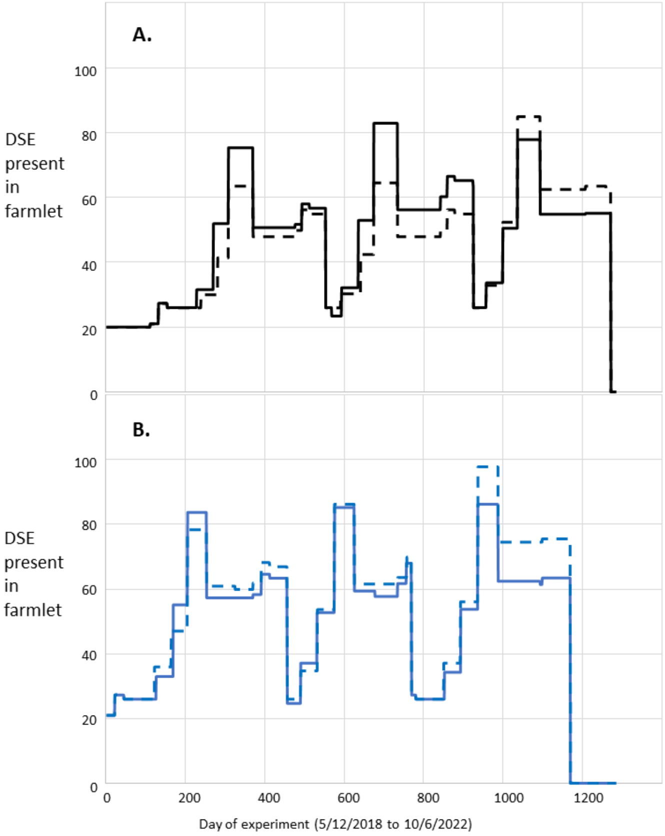

Figure 15 Feed requirements (dry sheep equivalents (DSE) per farmlet). The x-axis shows the day of the experiment beginning in December, 2018 and ending in June 2022. The y-axes show the number of DSE present in the farmlet. The upper graph (A) shows the two farmlets B (solid black line) and F (dashed black line) which had spring lambing ewes grazing DPC and pasture, and the lower graph (B) shows the farmlets A (solid blue line) and E (dashed blue line) which had autumn lambing ewes grazing DPC and pasture. In our calculations we used an equivalence of DSE/day to kg DM/day.

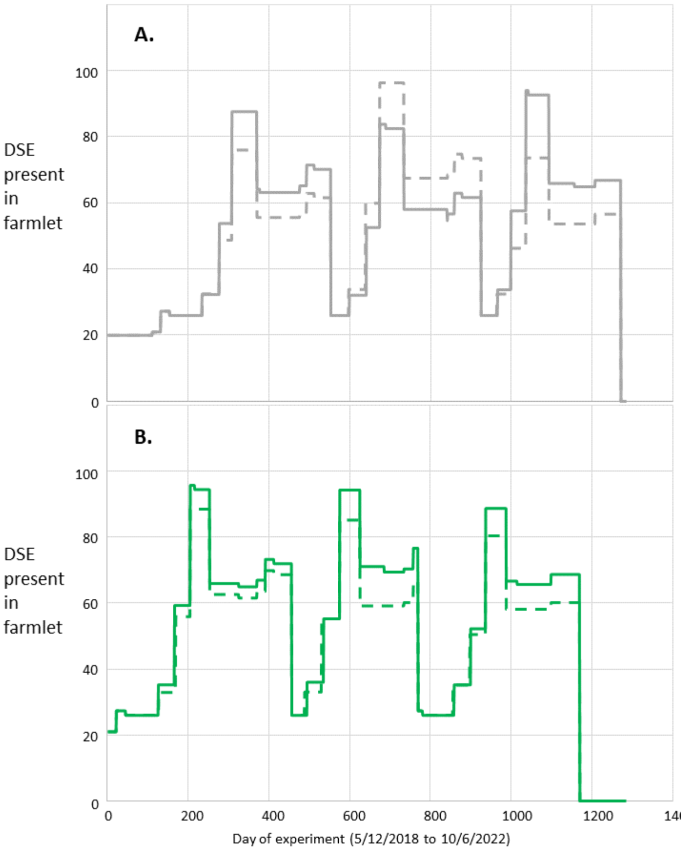

Figure 16 Feed requirements (dry sheep equivalents (DSE) per farmlet). The x-axis shows the day of the experiment beginning in December, 2018 and ending in June 2022. The y-axes show the number of DSE present in the farmlet. The upper graph (A) shows the two farmlets D (solid grey line) and H (dashed grey line) which had spring lambing ewes grazing pasture-only, and the lower graph (B) shows the farmlets C (solid green line) and G (dashed green line) which had autumn lambing ewes grazing pasture-only. In our calculations we used an equivalence of DSE/day to kg DM/day.

Grazing events were monitored by measuring feed available prior to and after each grazing event and comparing this to the feed required (see methods section 3.2.3.). The metric calculated, Feed provision (FP) is a negative value if feed provided was less than that required (deficit) and positive if feed provided exceeded that required (surplus). Of 420 grazing events monitored, 154 had a feed deficit and 266 had surplus feed. Using non-parametric tests, the proportion of grazing events in the deficit and surplus categories was significantly associated with lambing season ($p=0.003$), but not feed regime or whether ewes or lambs (or both) were grazing (Figure 17a). Using analysis of variance of the FP values however, there was no significant effect of lambing season, feed regime or the type of stock grazing.

We divided the grazing events based on month within which the mid-point of the grazing event occurred (Figure 17b,c). In this way the proportion of grazing events in deficit or surplus could be compared between feed regimes and/or lambing season for each month. Over all the treatment groups, the months where grazing events in deficit are more likely to occur than events in surplus are June (62%), July (67%), August (82%) and September (64%). The months least likely to include grazing events in deficit were November (13%), October (14%), April (15%) and March (18%). This supports the notion of a winter feed gap as a common issue, but also illustrates that feed gaps can occur at any time of the year in the summer rainfall system at Armidale.

Farmlets provided with DPC had a lower number of grazing events in deficit compared to pasture only farmlets in February, March, April, July, August and December (Figure 17). When considering lambing season within feed regime, farmlets with DPC had a lower proportion of feed deficit grazing events in February, March and August for all groups, compared to pasture-only farmlets. Spring lambing groups with DPC had a lower proportion of feed deficit grazing events in the additional months of April, June, July and September. However, Autumn lambing groups with DPC had a lower proportion of feed deficit grazing events in the additional months of October and December. For both spring and autumn lambing DPC/pasture farmlets, there were more deficit grazing events compared to pasture-only farmlets in January, November and May. Because of delays in sowing, in every year of the project we were unable to produce sufficient biomass for grazing of DPC by May. A goal for future work would be to develop feedbase solutions that can deliver in May, as well as the following four months, as these months are important for gestating and lactating ewes lambing in May or August. This would be the case even if Autumn lambing were brought forward to April, as lactating ewes would still create a high feed demand in May, June and into July.

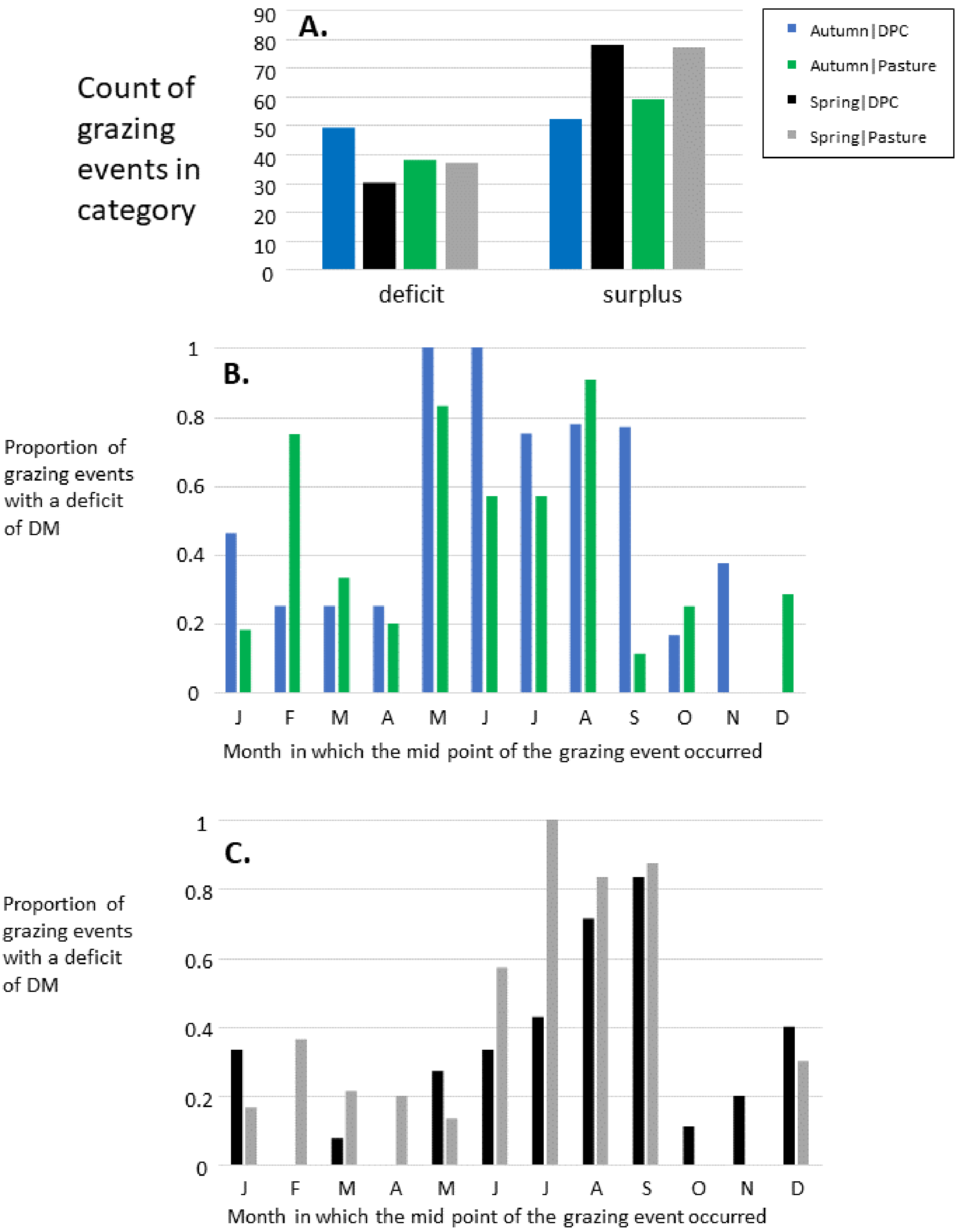

Figure 17 Feed deficits and surpluses. The pasture-only farmlets are compared between autumn (green bars) and spring (grey bars) lambing groups, and the DPC/pasture farmlets are compared between autumn (blue bars) and spring (black bars) lambing groups. The proportion of grazing events in deficit is provided for autumn lambing groups (B) and spring lambing groups (C) by month.

4.2.3 Animal health monitoring

Internal parasites were monitored regularly in the groups of ewes (Figure 18) and lambs (Figure 19) in the experiment using flock monitor worm egg counts. Using repeated measures (REML) analysis we compared the WEC monitor data between groups to detect any effects of the factors lambing season, feed regime and production cycle. For ewes and lambs, there were significant effects for lambing season (p<0.001) and production cycle (p<0.001), but not feed regime (p=0.338 ewes, p=0.542 lambs). The interaction between lambing season and production cycle was also significant for ewes (p=0.002) but not for lambs (p=0.12). When the interaction between production cycles and lambing season was considered in the REML model, mean differences between autumn and spring lambing groups of ewes were not significant for the third production cycle, mean WEC was 71% higher in spring lambing groups in the second production cycle and 366% higher in spring lambing groups in the first production cycle. In contrast, the autumn lambs had consistently lower WEC than spring lambs throughout the three production cycles. All WEC monitors conducted on the first production cycle autumn lambs were zero, whereas spring groups had positive WEC at some time points. In the second production cycle the mean WEC across timepoints was 21 fold higher in

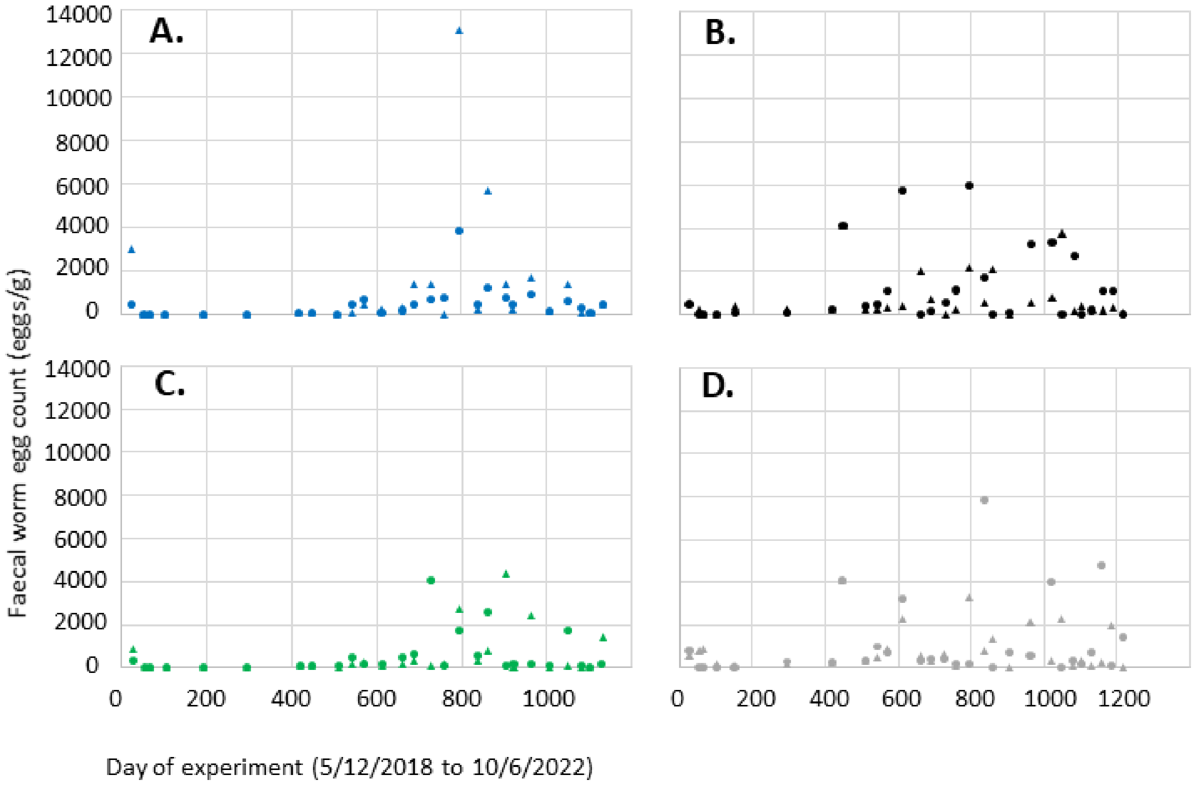

Figure 18 Flock monitor faecal worm egg counts (WEC) over time for ewes in the field demonstration trial. The experiment day is depicted on the x-axis (left and right panels), beginning in December 2018 and ending in February 2022 (left panels) or June 2022 (right panels). The y-axis depicts the raw WEC in eggs/g. The top left panel (A) shows data for the autumn lambing ewes in the DPC/pasture feed regime, with ewes from farmlet A (blue circles) and E (blue triangles). The top right panel (B) shows data for the spring lambing ewes in the DPC/pasture feed regime, with ewes from farmlet B (black circles) and F (black triangles). The bottom left panel (C) shows data for the autumn lambing ewes in the pasture-only feed regime, with ewes from farmlet C (green circles) and G (green triangles). The bottom right panel (D) shows data for the spring lambing ewes in the pasture-only feed regime, with ewes from farmlet D (grey circles) and H (grey triangles).

spring, compared to autumn lambs and in the third production cycle the mean WEC for spring lambs was 2.6 fold higher than for autumn lambs.

We used the WormBoss (https://www.paraboss.com.au/wormboss.php) tool to determine when drenching was required to treat internal parasites in flocks of sheep, based on the flock monitor WEC results. Despite the differences in mean WEC between lambing season groups, the number of drenches required for ewes did not differ significantly between lambing season or feed regime groups. The number of drenches for ewes did differ significantly across the three production cycles ($p<0.001$). Ewes received on average one drench in production cycle 1 (a drench on induction into the experiment), 2.5 drenches in production cycle 2 and 3.6 drenches in production cycle 3.

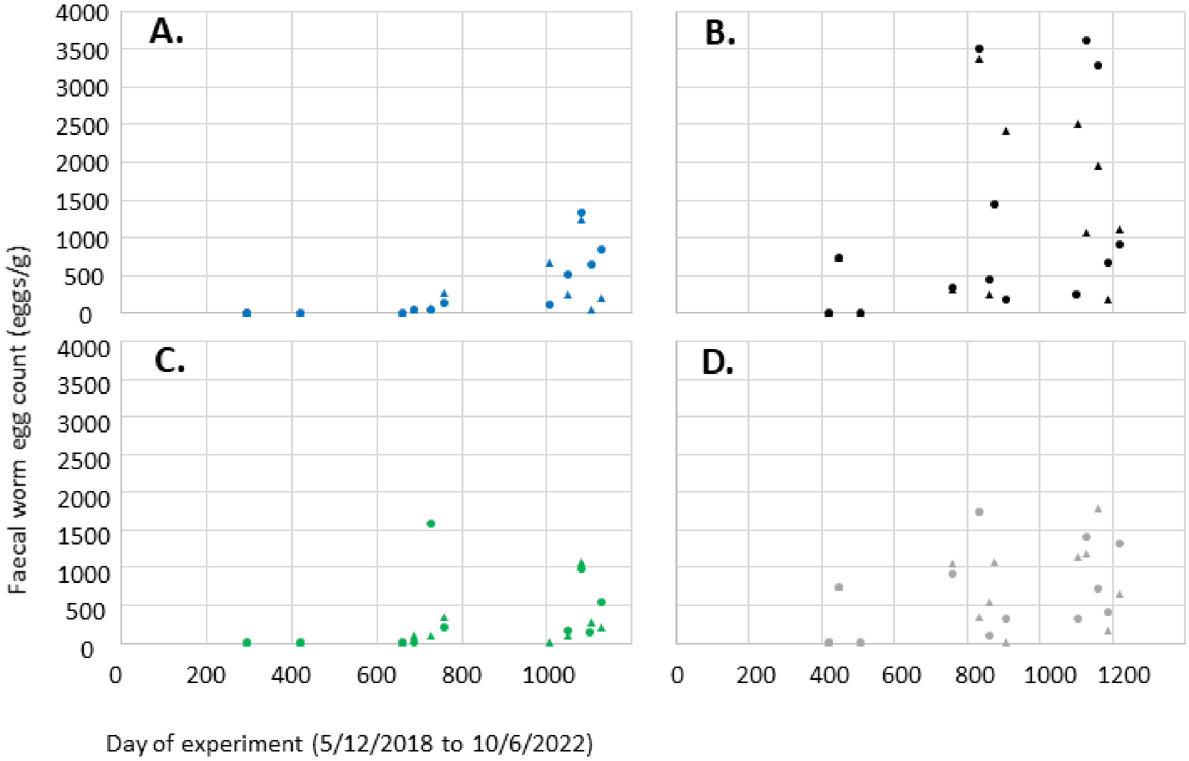

Figure 19 Flock monitor faecal worm egg counts (WEC) over time for lambs in the field demonstration trial. The experiment day is depicted on the x-axis (left and right panels), beginning in December 2018 and ending in February 2022 (left panels) or June 2022 (right panels). The y-axis depicts the raw WEC in eggs/g. The top left panel (A) shows data for the autumn lambs in the DPC/pasture feed regime, with lambs from farmlet A (blue circles) and E (blue triangles). The top right panel (B) shows data for the spring lambs in the DPC/pasture feed regime, with lambs from farmlet B (black circles) and F (black triangles). The bottom left panel (C) shows data for the autumn lambs in the pasture-only feed regime, with lambs from farmlet C (green circles) and G (green triangles). The bottom right panel (D) shows data for the spring lambs in the pasture-only feed regime, with lambs from farmlet D (grey circles) and H (grey triangles).

In concert with the differences in mean flock monitor WEC, autumn born lambs were drenched fewer times than spring lambs ($p<0.001$), and there was a significant difference across production cycles ($p<0.001$). Figure 20 shows the mean number of drenches administered to the autumn and spring lambs over the three production cycles.

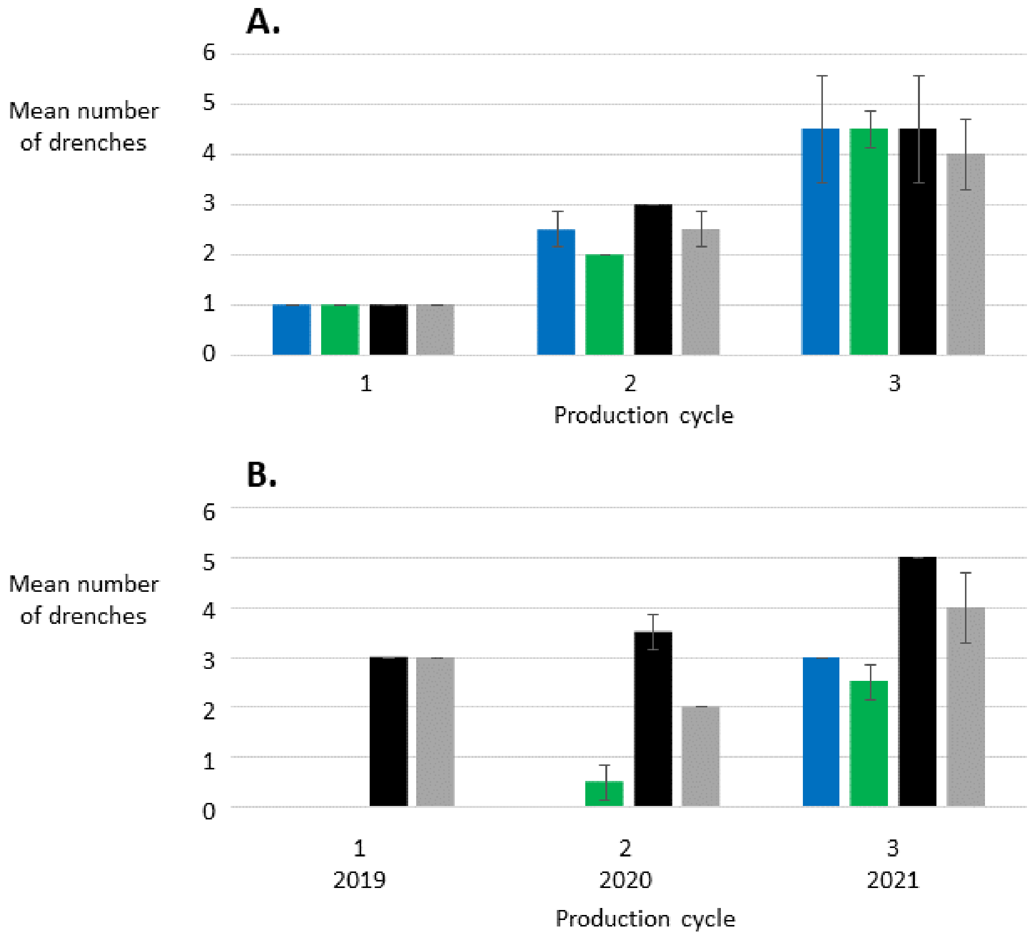

Figure 20 Lambs and ewes were drenched after flock monitor WEC exceeded thresholds in line with the WormBoss recommendations. The number of drenches (y-axis) over three production cycles is shown, for the ewes (A) and lambs (B) production cycles proceed over two years. In B, the year of birth is indicated under the production cycle number on the x-axis. The mean number of drenches for each of the four treatment groups is shown for each of the three production cycles, and error bars are twice the standard error of the mean. The groups shown are the autumn lambing groups provided with DPC/pasture (blue bars) and pasture-only (green bars), and spring lambing groups provided with DPC/pasture (black bars) and pasture only (grey bars).

We monitored sheep in their plots three times each week and twice daily during lambing. The ewes and lambs were inspected more closely when they were brought to the yards for weighing, body condition scoring, faecal sampling and other husbandry procedures (shearing, crutching, lamb marking, weaning, vaccinations, drenching, melatonin implants, mating, de-mating). Records were kept of treatments for fly strike, eye, limb and hoof ailments, injuries, metabolic and reproductive disorders. Taken together, 83% of ewes and 8% of lambs were treated at least once for these issues during the experiment, this includes the three production cycles and an additional fourth period for the ewes between the final weaning and last lamb sale.

Flystrike was of particular interest given the modelling predicted a large decrease in the number of lambs at risk of flystrike for autumn, compared to spring lambing. The modelling was undertaken using historical parameters based on Merino lambs (mulesed lambs were selected to mimic cross-bred lambs in the modelling). The effects of production cycle, lambing season and feed regime on the incidence of flystrike in the field experiments were analysed. For both ewes and lambs, the incidence of flystrike did not differ significantly between feed regime or lambing season groups. The variation between production cycles was significant for ewes (p<0.001) and lambs (p=0.018). Figure 21 shows the proportion of ewes and lambs treated for flystrike across the three production cycles.

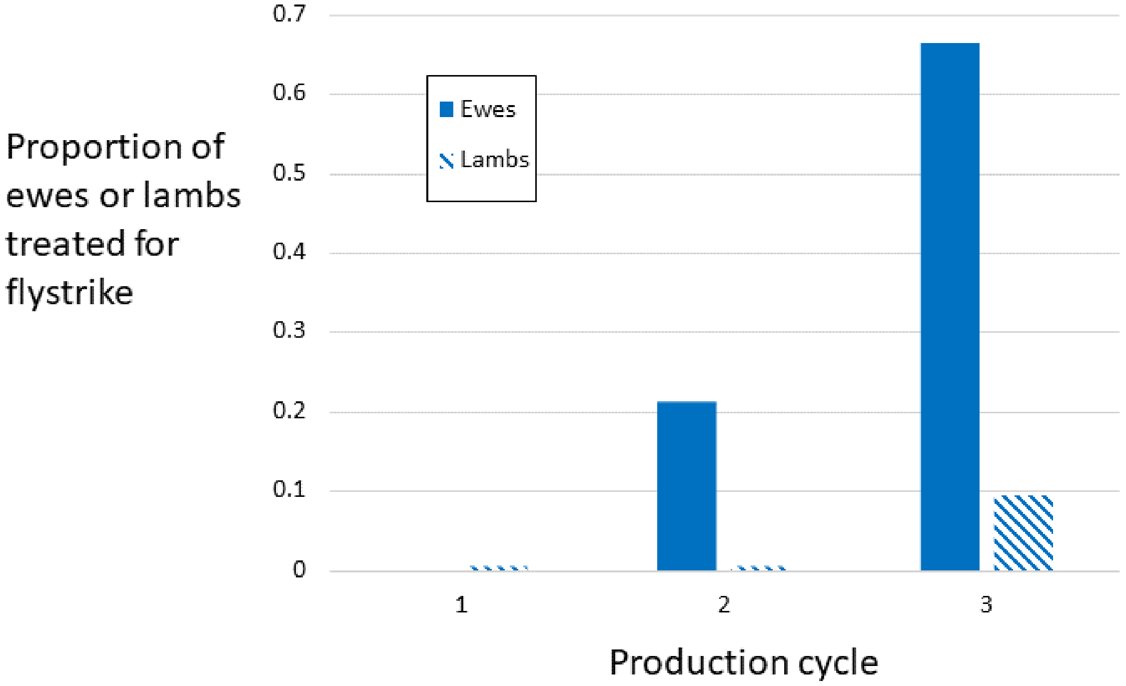

Figure 21. Lambs and ewes were treated for flystrike individually when flystrike was detected. The proportion of animals treated (y-axis) over three production cycles is shown, for the ewes (solid bars) and lambs (striped bars) production cycles proceed over two years. The number of flystrike treatments divided by the number of animals for either ewes or lambs is shown for each of the three production cycles.

Limb and hoof ailments (LHA) was the category for which the largest number of animals were treated over the three production cycles. Together, 62.5% of all ewes and 4.4% of all lambs were treated for LHA. The incidence of LHA increased towards the end of the study period, with 128 of 229 records occurring in 2022 (Figure 22a). Therefore the last drop of spring lambs and their dams were more exposed to a period conducive to LHA than their autumn counterparts. The production cycle was significantly associated with LHA incidence for ewes (p<0.001, Figure 22a) and lambs (p=0.03, Figure 22c). For the ewes, the number of treatments for LHA was significantly different between the spring and autumn lambing groups (p=0.003, Figure 22d). The accumulative total of LHA treatments for spring lambing ewes had exceeded that of the autumn lambing ewes by July 2019 and remained higher for the entire period until the autumn ewes were removed from the experiment in February 2022. Because of a non-linear change in incidence between production cycles, the interaction between season of lambing and production cycles for LHA incidence in ewes (Figure 22e) was also significant (p=0.018).

Ewes were treated for reproduction and lactation issues (RLI), mostly during the peri-natal period. The incidence of RLI was significantly higher in the last production cycle compared to the first two (p<0.001, Figure 22b). There was also a significant effect of feed regime on the incidence of RLI, with the ewes fed pasture only experiencing approximately twice the rate of RLI treatments (p=0.04, Figure 22f). Because the ewes from the DPC/pasture regime had a higher incidence of RLI during the second production cycle and a lower incidence in the other two production cycles, the interaction between feed regime and production cycles for RLI incidence in ewes was also significant (p=0.044, Figure 22g).

Injuries occurred, necessitating treatment in both ewes and lambs. These arose from a variety of causes but shearing cuts and collisions with fences/gates were the main ones. For the ewes, as might be expected, there was no association between the feed regime, lambing season or production cycle factors in the incidence of injuries. Overall, there were 8 ewes and 5 lambs treated for injuries during the trial, or 5% of ewes and 0.8% of lambs. The lamb injuries all occurred within the autumn lambs during the second production cycle so that the effects of lambing season, production cycle and the interaction between these factors are all significant (p<0.001 for all three effects). Despite this significance it is unlikely there was a “real” effect of lambing season or production cycle on the injury rate of lambs, but rather, the incidences of injury were associated with a particular event.

At the onset of the experiment we undertook to pay particular attention to eye injuries from grass seeds. It is possible that the occurrence of grass seeds might have been influenced by feed regime or differing summer feed demand between treatments. However, eye injuries were experienced rarely during the trial, in just two ewes and two lambs. Although all four incidents were likely caused by grass seeds, there is insufficient data to make any conclusions about the relationship between these eye injuries and the production cycle, feed regime or lambing season factors.

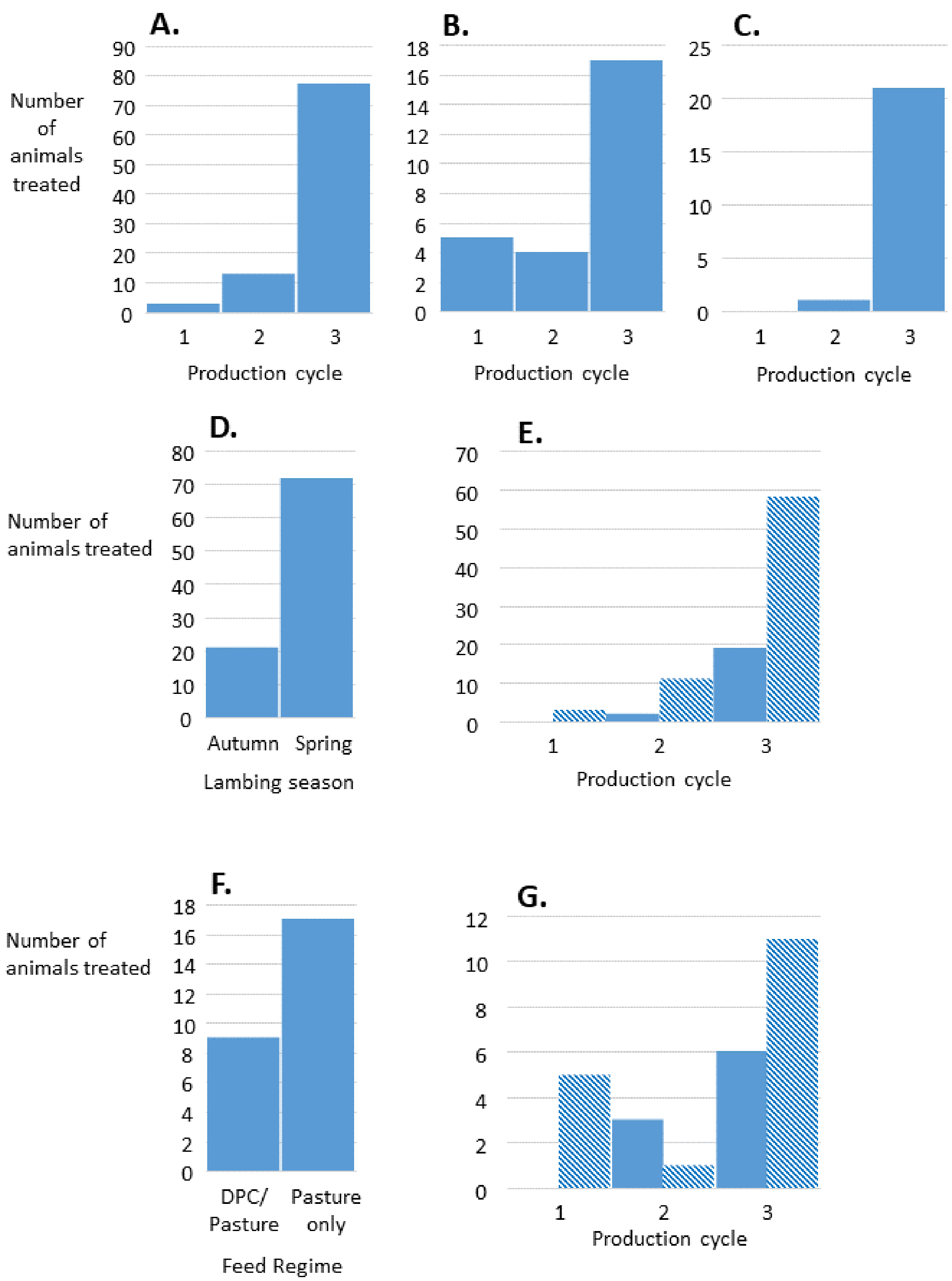

Figure 22. Animals treated for limb and hoof ailments (LHA) or reproduction issues over the trial period. The y-axis of all graphs illustrates the number of animals treated, and the categories are shown on the x-axis. There were significant differences between production cycles for LHA in ewes (A) and lambs (C) and for conditions associated with reproduction and lactation (B). The lambing season was significantly associated with the number of ewes treated for LHA (D), and there was a significant interaction between production cycle and lambing season (E – filled bars autumn, and striped bars spring lambing ewes). The feed regime was significantly associated with the number of ewes treated for reproduction/lactation issues (F), and there was a significant interaction between production cycle and feed regime for reproduction/lactation issues (G – filled bars DPC/pasture, and striped bars pasture only).

4.2.4 Gross margins

Lamb enterprise gross margins excluding cropping costs

The financial performance of the field trial farmlets differed substantially over three very different years. The effects of greatest magnitude for the lamb enterprises were supplementary feeding costs which were much higher in the first production cycle due to drought, and wool prices which rose substantially over the period 2019 to 2022. Statistical analysis is limited as there were only two replicates per treatment, however the effect of production cycle on feed costs (p<0.001) and wool income (p<0.001) were significant.

The net income from production cycle one was negative for all farmlets due to drought feeding and was positive in the subsequent two cycles. The variations between years in net income are much greater than the variations between the different treatment groups within any year (effect of production cycle, p<0.001). This is a consequence of the severe drought year (2019) occurring during the trial. Table 37 shows components of expenditure and income for the three production cycles in each of the four treatment groups. When considering the lamb production enterprise in isolation (without accruing costs against the dual purpose cropping) the farmlets with dual purpose crops perform most favourably over the three years (p=0.035), however in the second production cycle the spring lambing, pasture only system had a higher average net income than the spring lambing DPC/pasture system.

Comparing the autumn and spring lambing systems, income from lamb was greater for autumn (p=0.004) and varied across years (p=0.006) with income in 2022 (2021 drop) highest, followed by 2020 and 2021. Feed regime did not have a significant effect on lamb and skin income. In contrast to lamb, wool income was very similar between treatment groups, even though it changed substantially between production cycles increasing every year (p<0.001).

Most of the expenditure components were stable over time across the years. Most of the variation was due to scalable expenses incurred because of varying numbers of lambs produced. Shearing costs were greater in the third production cycle as lambs were shorn to prevent fly strike. Supplementary feed and animal health costs varied most across years and between treatment groups (Figure 23).

As anticipated, animal health costs were lower in the autumn lambing groups than the spring lambing groups in every production cycle (p<0.001). In the second production cycle, a fly strike preventative treatment was not administered to any groups, substantially lowering costs (effect of production cycle, p<0.001). Also, in the third production cycle a cyromazine-based product was used as a flystrike preventative which was substantially less costly than the dicyclanil-based product used in the first year. This saving helped to balance out the increased costs of GIN in the third production cycle, however cyromazine products are not as long lasting, and this influenced the increased number of flystrike treatments in the second half of the summer.

Supplementary feeding costs had the largest single effect on net income due to drought feeding in the first production cycle costs (effect of production cycle, p<0.001). Although drought feeding and stock retention choices were not part of this project, these results demonstrate the importance of these factors for longer term farm profitability.

Whole of enterprise gross margins

The grazing provided by Canola and wheat crops in the first and second production cycles had a positive effect on lamb production and reduced drought feeding costs in cycle one by a small amount. Despite these benefits, the costs of growing crops exceeded the income from them in the second production cycle (Table 38), and there was no income directly from the crops in the first production cycle. As a result, the farmlets with dual purpose crops suffered a financial penalty relative to the pasture only enterprises and this was statistically significant (p=0.003). Notably, the accumulative net income did not become positive until production cycle three for the farmlets with dual purpose crops, whereas pasture only systems returned to a positive accumulative net income in the second production cycle.

There are some considerations which need to be taken into account when reviewing these outcomes. Importantly, we included the cost of contract labour for the cropping enterprises, but apart from shearing and crutching, did not include contract labour costs for the lamb production system. The rationale for this is that whilst the northern tablelands is a typical prime lamb production environment, cropping enterprises are rarer, and so a producer might need to use a contractor for the cropping component. There appears to be an income advantage for the lamb enterprise within the DPC/pasture system, but how much of this is attributable to the DPC grazing is difficult to ascertain.

The ranking of gross margins for the lamb production enterprise between the four treatment groups placed the autumn lambing systems above the pasture only systems in the model simulation whereas in the field trial there was no significant difference between the two lambing seasons. The values of net income are very different between the simulation model and the field trial outcomes. The simulations used long term estimates for income and expenses, which differed from the values experienced during the field trial. In particular the income for wool and lamb was substantially higher ($16.64 - $26.62/kg wool, $7.40 - $8.50/kg lamb) across the period 2019 to 2022, compared to the values used in the simulation ($14.24/kg wool, $5.87/kg lamb). Although wool prices were high and rising during the field trial period, the wool produced was also finer (16-17 micron) compared to the assumption in the model (medium wool Merinos). The variable expenses for lamb production in the model were set at $25 per ewe, and this is substantially lower than the expenses incurred during the field trial (Table 37). Supplementary feed costs were also substantially higher during the field trial ($510/t) compared to the value used in the simulation ($255/t).

Compared to the simulation modelling, the ranking of gross margins for the combined crop and lamb gross margins is very different. Input costs for the crop enterprise exceeded income in both years of the field trial where crops were sown, whereas the simulations achieved a positive gross margin for the grain enterprise even in poor years. Therefore, in the simulations the dual purpose crop treatment groups always achieved a higher net income than pasture only systems, whereas in the field trial the dual purpose crop enterprises had negative net incomes, and their ranking for total net income (lamb + crops) was lower than for the pasture-only treatments.

Table 37 – Components of expenditure and income ($ per ewe) for the lamb enterprises over the three production cycles, excluding cost of cropping operations

Treatment group	**Autumn|DPC+Pasture**			**Autumn|Pasture**			**Spring|DPC+Pasture**			**Spring|Pasture**		
Production cycle	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Expenditure												
Shearing	$9.25	$9.25	$15.90	$9.25	$9.25	$16.30	$9.25	$9.25	$12.88	$9.25	$9.25	$13.11
Marking	$3.07	$3.19	$3.19	$3.39	$3.39	$3.39	$2.24	$2.62	$2.94	$3.00	$3.33	$3.13
Animal Health	$9.58	$4.58	$10.32	$9.68	$4.66	$10.35	$12.94	$7.23	$13.03	$13.92	$8.01	$13.19
Feeding	$378.88	$19.45	$63.08	$438.93	$19.82	$63.54	$279.48	$8.98	$31.64	$357.25	$10.03	$50.29
Reproduction	$11.00	$11.00	$11.00	$11.00	$11.00	$11.00						
Sale costs	$11.33	$9.07	$12.04	$10.88	$8.64	$11.29	$7.49	$7.53	$10.53	$8.40	$8.93	$10.30
AWEX and AWTA	$3.65	$3.65	$3.65	$3.65	$3.65	$3.65	$3.65	$3.65	$3.65	$3.65	$3.65	$3.65
Total expenditure	$434.74	$60.18	$123.81	$486.77	$60.41	$119.52	$315.08	$39.25	$74.67	$395.50	$43.20	$93.69
Income												
Lamb & skins income	$264.85	$192.65	$254.34	$253.91	$183.07	$235.69	$163.95	$152.45	$229.45	$186.27	$187.53	$217.99
Wool income	$48.69	$90.57	$129.21	$48.37	$87.49	$129.50	$62.22	$95.23	$113.85	$63.14	$95.29	$105.63
Total Income	$313.54	$283.22	$378.67	$302.28	$270.55	$365.18	$226.17	$247.68	$343.30	$249.41	$282.82	$323.62
Net income												
Per ewe	-$121.20	$223.04	$254.86	-$184.49	$210.14	$245.76	-$88.91	$208.43	$268.63	-$146.09	$239.62	$229.93
Per ha (5 ewes/ha)	-$606.00	$1,115.20	$1,274.30	-$922.45	$1,050.70	$1,228.80	-$444.55	$1,042.12	$1,343.16	-$730.45	$1,198.11	$1,149.64
Accumulative net income												
Per ewe	-$121.20	$101.84	$356.70	-$184.49	$25.65	$271.41	-$88.91	$119.52	$388.15	-$146.09	$93.53	$323.46
Per ha (5 ewes/ha)	-$606.00	$509.20	$1,783.50	-$922.45	$128.25	$1,357.05	-$444.55	$597.58	$1,940.74	-$730.45	$467.66	$1,617.29

Table 38 – Expenditure and income ($ per hectare) for the lamb, Canola and wheat enterprises over the three production cycles.

Treatment group	**Autumn|DPC+Pasture**			**Autumn|Pasture**			**Spring|DPC+Pasture**			**Spring|Pasture**		
Production cycle	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Income												
Lamb enterprise	$1,567.68	$1,416.08	$1,893.33	$1,511.40	$1,352.75	$1,825.92	$1,130.83	$1,238.38	$1,716.49	$1,247.05	$1,414.08	$1,618.08
Canola	$0.00	$202.00	$0.00	$0.00	$0.00	$0.00	$0.00	$120.50	$0.00	$0.00	$0.00	$0.00
Wheat	$0.00	$165.50	$0.00	$0.00	$0.00	$0.00	$0.00	$156.00	$0.00	$0.00	$0.00	$0.00
Total Income	$1,567.68	$1,783.58	$1,893.33	$1,511.40	$1,352.75	$1,825.92	$1,130.83	$1,514.88	$1,716.49	$1,247.05	$1,414.08	$1,618.08
Expenditure												
Lamb enterprise	$2,173.70	$300.90	$619.05	$2,433.85	$302.05	$597.60	$1,575.38	$196.25	$373.33	$1,977.50	$215.98	$468.44
Canola	$384.25	$289.00	$0.00	$0.00	$0.00	$0.00	$384.25	$289.00	$0.00	$0.00	$0.00	$0.00
Wheat	$361.35	$300.00	$0.00	$0.00	$0.00	$0.00	$361.35	$300.00	$0.00	$0.00	$0.00	$0.00
Total Expenditure	$2,919.30	$889.90	$619.05	$2,433.85	$302.05	$597.60	$2,320.98	$785.25	$373.33	$1,977.50	$215.98	$468.44
Net income												
Per ewe	-$270.32	$178.74	$254.86	-$184.49	$210.14	$245.66	-$238.03	$145.93	$268.63	-$146.09	$239.62	$229.93
Per ha (5 ewes/ha)	-$1,351.62	$893.68	$1,274.28	-$922.45	$1,050.70	$1,228.32	-$1,190.15	$729.63	$1,343.16	-$730.45	$1,198.10	$1,149.64
Accumulative net income												
Per ewe	-$270.32	-$91.59	$163.27	-$184.49	$25.65	$271.31	-$238.03	-$92.11	$176.53	-$146.09	$93.53	$323.46
Per ha (5 ewes/ha)	-$1,351.62	-$457.94	$816.34	-$922.45	$128.25	$1,356.57	-$1,190.15	-$460.53	$882.64	-$730.45	$467.65	$1,617.29

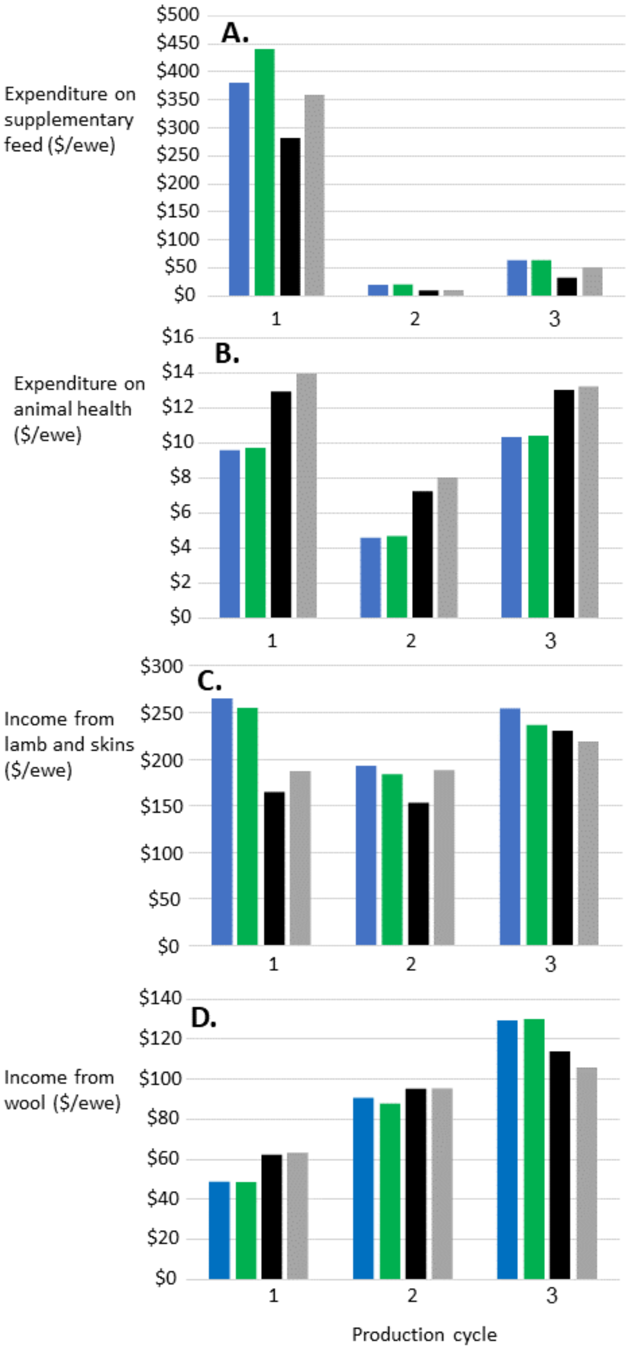

Figure 23 Comparison of selected expenditure and income components between the four treatments over the three production cycles. The autumn lambing DPC/pasture system is illustrated with blue bars, the autumn lambing pasture-only system with green bars, the spring lambing DPC/pasture system with black bars and the spring lambing pasture-only system with grey bars.

4.3 Producer Engagement

4.3.1 Northern advisory committee

Some of the producer engagement was with producers and advisors/consultants who participated in the Northern Advisory Committee (NAC) meetings in conjunction with other LPP projects.

There were three NAC meetings, the first in December, 2018 at Armidale (CSIRO), the second in November, 2019 at Tamworth (NSW DPI) and a third online following the online webinar in November 2020 (see below). The NAC comprised three farm consultant representatives (Lester McCormick, Mick Duncan, Robert Freebairn) and producers (Jared Doyle, Brett Smith, Aidan Rodstrom).

4.3.2 Field days, webinar and podcast

1) We discussed the project and project outcomes as part of AWI's sheepconnect program. A recorded webinar is available on the website (link below) and there was also a podcast, which had 422 downloads by the 17th of December 2021. Within the webinar recording there were Q&As from the producer audience.

https://register.gotowebinar.com/recording/1449034698896322831

2) We presented the project and project outcomes as part of a NSW DPI field day in January 2022. The YouTube video (link below) is of our senior team member Jody McNally talking about the project. Jody took Q&As from the producers present after the talk. The video has had 63 views (accessed 6/5/2022), since it was uploaded on the 25th of January 2022.

https://www.youtube.com/watch?v=P7fles3zW1o

3) We conducted a LPP webinar series in November 2020 and the recordings are available on YouTube. There are multiple talks in the recording (there are another two of these on different topics). The weblink is provided below. Q&As from the producers present were taken on the day and the video has had 238 views (accessed 6/5/2022) since it was uploaded on the 16th of November 2020.

https://www.youtube.com/watch?v=cvfo7IG8eVQ

4) We also conducted a field day on site at Chiswick (CSIRO Armidale) in March 2022 which was a collaboration between NSW DPI and CSIRO. There were 45 attendees. The project and project outcomes were presented and Q&As conducted. We also conducted a question poll after the event. Twelve out of fourteen respondents rated the day "good" or "excellent". We also asked, "What might prevent you from considering a change from spring to autumn lambing?" and provided five options (multiple could be selected), which were selected as below:

Concern about feed availability at crucial times (6/14)

Concern about conception rates (7/14)

Shearing and shearing contractor availability (3/14)

Concern about ability to finish lambs (3/14)

We also asked "The Agripest challenge is coming. What more can Research and Development do to help each property manage worms and flies?" and the answers were:

We need to re-think the way we do things, type of sheep, timing of operations, being more vigilant about monitoring (13/14)

We need vaccines (8/14)

We need more long-acting drenches/backlines (5/14)

We also asked "Diversifying the feed base is important for changing production systems, climate and markets. What Research and Development is needed to help properties find the right mix?" but none of the respondents answered this question.

Producer questions posed at these various occasions can be described as follows:

1) Questions about autumn lambing were the most common category. Many producers wanted to know whether there are alternatives to Regulin® for effective late spring/summer mating. Although teaser rams and other strategies may help, the use of Regulin® is the most effective strategy we are aware of. It seems many producers are reluctant to consider Regulin®, but few have elucidated why that is. In the seminars we have described from first-hand experience how effective and low cost the strategy is, however, some producers remain concerned about low conception rates. This is a confusing observation of producer attitudes, it seems unlikely that so many producers did not hear the message, so why were they still concerned? We spoke with one producer who stated they did not want to use "chemical products" in their system, presumably an organic producer, but they could not confirm that they were accredited when questioned.

2) Producers raised several questions about the effect of changing the time of lambing on wool characteristics. We only did the minimal wool testing on the fleeces we examined, and the measures of wool strength and position of break were not investigated. We also tested only one scenario, that where shearing remains the same amount of time before lambing for either autumn or spring lambing. Many questions therefore remain regarding the effects of lambing time change on wool characteristics.

3) There were a range of questions seeking clarification about how the modelling or the field work was conducted. These were not particularly informative (for researchers) except to acknowledge the level of producer interest these questions reveal.

4) One producer asked an insightful question about the relative importance of parasite issues in different times throughout the year at different locations. The work we have done is clearly aimed at the summer rainfall zone, and the findings regarding animal health outcomes are specific to that zone. There have not been similar studies conducted in the winter rainfall zone, but some attention to that part of Australia may be informative as well.

After the project had been completed a webinar was conducted with MLA:

LPP Dual crops for lamb production in southern QLD and northern NSW - YouTube

5. Conclusion

5.1 Key findings

Through simulation modelling and a field experiment we have comprehensively demonstrated the benefits of autumn lambing for reducing animal health inputs to prime lamb production. A looming challenge in blowfly, GIN and tick control is almost upon the livestock sector whereby most chemical actives used to control these parasites will no longer be effective due to resistance, and no replacements are likely. Non-product based methods such as altering lambing time will be sorely needed in this future scenario.

The provision of dual purpose winter crops as an adjunct to pasture-based systems was explored via simulation modelling and a field experiment. Modelling shows comprehensively that winter feed gaps can be filled utilising dual purpose winter crops, enabling production at higher stocking rates and improving profits. The field experiment we conducted was crucial for identifying factors not included in model scenarios that have impact on the viability of dual purpose cropping in the NSW northern tablelands environment. Most importantly, the run of seasons during the trial was extreme, allowing us to experience:

- Canola was superior to wheat in the extreme dry conditions of 2019, surviving despite heavy grazing and returning green feed once more 10 months after sowing when summer rainfall occurred. Note that harvestable grain was not produced from either the wheat or Canola crops sown in 2019.
- Canola was sown in 1/8th of the trial farm areas. Although this provided a measurable advantage during the drought year (less grain fed, greater lamb growth rates), it was not enough to bring the gross margin back to profit.
- The cost of using contractors to conduct cropping work within the target zone is not conducive to making profits from dual purpose crops. Our advisor, Robert Freebairn who is an advocate for dual purpose cropping and a member of our project advisory committee, has provided feedback on this. He believes that dual purpose crops will most likely be profitable where the machinery and labour required is available within the farming enterprise.
- Soil moisture levels were extremely high in the 2020 and 2021 sowing windows, this caused a delay in sowing due to the risk to equipment. The 2020 crop was sown late, and no possibility of sowing presented within the sowing window in 2021.
- The harvest of the 2020 crops was affected by a combination of late spring early summer rainfall which delayed ripening and caused some lodging, and of damage from the mouse plague that occurred.

5.2 Benefits to industry

In summer rainfall zones where flystrike and Barber's pole worm are summer problems, autumn lambing can be used to limit exposure of lambs to these disease issues. This saves labour and input costs.

Feed gaps can occur at any time of the year, so having options available to fill feed gaps is important. The use of dual purpose winter crops is one of these options that can provide additional feed in late autumn through to spring. Later grazing is also possible but will reduce or eliminate the possibility of a grain harvest.

6. Future research and recommendations

Application of the project insights

1) Feed provision

The following points should be considered by producers contemplating dual purpose crop provision as part of their feedbase strategy.

- Dual purpose winter crops can play a useful role in filling winter feed gaps in the summer rainfall zone, but they were most likely to provide feed in excess of pasture systems if early sowing was possible.
- Setting aside an area of production for cereal grain and/or oilseed cropping will result in that area being unavailable for grazing during the latter part of summer fallow, during the juvenile stages of the crop and from early flowering of the crop until harvest. Despite these limitations, the modelling and field trial results indicate that the crop grazing will likely compensate for these grazing limitations, as the winter months have the greatest feed deficit.
- In the field trial we were only able to achieve a grain harvest in one of the three years. Although we experienced an unfavourable run of years, producers should be aware that crops can fail and expected returns not realised in at least some years. Further work is needed to assess the long-term viability of dual-purpose cropping in the New England tablelands.
- In 2019, dual purpose crops provided additional grazing when no other pasture was available. This increased lamb growth rates and slightly reduced the expense of supplementary grain and hay. Where de-stocking is not an option, dual purpose crops or other forage crops may be a helpful part of the approach to keeping animals on farm.
- The costs of establishing, tending and harvesting crops via contract labour are high. Even with a reasonable grain yield a profit from the grain enterprise is unlikely, although there are still potential benefits for the lamb enterprise. Where producers have their own equipment and labour, the profitability of the grain enterprise may be more favourable, though this is subject to the producer's evaluation of the value of their own labour.

2) Time of lambing

The following points should be considered by producers contemplating a change from spring to autumn lambing.

- In the modelling and the field trial we achieved net incomes for lamb production with May lambing that were comparable to those achieved with August/September lambing for Armidale and for modelling at Goulburn. In the field trial the relative merit of spring and autumn lambing fluctuated between years, but outcomes were within 5-12% for the two systems across the non-drought years. In the first production cycle the spring lambing produced a superior net income, but the effects of drought were not equal between the two systems with the spring lambs finishing on pasture.

- In the modelling higher net income outcomes were observed for autumn lambing at both Armidale and Goulburn, this is mostly driven by expenditure on supplementary feed, and so was most evident when stocking rates were higher. The risk of summer feed gaps is higher at both locations compared to more westerly districts and is particularly high at Goulburn.

- The outcome of superior net income from autumn lambing was driven in the modelling by superior growth rates, but in the field demonstration trial the number of lambs and the favourable price at sale were potentially the most significant factors behind the advantage of autumn lamb carcase value, though this did not always translate to higher net income.

- Modelling of the effect of lambing season at the western slopes/plains locations of Gulargambone and Temora gave different results compared to the tablelands locations. Spring lambing had higher median modelled gross margins at Gulargambone across all situations except where stocking rate was high (50% DM utilisation) and DPC were provided in the feedbase. Spring lambing had higher median modelled gross margins at Temora across all situations except where stocking rate was moderate (40% DM utilisation) and the feedbase was pasture only. Slopes districts have lower rainfall and higher temperatures compared to tablelands districts, so these factors likely are behind the differences in model outcomes.

- We followed best practice for autumn lambing that included the use of a melatonin implant at out of season mating for both ewes and rams (Regulin), that was not used for the spring ewes mated within season. It is not advisable to try and replicate our system without using the melatonin implant.

- There were significantly higher numbers of multiple pregnancies (twins and triplets) in our autumn lambing groups compared to the spring lambing groups, presumably enabled using melatonin. Autumn lambing produced more lambs/ewe for sale, but neonatal deaths were also higher. The outcome of increased reproduction was not expected, and we cannot predict the circumstances where this will or will not occur.

- Autumn lambs were produced with significantly lower worm burdens and use of drenches compared to spring lambs. This will be important to slow down selection for drench resistance, but the reduced number of drenches is only a small cost saving in comparison to the increased production advantage provided by autumn lambing.

- In our modelling, the best parasite control option for grazing dual purpose crops was to graze them over one period (for each paddock) rather than returning lambs or ewes to graze the dual purpose crop a second time. We did not test this in the field trial.

Future R&D

An increase in the climate variation between years including more extreme weather events are a predicted outcome of climate change even under moderate global warming predictions (Hoegh-Guldberg et al., 2018). The production of grazing livestock will be particularly challenged in this future scenario, with decreases in fodder quality predicted and extreme rainfall events more frequent. During this study we experienced significant effects of severe rainfall, which delayed crop sowing in 2020 and precluded sowing entirely in 2021. The early summer of 2020/21 was very wet, and conditions resulted in a cessation of growth for many lambs (Figure 13). Further research to help producers mitigate against extreme wet and extreme dry periods is needed. Although dual purpose crops and winter active forages are useful for mitigating winter feed gaps, solutions are needed for seasons where these approaches cannot be used. Further, feed gaps can occur at any time of the year, so a variety of feed provision options are needed. More importantly guidance is needed about which of these feed provision options is suited to particular situations and the likely financial consequences of these decisions. Our modelling showed the complexity of predicting gross margin outcomes for changes to the lambing season and feedbase across multiple locations. It will be important to develop guidance about these issues separately for different regions, and on-farm demonstrations will be useful for this purpose.

The control of diseases in livestock over time will also likely be affected by climate change (Hoegh-Guldberg et al., 2018). In the short term however, there are additional considerations. Drug and chemical resistances have already had an impact on the control of internal and external parasites in sheep and cattle within Australia. Furthermore, antibiotic resistance has made the treatment of bacterial infections in medicine and veterinary practice more complex. The research and development pathways towards new actives have slowed, and in most cases relevant to livestock husbandry, no new actives are likely to appear within the next decade. There are no definitive reasons for the slowing of new active development, but some possible influences are (1) discovery of new actives is difficult and expensive, (2) large international corporations have a profit motive and agricultural applications are less lucrative than competing areas such as medicine, and (3) even within agriculture some industries have a small market globally (e.g. sheep) and the development of products specific to those industries (e.g. sheep blowfly prevention) is not attractive to investors. In combination, these two effects will inevitably result in an impedance of disease control within livestock enterprises. Additionally, market pressures may limit access to some pharmaceuticals and chemicals in future, either directly or via regulators. We call the combinations of all these effects across many food and fibre industries the “Agripest Challenge”.

We have demonstrated in this project that a change to autumn lambing may be a useful part of the response of sheep producers to the Agripest Challenge because lambs can be raised with a lower prevalence of internal parasites before an early to mid-summer sale avoiding the late summer and autumn peak in parasite challenge. The advantages of autumn lambing we observed have been in the context of a summer rainfall tablelands environment, and further research will be needed to understand if these positive effects will also occur in other environments.

There are additional non-chemical measures that can be taken to limit parasitic disease effects, including the use of pasture rotations, breeding resistant or resilient livestock and the use of vaccines (e.g. BarberVax) or biological control products (e.g. BioWorma). Research to develop additional non-chemical options is underway for some diseases, however there should be more research programs if the raft of important disease challenges for sheep and cattle is to be addressed. Furthermore, research that seeks to optimise the combination of approaches to disease control is also needed. The future will likely be more profitable if producers can be enabled to use the best combination of disease control approaches applicable to their circumstances. There are research, development and adoption opportunities that should be supported towards this end.

Field Trial compared to model outcomes

There were multiple aspects of the field study that were either not taken into account in the model simulations or where the outcomes in the field trial differed to the predictions from the simulation model.

The growth rate of lambs can be influenced by factors other than the provision of feed. In particular we observed an almost cessation of lamb growth during the early summer of 2020/21 which models do not predict. The effect of colder than usual wet weather was likely the cause. A model which includes a greater ability to account for a broader range of physiological challenges may achieve estimates of growth rate that are closer to those seen in the field.

The effect of correcting low ovulation rates for autumn lambing ewes with melatonin implants was not included in the model. Therefore, the model assumed a lower marking percentage than we observed in the field trial for autumn lambing. We have accumulated a small amount of data in this project which might help model developers incorporate the effects of melatonin implants, but more data would likely be needed.

We encountered some logistical difficulties when seeking to sell lambs near to the Christmas/ new year period. This may cause producers to choose an earlier or later lambing time for autumn lambs, or to aim production to a different market (store lambs) rather than aiming to finish lambs for slaughter.

Delays to crop sowing (2020) and a failed crop (2021) caused by excessive wet weather were not taken into account in the model simulations. Perhaps there is an opportunity to improve this aspect of the crop models.

The overall growth rates of lambs achieved on a Phalaris dominant pasture in the field trial (161 – 173 g/day) were lower than the 200 g/day, or 250 g/day marks considered in the animal health models. The reasons behind this are likely to be multi-factorial and would include the difference between first cross lambs from fine wool Merino dams and lambs from medium wool Merino dams and the difference between a complex, but Phalaris dominant pasture and a simpler Phalaris/subterranean clover pasture used in the model. Another factor to consider is that we were operating at both extremes of rainfall across the field trial rather than years where median conditions occurred, which comprise the majority of the years in the model simulations.

Despite slower growth rates, an advantage of autumn lambing for internal parasites was still observed. The model used predicts the burden of parasites and the subsequent physiological challenge and production outcomes. However, there are immunological challenge and immune system maturity effects at play in this situation. A more sophisticated model which includes some assessment of these immunological parameters may have more accurately predicted the outcomes observed.

There was no observed advantage in lower rates of flystrike for autumn lambs. The model used has been developed for Merino lambs and does not accurately predict flystrike risk for crossbred lambs. We have accumulated a small amount of data on flystrike in crossbred lambs as part of the field trial, but a much larger volume of data would be needed to develop a crossbred lamb flystrike risk model (Brian Horton TIA, Pers. Comm.)

The costs of various inputs, and prices received for outputs, are variable and so financial outcomes can vary significantly from model predictions, this is an inherent property of most whole farm system models.

Post-project communications

A paper has been submitted to the journal *Agricultural Systems* which describes the pasture and dual purpose crop modelling relative to autumn or spring lambing at four locations:

> Lucinda J. Watt, Lindsay W. Bell, Neville I. Herrmann, and Peter W. Hunt (2022) Integrating dual-purpose crops facilitates improved lamb production systems. 1. Feedbase risk mitigation and livestock productivity benefits. *Animal Production Science* (under review).

A second paper is in preparation which will describe in full the outcomes of the animal health modelling under the different crop/pasture and lambing season combinations.

We expect there to be some ongoing producer engagement beyond the end of the project.

Some aspects of the work overlap with other project activities we are conducting. Where that occurs, we will include information about this project where relevant in future communications with producers and stakeholders.

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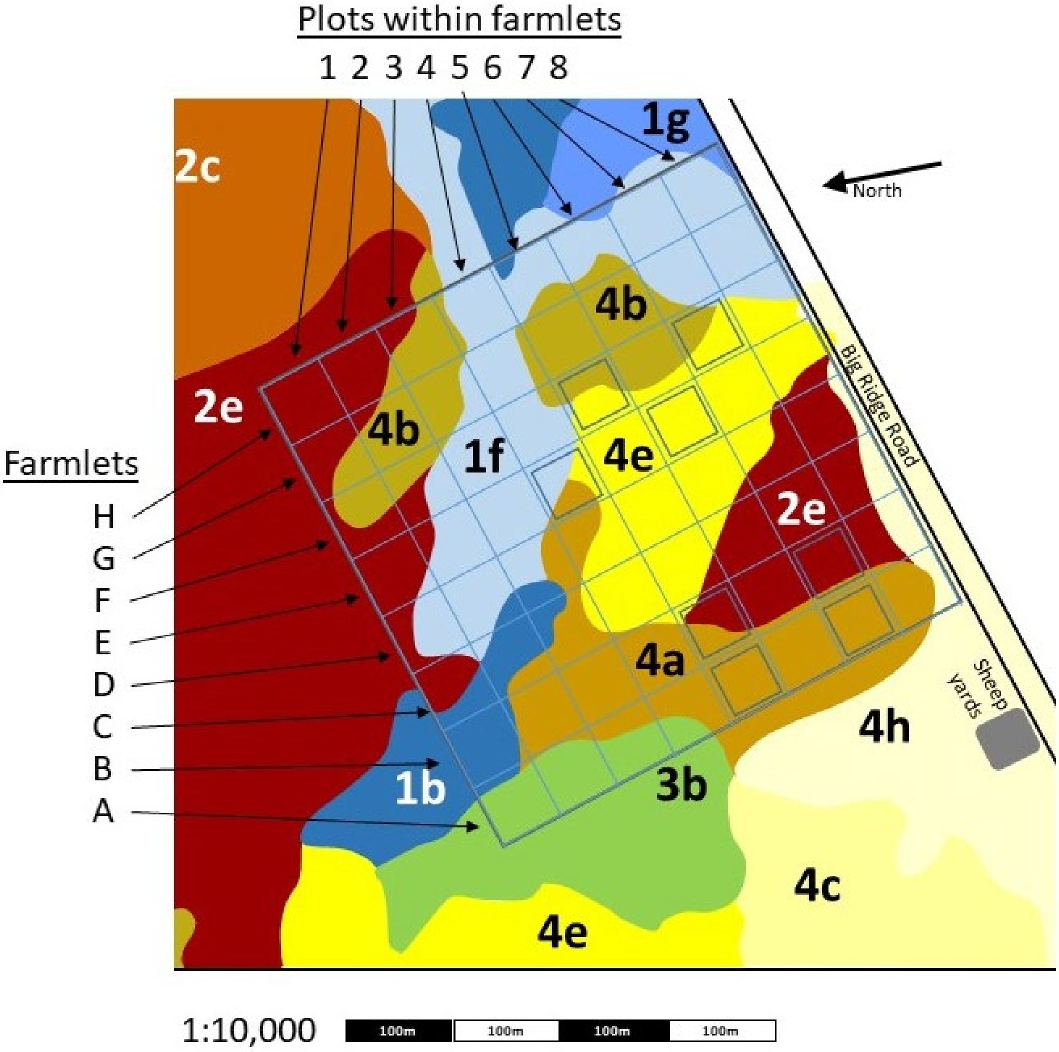
WormBoss http://www.wormboss.com.au

8. Appendices

8.1 Appendix 1 Soils and field site

8.1.1 Soil types at the field demonstration site



The map above shows the boundary of the trial site facility with the farmlets and plots within farmlets marked in fine blue lines. Plots used for cropping are delineated with double lines. The farmlets (A-H) run approximately north south and are indicated by the labels and arrows to the left of the Figure. Each farmlet contains eight plots arranged with 1 at the northern end and 8 at the southern end as indicated by labels and arrows at the top of the Figure. The Big Ridge road and the sheep yards (not to scale) at the property entrance are shown to help locating the site. Mapped soil types are illustrated as coloured shapes which have been labelled according to the Chiswick soil series descriptors (Tables on following pages).

Soil type descriptions at the trial site (from Schafer 1980)

Series	Map Unit	Northcote Key	Australian great soil groups	Location	Topography	Parent material	Drainage (surface)	Drainage (internal)	Microrelief	Layers identified
Log Gully	1b	P.P.F. Um 5	Wiesenboden	66	Very gently undulating, 1° lower slope, easterly aspect	Basalt/basaltic colluvium	well drained	imperfect	Smooth. These soils crack when dry but do not qualify as seasonally cracking soils.	6
Top East	1f	P.P.F. Gn 2.62	Wiesenboden	67	Flat 1/2° slope, easterly aspect	Basaltic colluvium and fine-grained sediments	well drained	imperfect	Smooth. Some evidence of seasonal cracking.	7
Kelly's Plains	1g	P.P.F. Ug 5.14	Prairie	31	Gently undulating 1° lower slope, northerly aspect	Basaltic colluvium	seasonally flooding	impeded	Seasonally cracking, smooth surface	7
Upper Kirwans	2e	P.P.F. Uf 4.4	Chocolate (normal subgroup) (shallow ortstein)	166	Very gently undulating, 2° convex upper to mid slope westerly aspect	Basalt colluvium overlying lateritized tertiary sediments	well drained	impeded at depth	no description	5
Log	3b	P.P.F. Gn 2.11	Euchrozem (shallow stoney)	51	Gently undulating, 2° lower convex slope, easterly aspect	Lateritized basalt	well drained	well drained	no description	3
Chiswick	4a	P.P.F. Gn 4.64	Grey-brown podzolic	2	Very gently undulating; 1° slightly convex midslope, westerly aspect.	Basalt colluvium and sediments	well drained	imperfect	no description	6
Ram	4b	P.P.F. Gn 3.74	Lateritic podzolic/ grey brown podzolic (intergrade)	130	Very gently undulating 2-3° concave midslope, north-west aspect.	Paleozoic sediments	well drained	well drained	no description	5
Saumarez	4e	P.P.F. Dg 4.43	Gleyed podzolic	6	Drainage line, northerly aspect	Lateritized tertiary sediments	imperfect	impeded	no description	5
East Armidale	4h	P.P.F. Dy 5.6	Yellow-Red podzolic	73	Gently undulating 1.5° upper convex crest, northerly aspect	Tertiary sediments	well drained	good	no description	4

Soil type layer descriptions at the trial site (from Schafer 1980)

Series	Map Unit	Layer	Horizon name	Lower depth (mm)	Boundary	Description
Log Gully	**1b**	1	Ap	150	Surface	Brown (10YR5/3 dry), to dark greyish brown (10YR4/2); silty clay loam; very weak fine subangular blocky; earthy fabric; moist very friable, wet sticky and plastic; Field pH 6.0;
		2	B1	400	Clear smooth	Brown (10YR5/3 dry and moist); gravelly silty clay loam; very weak fine subangular blocky; earthy fabric; moist very friable, wet sticky and plastic; Field pH 6.5;
		3	B21	550	Clear Smooth	Yellowish brown (10YR5/4 dry and moist); gravelly silty clay; massive; earthy fabric; moist friable, wet sticky and plastic; Field pH 6.5; 30% gravels 2-5 mm diameter, subangular, strongly cemented, ferromanganiferous nodules;
		4	B2 FeMn	850	Diffuse	Mottled grey (10YR6/1), dark brown (7.5YR3/2), yellowish red with black manganese staining (5YR4/8); gravelly fine sandy clay; massive; earthy fabric; moist firm, wet sticky and plastic; Field pH 7.0; 60% gravels 2-5 mm diameter, subangular, strongly cemented, ferromanganiferous nodules;
		5	BC	1100	Gradual	Strong brown (7.5YR5/8 moist), with grey (7.5YR3/2), yellowish brown common medium distinct mottles (10YR5/6); fine sandy clay; massive; rough ped fabric; moist firm, wet sticky and very plastic; Field pH 8.0; Occasional fragments of weathered basalt;
		6	C	continuing	Clear	Weathered basalt
Top East	**1f**	1	A1	100	Surface	Brown (10YR5/3 dry), to dark brown (10YR4/3 moist); gritty clay loam; weak fine subangular blocky; earthy fabric; moist very friable, wet slightly sticky and slightly plastic; Field pH 6.0;
		2	B1	300	Abrupt smooth	Dark Brown (10YR4/3 moist); gritty clay loam; weak fine subangular blocky; earthy fabric; moist very friable, wet slightly sticky and plastic; Field pH 6.0;
		3	B21	450	Gradual	Dark brown (10YR4/3 moist); gravelly sandy clay; weak fine subangular blocky; earthy fabric; moist firm, wet sticky and plastic; Field pH 6.5; Common, subrounded, ferromanganiferous nodules;
		4	B22	750	Clear	Light yellowish brown (10YR6/4 moist), to yellowish brown (10YR5/4 dry); gravelly sandy clay; massive; earthy fabric; moist firm, wet sticky and plastic; Field pH 7.0; Common subrounded, ferruginous gravels;
		5	B23	1050	Gradual	Greyish brown (10YR5/2 moist), with many medium distinct yellowish brown (10YR5/6), and common medium distinct red mottles (2.5YR4/8); medium clay; rough ped fabric; moist very firm, wet sticky and plastic; Field pH 7.5; Rare ferruginous gravels;
		6	BC	1250	Clear	Light yellowish brown (2.5YR6/4 moist), with common fine to coarse distinct dark yellowish brown (10YR4/4), strong brown (7.5YR5/6), and grey mottles (10YR5/1); medium clay; massive; rough ped fabric; moist very firm, wet sticky, very plastic; Field pH 7.0;
		7	C	continuing	Clear	Weathered basalt - speriodally weathered with prominent colour banding.
Kellys Plains	**1g**	1	A11	5	Surface	Very dark greyish brown (10YR3/5 moist) clay loam, fine crumb, self mulching surface. Field pH 6.0.
		2	A12	100	Abrupt smooth	Very dark greyish brown (10YR3/5 moist), light clay, weak fine subangular blocky, rough ped fabric, moist firm, wet sticky and plastic. Field pH 6.0. Rare weathered basalt gravels.
		3	A13	250	Clear smooth	Black (10YR2/1 moist) with few medium faint yellowish brown (10YR5/6) mottles, light-medium-clay, massive, smooth ped fabric, moist firm, wet sticky and plastic. Field pH 6.0.
		4	B21	500	Diffuse	Very dark grey (10YR3/1 moist) with common fine faint yellowish red (5YR4/6) mottles, gravelly medium clay, massive, smooth ped fabric, moist firm, wet sticky and plastic. Field pH 7.0. 20% subangular weathered basalt gravels.
		5	B22	700	Diffuse	Dark grey (10YR4/1 moist) with common large distinct dark brown (7.5YR4/4) mottles, gravelly medium clay, massive, smooth ped fabric, moist firm, wet sticky and very plastic. Field pH 7.5. 60% subangular weathered basalt gravels.
		6	C	continuing	no description	Weathered basalt.
Upper Kirwans	**2e**	1	A1	100	Surface	Very dark greyish brown (10YR3/2 moist); clay loam; strong fine subangular blocky; earthy fabric; moist firm, wet slightly sticky and plastic; Field pH 6.0; Occasional subrounded to subangular basalt gravel.
		2	AB	650	Clear smooth	Dark greyish brown (2.5YR4/2 moist); medium clay; strong fine angular blocky; rough ped fabric; moist firm; wet sticky and very plastic; Field pH 7.0; Occasional subrounded to subangular basalt gravel;
		3	B2	950	Clear	Dark grey (10YR4/1 moist); medium clay; strong medium angular blocky; smooth ped fabric; moist very firm, wet sticky and very plastic; Field pH 7.5;

		4	B2 FeMn	1150	Abrupt	Dark reddish brown (5YR3/4 moist), with common fine distinct yellowish red mottles (5YR5/8); gravelly light clay; massive; earthy fabric; moist firm, wet sticky and plastic; Field pH 8.0; 50% 1-10 mm diameter subrounded to subangular strongly cemented ferromanganiferous nodules;
		5	C	continuing	Abrupt	Impenetrable ferromanganiferous laterite
Log	**3b**	1	A1	100	Surface	Yellowish red (5YR4/6 dry), to dark reddish brown (5YR3/4 moist); gravelly clay loam; weak medium subangular blocky; earthy fabric; moist friable, wet slightly sticky, slightly plastic; Field pH 6.0; Few fine rounded ferruginous nodules;
		2	B2	250	Clear	Red (2.5YR4/6 dry), to dark red (2.5YR3/6 moist); light clay (subplastic); weak medium subangular blocky; earthy fabric; moist friable, wet sticky and plastic; Field pH 6.0; broken pieces of ferruginized basalt and haematite, few fine rounded furruginized basalt gravels;
		3	C	continuing	Abrupt	Impenetrable lateritized basalt
Chiswick	**4a**	1	A1	120	Surface	Very dark greyish brown (10YR3/2 moist); fine sandy loam; moderate very fine subangular blocky; earthy fabric; moist friable, wet sticky and plastic. Field pH 6.5;
		2	A21 (conspicuous bleach)	200	Abrupt smooth	Light grey (10YR7/2 dry), to brown (10YR5/2 moist); fine sandy clay loam; massive; earthy fabric; moist very friable, wet sticky slightly plastic; Field pH 6.0; Rare iron staining of root channels;
		3	A22 (conspicuous bleach)	360	Gradual smooth	Light grey (2.5Y7/2 dry), to light brownish grey (10YR6/2 moist); fine sandy clay loam; massive; earthy fabric; moist friable, wet sticky slightly plastic; Field pH 6.5; Few root channels;
		4	B1	460	Abrupt	Pale brown (10YR6/3 dry), to brown (10YR5/3 moist); gritty light sandy clay; strong fine angular blocky; rough ped fabric; moist firm wet sticky and plastic; Field pH 6.5; Some inclusion of A2 material;
		5	B21	1140	Clear	Pale brown (10YR6/3 dry and moist) with many large distinct yellowish brown mottles (10YR5/8); medium sandy clay; strong fine angular blocky; rough ped fabric; moist very firm, wet very sticky and plastic; Field pH 6.5; some secondary roots;
		6	B22	1600	Clear	Brown (10YR5/3 dry and moist) with many large distinct yellowish brown mottles (10YR5/8); gravelly medium sandy clay; strong fine angular blocky; rough ped fabric; moist very firm, wet sticky and plastic; Field pH 6.0; Occasional, 2-5 mm diameter, subrounded, strongly cemented ferromanganiferous gravels;
Ram	**4b**	1	A1	120	Surface	Ver dark greyish brown (10YR3/2 moist); very fine sandy clay loam; weak fine subangular blocky; earthy fabric; moist very friable, wet slightly sticky, slightly plastic; Field pH 6.0; Rare ferromanganiferous gravels;
		2	A2	300	Clear	Pale brown (10YR6/3 dry), to brown (10YR5/3 moist); very fine sandy clay loam; weak fine subangular blocky; earthy fabric; moist very friable, wet slightly sticky, slightly plastic; Field pH 6.0; Rare gravels;
		3	B2 FeMn	750	Abrupt	Yellowish brown (10YR5/6 moist); gritty fine sandy clay; massive; earthy fabric; moist friable, wet sticky and plastic; Field pH 6.5; 60%, 2-12 mm subangular to subrounded strongly cemented ferromanganiferous nodules and concretions;
		4	B22	1000	Gradual	Yellowish brown (10YR5/8), with yellowish brown, common medium distinct mottles (10YR5/4), common medium faint mottles (10YR5/6); fine sandy clay; weak platy; smooth ped fabric; moist firm, wet sticky and plastic; Field pH 6.5; 10% nodules and ferromanganiferous concretions;
		5	B23	1600	Clear	Strong brown (7.5YR5/8 moist) with common large distinct grey mottles (10YR6/1 and 10YR5/1); fine sandy clay; smooth ped fabric; moist firm wet sticky and plastic; Field pH 7.0; Occasional strongly cemented ferromanganiferous nodules and concretions;
Saumarez	**4e**	1	A1	110	Surface	Light grey (10YR7/2 dry), to dark greyish brown (10YR4/2 moist); fine sandy loam; massive; earthy fabric; dry slightly hard, moist very friable, wet non-sticky, non-plastic; Field pH 6.0; Abundant roots;
		2	A2 (conspicuous bleach)	310	Clear	Light grey (10YR7/2 dry), to light brownish grey (10YR6/2 moist); fine sandy loam; massive; earthy fabric; dry slightly hard, moist very friable, wet sticky slightly plastic; Field pH 6.5; Few roots;
		3	B1	420	Clear	Pale brown (10YR6/3 dry), to greyish brown (10YR5/3 moist), with common fine distinct yellowish brown mottles with a few inclusions of A2 material; fine sandy clay; fine strong subangular blocky; rough ped fabric; dry hard, moist friable to firm, wet sticky and plastic; FIeld pH 5.8; Few roots;
		4	B21	1010	Abrupt	Greyish brown (10YR5/2 dry), to brown (10YR5/3 moist), with common fine distinct yellowish brown mottling (10YR5/6 moist); fine sandy medium clay; fine strong subangular blocky; rough ped fabric; dry very hard, moist firm, wet sticky and plastic; Field pH 5.8;
		5	B2G	1500	Gradual	Greenish grey (7.5GY5/1 moist and dry), with common medium distinct yellowish brown mottles strongly gleyed (10YR5/6 moist); fine sandy medium clay; fine strong subangular blocky; smooth ped fabric; dry very hard, moist firm, wet sticky and plastic; Field pH 5.0; Few subangular to subrounded, strongly cemented ferruginous nodules over 130-150 cm;

East Armidale	**4h**	1	A1	4	Surface	Dark brown (7.5YR4/2 dry, 3/2 moist), fine sandy clay loam, weak medium subangular blocky, earthy fabric, moist friable, wet sticky and plastic. Field pH 6.5.
		2	A2	22	Clear	Brown (10YR5/3 dry) to dark yellowish brown (10YR4/4 moist), sandy clay loam, weak medium subangular blocky, earthy fabric, moist friable, wet sticky and plastic. Field pH 6.5. 15%, 2-15 mm subangular ferruginized fine mudstone gravels.
		3	B21	85	Clear	Strong brown (7.5YR4/8 moist) with red (10YR4/8 and 2.5YR4/8) common medium prominent mottles, light clay, massive, earthy fabric, moist firm, wet sticky and plastic. Field pH 6.0. Occasional ferruginized gravels.
		4	B22	160 continuing	Gradual	Yellowish red (5YR4/8 moist) with common medium prominent grey (10YR5/1) common large prominent weak red (10R4/4) and red (10YR4/8) mottles, light clay, massive, earthy fabric, moist firm, wet sticky and plastic. Field pH 5.0. 10% 3-5 mm subangular ferruginized sediments.

Soil test outcomes prior to the field trial

The trial site occupied part of each of the two previous paddocks called “Top East” and “Hilders”.

Parameter	Units	Top East	Hilders	Optimum
pH Water		5.58	5.66	6.5
pH CaCl		4.74	4.74	*5.2-5.5*
Boron	mg/kg	0.3	0.2	*1-2*
K	mg/kg	147.3	93.6	*190*
Ca	mg/kg	1295.9	874.7	*2150*
Mg	mg/kg	396.6	287.8	*200*
Na	mg/kg	27.6	31	*60*
Cu	mg/kg	2.51	1.69	*>2.4*
Zn	mg/kg	1.32	1.76	*>6*
Mn	mg/kg	37.19	56.41	*>25*
Fe	mg/kg	238.3	183	*>25*
Nitrate NO3	mg/kg	22.8	11	*13*
Ammonium NH4	mg/kg	2.1	1.8	18
Colwell K	mg/kg	106	45	120-150
Organic Carbon	%	2.94	2.25	>5
Colwell P	mg/kg	51	31	>34
KCL Sulfur	mg/kg	12.9	8.8	*>10*
ECEC	c.mol/kg	10.228	7.108	4-20
Exch K	%	3.68	3.37	2-5
Exch Ca	%	63.23	61.41	76
Exch Mg	%	31.92	33.33	12
Exch Na	%	1.17	1.90	2
Exch H+	%	0.00	0.00	7
ExchAl	%	0.00	0.00	<5
Ca:Mg	ratio	1.981	1.843	2-15
Area	Ha	37.98	16.16	na

8.1.2 Images of the field demonstration site

Aerial photographs of the trial site in July, 2019. The DPC crops are clearly seen as green squares. In these photos the wheat plots are on the left, and the Canola plots on the right within each of the 8 farmlet strips which run from left to right in the photos. The degradation of plots 1 and plots 8 where hand feeding is occurring is also visible. Photographs provided by Edwina Toohey (NSW DPI).

Google Earth image of the trial site in January 2022.

8.2 Appendix 2 Sources of information for net income calculations

Nematode model input – livestock commodity prices and drench costs

Model inputs for the Risk Management Model for Nematodes including lamb meat and wool prices, and Australian dollar to United States dollar (AUD-USD) conversions based on historical data.

Year	Average closing price (AUD-USD; $)	Average lamb meat price ($/kg carcass weight)	Average wool price (21 micron; $/kg)
2017	0.77	6.17	15.5
2018	0.75	6.86	20.9
2019	0.70	7.62	19.9
2020[1]	0.66	7.76	17.9
Maximum price (4 years)		7.76	20.9
Minimum price (4 years)		6.17	15.5
Mean (maximum and minimum)	0.72[2]	6.97	25.3[3]

[1] Data for year 2020 obtained from 1-Jan to 1-Apr.

[2] Average closing price from 2017-2020.

[3] Average of minimum and maximum multiplied by the mean AUD-USD.

Model inputs for the Risk Management Model for Nematodes including drench costs and associated labour based on data from WormBoss (http://www.wormboss.com.au)

Drench name	Cost/50 kg animal ($)	Cost/55 kg ewe ($)	Cost/28 kg lamb ($)
Startect®	0.88	0.97	0.49
Zolvix®	1.07	1.18	0.60
Combination drench	0.51	0.56	0.29
Labour cost/1000 animals ($)	500		

Field trial Lamb enterprise expenditure

Shearing costs were taken from the gross margin calculator published by PIRSA (primary industries and regions SA).

Lamb marking was undertaken using the Numnuts system, and the price for marking using Numnuts is from AWI (Beyond the bale, December, 2019). Eartags were included in the cost at marking, even though these were administered close to birth during lambing rounds rather than at marking. Each lamb received both a visual and an electronic ear tag, priced according to purchase costs (Shearwell).

Animal health costs other than Numnuts used prices from the following websites: https://www.farmco.com.au/, https://www.fmb.com.au/all-products.html, https://specialistsales.com.au/

Animal health costs included a booster vaccination of 6-in-1 (GlanVac6), and lambs received the same vaccine at lamb marking and at weaning. Flystrike preventative applied to all ewes and lambs was dicyclanil (Clik, at the longwool rate for all ewes, short wool rate for spring lambs). Flystrike treatments were priced according to an estimated dose of extinosad (Extinosad eliminator - 25 g/L Spinosad, 2mL/sheep taking into account dilution rate). Cost of parasite treatments was calculated from price of drenches, and a rotation of products was assumed (naphthalophos (Pole-Axe)/monepantel (Zolvix)/abamectin+derquantel (Startect)), though monepantel was not administered to lambs due to the long ESI and FirstMectin (abamectin/praziquantel) was substituted. The decision to drench was based on flock monitor tests undertaken with each group of sheep, by farmlet, so that the treatment dates for the different groups varied.

Feed was administered to animals according to an individual requirement (grain) and trail fed either by bucket or from a small feed trailer. Grain was priced at $660/t which was an average priced paid by CSIRO for the whole farm during the 2019 drought period. Hay was provided to animals as they ran out of either standing feed or the previous lot of hay. Hay prices varied enormously across the year, and CSIRO was also supplied with some hay free of charge from failed crops at our Boorowa research farm. Therefore, hay was priced at $0.50 per kg, or $500/t as an average price for cereal and pasture hay from the Dairy Australia website for Northern NSW (https://www.dairyaustralia.com.au/industry/farm-inputs-and-costs/hay-report). Mineral supplements were supplied *ad libitum* to all sheep during supplementary feeding, and we estimated the cost at $0.02/hd/day.

Reproduction costs included only the Regulin® implants (Ceva) treatment that Autumn ewes and their rams were administered (actual costs via Nutrien, Armidale - $0.33/ewe including an amount for the implants given to rams).

Sale costs for lamb were calculated from invoices received (more below), but wool sale costs were estimated using AWEX and AWTA pricing guides.

Labour was not costed for the lamb enterprise. The enterprise change model for this demonstration trial is a grazing only property changing to cropping and grazing. The assumption was that the specialist cropping activities would need specialist contractors, whilst the lamb operations (except shearing) could be undertaken by the producer.

Field trial Lamb enterprise income

Lambs were sold to Thomas Foods International, Tamworth via the Armidale based stock agent Schute Bell. The spring and autumn lambs were sold as single lots, and lambs from spare ewes were included in the lot. By working on the slaughter chain, we were able to capture the carcase weight for each lamb. Using the sale price grid for the day of sale we were able to calculate the income from carcases and skins for each of the four farmlets contributing lambs to the lot. Agent fees and transport costs were collected from each sale and used in the net income calculations.

Ewes were shorn three to five weeks prior to lambing. The fleece weights for each animal were collected at shearing. The value of wool for each farmlet was calculated from this information using prices published by AWI. Lamb fleece from the third production cycle was included with an estimated fleece weight of 1.3kg and price received 300 cents/kg based on proceeds from sale. Crutchings were not included in the income estimation.

8.3 Appendix 3 Weather over the period of the field trial

A weather station was installed at the site in October 2018. Below are some summaries of the data collected with respect to the experiment timeline.

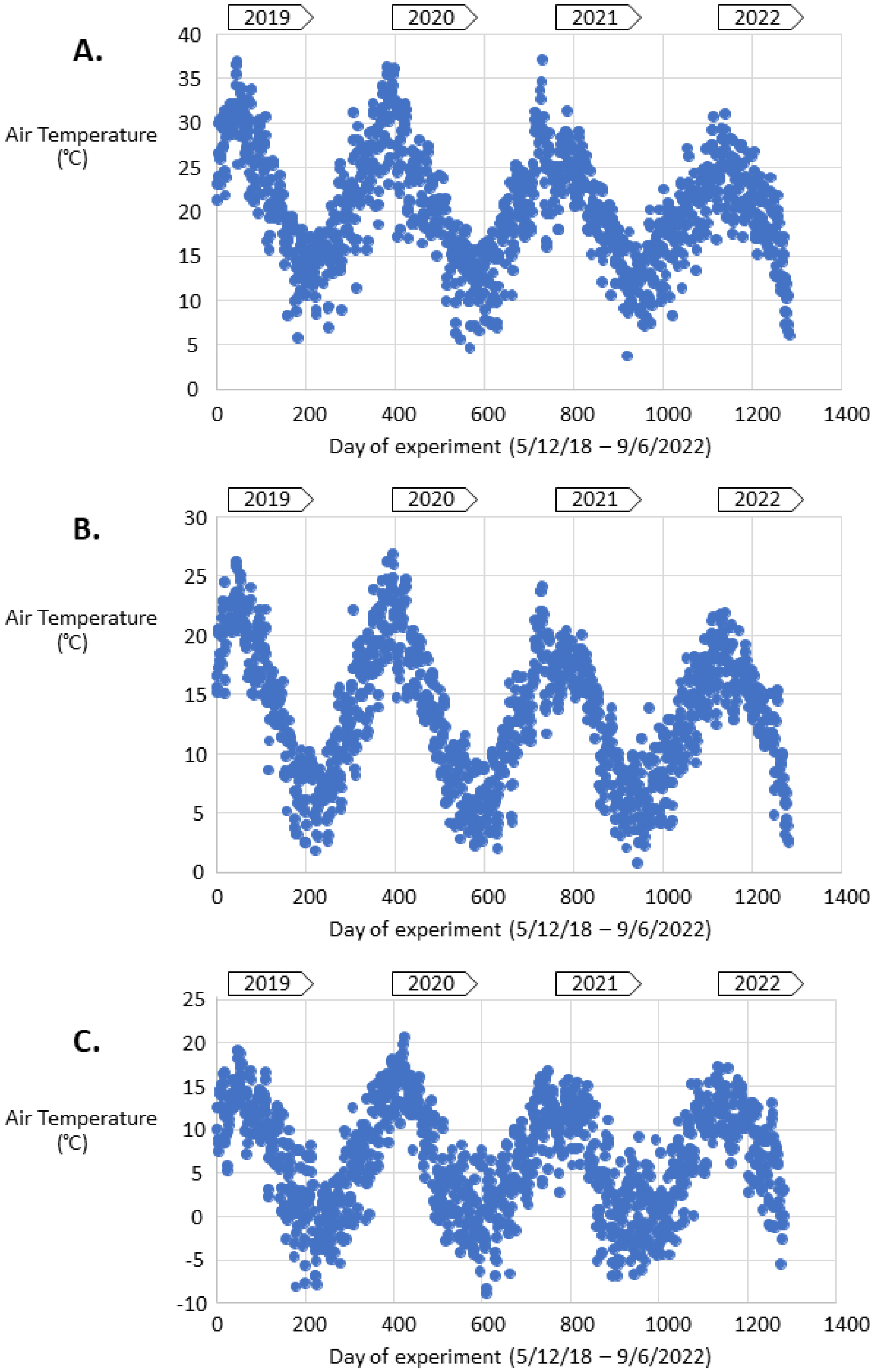


Figure 8.3.1. Daily air temperatures over the period in which the field demonstration trial was conducted. Maximum daily temperature (A), average daily temperature (B) and minimum daily temperature (C) is shown. Flags at the top of each graph illustrate the beginning of each calendar year.

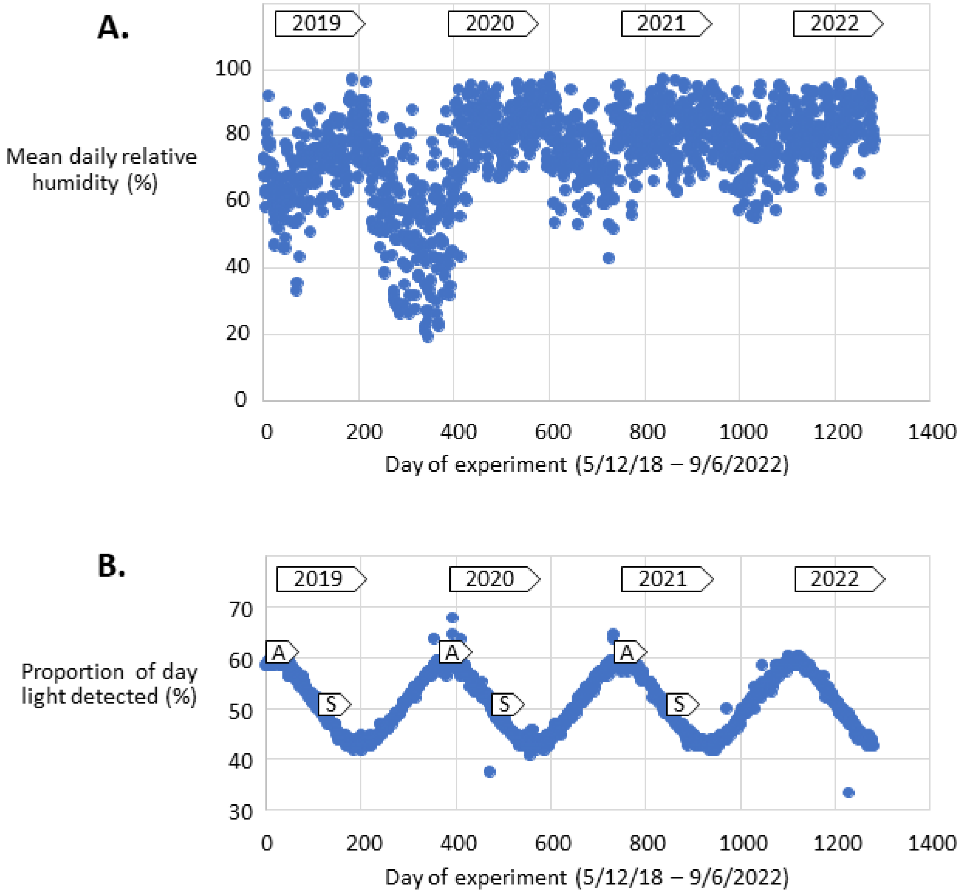


Figure 8.3.2. Relative atmospheric humidity (A) and recorded daylight hours (B) over the period in which the field trial was conducted. In both graphs, flags at the top illustrate the beginning of each calendar year. In (B) flags marked A indicate the beginning of mating for autumn lambing ewes and flags marked B indicate the beginning of mating for spring lambing ewes. It is clear that daylengths are decreasing therefore stimulating oestrus in the ewes during the spring mating periods which occur just after the autumn equinox. In contrast, during the autumn mating periods daylength is stable either side of the summer solstice.

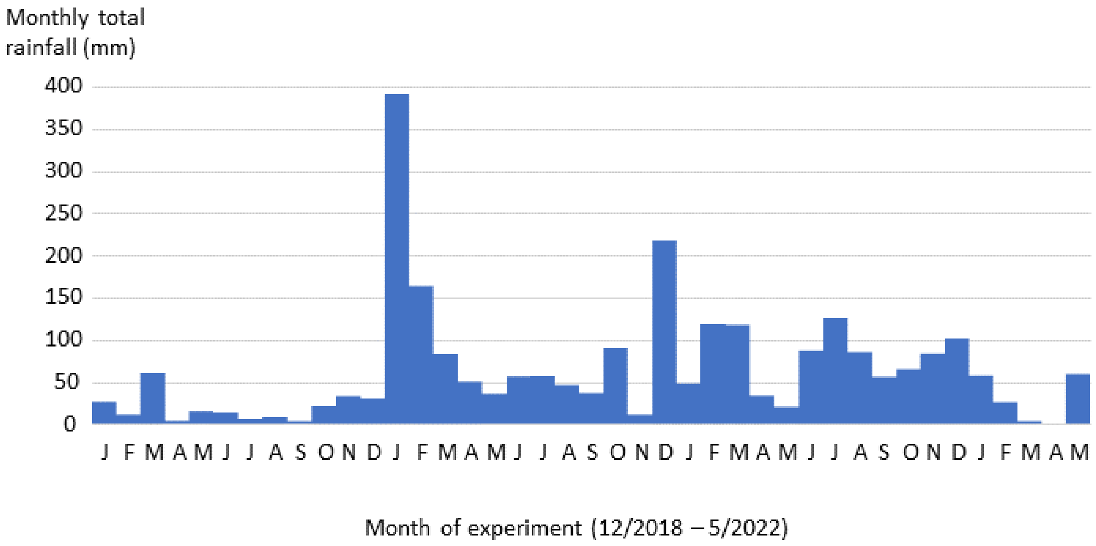
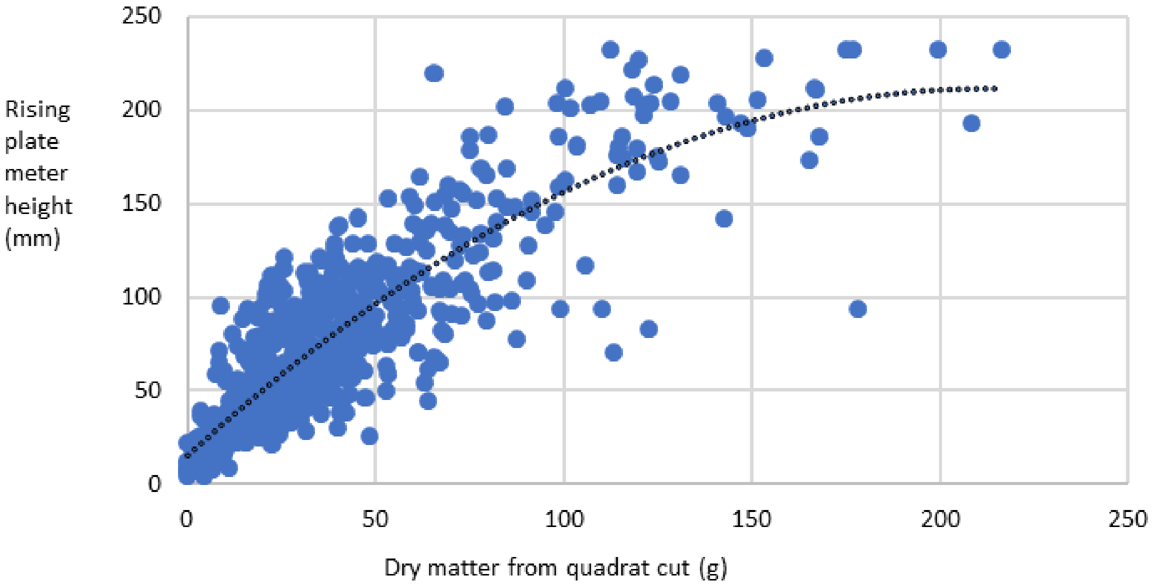


Figure 8.3.3. Rainfall totals by month over the period in which the field trial was conducted.

8.4 Appendix 4 Rising plate meter calibration



Calibration of rising plate meter method of pasture biomass calculation against quadrat pasture cuts. Quadrats were placed on the ground within farmlet plots, measured with the rising plate meter instrument, then pasture was harvested, dried and weighed. The data are from 337 cuts made prior to grazing and 325 cuts made after grazing had occurred in the plot. Using a quadratic regression, the R-squared value was 0.75. The regression equation was:

$y = -0.0043x^2 + 1.8433x + 15.816$

8.5 Appendix 5 Reproductive performance for individual farmlets

Reproductive performance for the eight farmlets over three production cycles.

Year	Lambing season	Feed Regime	Farmlet	**Lambs dead**	**Lambs alive**	**Scan***	**Lambing***	**Marking***	**Dry**	**LAL**	**LAL***	**S**	**T**
2019	Autumn	DPC	A	5	23	1.25	1.40	1.15	2	1	3	8	6
			E	10	25	1.65	1.75	1.25	1	4	3	2	10
		pasture	C	6	27	1.55	1.65	1.35	0	1	4	7	8
			G	3	25	1.45	1.40	1.25	3	0	3	6	8
	Spring	DPC	B	6	18	1.25	1.20	0.90	1	3	3	11	2
			F	4	17	1.25	1.05	0.85	4	4	0	7	5
		pasture	D	0	26	1.40	1.30	1.30	1	2	0	9	8
			H	6	21	1.40	1.35	1.05	2	3	1	8	6
2020	Autumn	DPC	A	13	25	1.70	1.90	1.25	0	3	4	5	8
			E	6	26	1.55	1.60	1.30	1	2	2	6	9
		pasture	C	5	30	1.55	1.75	1.50	0	2	0	6	12
			G	5	23	1.50	1.40	1.15	2	1	3	8	6
	Spring	DPC	B	3	23	1.35	1.30	1.15	3	1	2	7	7
			F	5	17	1.30	1.10	0.85	5	3	1	6	5
		pasture	D	2	24	1.30	1.30	1.20	3	1	0	8	8
			H	2	28	1.50	1.50	1.40	1	0	2	8	9
2021	Autumn	DPC*	A	6	25	1.65	1.55	1.25	1	2	2	7	8
			E	6	32	1.85	1.90	1.60	1	1	4	1	13
		pasture	C	5	28	1.75	1.65	1.40	0	3	2	4	11
			G	8	25	1.60	1.65	1.25	1	3	2	5	9
	Spring	DPC*	B	8	21	1.60	1.45	1.05	0	4	4	8	4
			F	3	25	1.45	1.40	1.25	3	1	1	6	9
		pasture	D	2	28	1.50	1.50	1.40	2	0	2	6	10
			H	6	21	1.30	1.35	1.05	3	3	1	6	7

Reproductive performance for two and three factor effects

2019	Autumn	DPC	15	48	1.45	1.58	1.20	3	5	6	10	16
		pasture	9	52	1.50	1.53	1.30	3	1	7	13	16
	Spring	DPC	10	35	1.25	1.13	0.88	5	7	3	18	7
		pasture	6	47	1.40	1.33	1.18	3	5	1	17	14
2020	Autumn	DPC	19	51	1.63	1.75	1.28	1	5	6	11	17
		pasture	10	53	1.53	1.58	1.33	2	3	3	14	18
	Spring	DPC	8	40	1.33	1.20	1.00	8	4	3	13	12
		pasture	4	52	1.40	1.40	1.30	4	1	2	16	17
2021	Autumn	DPC*	12	57	1.75	1.73	1.43	2	3	6	8	21
		pasture	13	53	1.68	1.65	1.33	1	6	4	9	20
	Spring	DPC*	11	46	1.53	1.43	1.15	3	5	5	14	13
		pasture	8	49	1.40	1.43	1.23	5	3	3	12	17
ALL	Autumn	DPC	46	156	1.61	1.68	1.30	6	13	18	29	54
		pasture	32	158	1.57	1.58	1.32	6	10	14	36	54
ALL	Spring	DPC	29	121	1.37	1.25	1.01	16	16	11	45	32
		pasture	18	148	1.40	1.38	1.23	12	9	6	45	48
2019	Autumn	ALL	24	100	1.48	1.55	1.25	6	6	13	23	32
	Spring	ALL	16	82	1.33	1.23	1.03	8	12	4	35	21
2020	Autumn	ALL	29	104	1.58	1.66	1.30	3	8	9	25	35
	Spring	ALL	12	92	1.36	1.30	1.15	12	5	5	29	29
2021	Autumn	ALL	25	110	1.71	1.69	1.38	3	9	10	17	41
	Spring	ALL	19	95	1.46	1.43	1.19	8	8	8	26	30
2019	ALL	DPC	25	83	1.35	1.35	1.04	8	12	9	28	23
	ALL	pasture	15	99	1.45	1.43	1.24	6	6	8	30	30
2020	ALL	DPC	27	91	1.48	1.48	1.14	9	9	9	24	29
	ALL	pasture	14	105	1.46	1.49	1.31	6	4	5	30	35
2021	ALL	DPC*	23	103	1.64	1.58	1.29	5	8	11	22	34
	ALL	pasture	21	102	1.54	1.54	1.28	6	9	7	21	37

*Scan, Lambing and Marking – proportion of lambs compared to ewes

8.6 Appendix 6 Supplementary feeding

Supplementary feeding of lambs and ewes in production cycle 1

Animal class	Lambing season	Feed regime	Farmlet	Animals	Start	End	Hay (t)	Grain (t)	Days on feed	Average grain/hd/day (kg/hd/day)
Ewes	Autumn	DPC+Pasture	A	20	18/03/2019	6/12/2019	7.88	2.36	235	0.449
			E	20	18/03/2019	6/12/2019	6.83	2.36	235	0.449
		Pasture	C	20	18/03/2019	6/12/2019	7.37	2.36	263	0.449
			G	20	18/03/2019	6/12/2019	8.51	2.36	263	0.449
	Spring	DPC+Pasture	B	20	25/03/2019	23/03/2020	5.03	2.81	207	0.385
			F	20	25/03/2019	23/03/2020	4.85	2.81	207	0.385
		Pasture	D	20	25/03/2019	23/03/2020	6.18	3.05	357	0.420
			H	20	25/03/2019	23/03/2020	7.27	3.05	357	0.420
Lambs	Autumn	DPC+Pasture	A	22	14/08/2019	5/03/2020	0.91	2.79	178	0.621
			E	24	14/08/2019	5/03/2020	1.00	3.04	178	0.621
		Pasture	C	27	14/08/2019	5/03/2020	1.90	3.74	203	0.680
			G	25	14/08/2019	5/03/2020	1.76	3.47	203	0.680
	Spring	DPC+Pasture	B	18	6/01/2020	10/06/2020	0.24	1.87	156	0.668
			F	17	6/01/2020	10/06/2020	0.22	1.77	156	0.668
		Pasture	D	26	6/01/2020	10/06/2020	0.34	2.71	156	0.668
			H	21	6/01/2020	10/06/2020	0.28	2.19	156	0.668

Supplementary feeding of lambs and ewes in production cycle 2

	Feeding events					
Farmlet	**First date**	**Last date**	**supplement**	**Daily quantity (kg/farmlet)**	**per head (g/day)**	**Cost/ farmlet**
A	9/12/2019	6/01/2020	Canola hay	5.1	255	$ 40.00
C	9/12/2019	6/01/2020	Canola hay	5.1	255	$ 40.00
E	9/12/2019	6/01/2020	Canola hay	5.1	255	$ 40.00
G	9/12/2019	6/01/2020	Canola hay	5.1	255	$ 40.00
A	5/10/2020	12/10/2020	cotton seed meal pellets	3.2	158	$ 12.19
C	10/09/2020	14/10/2020	cotton seed meal pellets	4.6	230	$ 85.98
E	10/09/2020	26/10/2020	cotton seed meal pellets	4.6	231	$ 117.04
G	10/09/2020	26/10/2020	cotton seed meal pellets	4.3	213	$ 107.80
E lambs	10/09/2020	12/10/2020	cotton seed meal pellets	4.2	168	$ 73.79

Supplementary feeding of lambs and ewes in production cycle 3

Farmlet	First date	Last date	Supplement	Daily quantity (kg/farmlet)	per head (g/day)	Cost/ farmlet ($)	Total amount fed (kg)
A ewes	21/07	9/08	cotton seed pellets	5.62	281	60.18	118
	11/08	10/09	lucerne based pellets	5.38	269	172.00	172
	4/08	23/08	lucerne hay	8.61	430	255.42	198
	21/07	21/07	wheaten hay	25.54	1277	300.30	715
C ewes	4/08	9/08	cotton seed pellets	4.14	207	14.79	29
	11/08	10/09	lucerne based pellets	5.06	253	162.00	162
	6/08	30/08	lucerne hay	6.29	314	227.04	176
	-	-	wheaten hay	-	-	-	-
E ewes	13/07	9/08	cotton seed pellets	5.47	273	80.84	159
	11/08	8/09	lucerne based pellets	5.77	288	173.00	173
	4/08	25/08	lucerne hay	7.48	374	241.23	187
	21/07	21/07	wheaten hay	25.54	1277	300.30	715
G ewes	28/07	9/08	cotton seed pellets	4.71	236	33.66	66
	11/08	8/09	lucerne based pellets	5.57	278	167.00	167
	4/08	20/08	lucerne hay	8.80	440	227.04	176
	-	-	wheaten hay	-	-	-	-
A lambs	18/08	10/11	lucerne based pellets	3.59	180	309.00	309
	29/09	29/09	lucerne hay	2.75	138	14.19	11
C lambs	18/08	10/11	lucerne based pellets	3.73	187	321.00	321
	-	-	lucerne hay	-	-	-	-
E lambs	18/08	10/11	lucerne based pellets	4.15	208	357.00	357
	-	-	lucerne hay	-	-	-	-
G lambs	18/08	10/11	lucerne based pellets	3.49	174	300.00	300
	-	-	lucerne hay	-	-	-	-

* Mean per farmlet

8.7 Appendix 7 Statistical analysis of lamb weight and growth parameters within and across production cycles

Analysis of Variance (ANOVA)
P values less than 0.05 in red
Drop=production cycle 1,2 or 3 (birth years 2019, 2020 or 2021)
Parity=single (S) or multiple (M) births
Age and Replicate factors were variable and fixed factors in the model respectively
Ratio= Carcase Weight/Final Weight

Variate	**Factor or combination**	**F probability**			
		Across cycles	**Cycle 3 2021**	**Cycle 2 2020**	**Cycle 1 2019**
Birth_Weight	Drop	0.066	-	-	-
Birth_Weight	Drop.Feed_Regime	0.021	-	-	-
Birth_Weight	Drop.Feed_Regime.Parity	0.841	-	-	-
Birth_Weight	Drop.Feed_Regime.Sex	0.463	-	-	-
Birth_Weight	Drop.Lambing_Season	0.817	-	-	-
Birth_Weight	Drop.Lambing_Season.Feed_Regime	0.800	-	-	-
Birth_Weight	Drop.Lambing_Season.Parity	0.064	-	-	-
Birth_Weight	Drop.Lambing_Season.Sex	0.262	-	-	-
Birth_Weight	Drop.Parity	0.074	-	-	-
Birth_Weight	Drop.Parity.Sex	0.862	-	-	-
Birth_Weight	Drop.Sex	0.568	-	-	-
Birth_Weight	Feed_Regime	<.001	<.001	0.057	0.547
Birth_Weight	Feed_Regime.Parity	0.203	0.445	0.107	0.732
Birth_Weight	Feed_Regime.Parity.Sex	0.262	0.155	0.485	0.894
Birth_Weight	Feed_Regime.Sex	0.276	0.073	0.588	0.975
Birth_Weight	Lambing_Season	<.001	<.001	<.001	<.001
Birth_Weight	Lambing_Season.Feed_Regime	0.169	0.522	0.229	0.299
Birth_Weight	Lambing_Season.Feed_Regime.Parity	0.481	0.550	0.021	0.820

Birth_Weight	Lambing_Season.Feed_Regime.Sex	0.669	0.579	0.860	0.093
Birth_Weight	Lambing_Season.Parity	0.067	0.975	0.004	0.804
Birth_Weight	Lambing_Season.Parity.Sex	0.843	0.747	0.519	0.092
Birth_Weight	Lambing_Season.Sex	0.276	0.061	0.834	0.881
Birth_Weight	Parity	<.001	<.001	<.001	<.001
Birth_Weight	Parity.Sex	0.995	0.720	0.779	0.653
Birth_Weight	Replicate	0.373	0.079	0.213	0.280
Birth_Weight	Sex	<.001	0.001	<.001	<.001
Final_Weight	Age_at_final_weigh	<.001	<.001	<.001	0.335
Final_Weight	Drop	0.002	-	-	-
Final_Weight	Drop.Feed_Regime	<.001	-	-	-
Final_Weight	Drop.Feed_Regime.Parity	0.093	-	-	-
Final_Weight	Drop.Feed_Regime.Sex	0.534	-	-	-
Final_Weight	Drop.Lambing_Season	0.162	-	-	-
Final_Weight	Drop.Lambing_Season.Feed_Regime	<.001	-	-	-
Final_Weight	Drop.Lambing_Season.Parity	0.055	-	-	-
Final_Weight	Drop.Lambing_Season.Sex	0.716	-	-	-
Final_Weight	Drop.Parity	0.182	-	-	-
Final_Weight	Drop.Parity.Sex	0.921	-	-	-
Final_Weight	Drop.Sex	0.564	-	-	-
Final_Weight	Feed_Regime	<.001	0.288	0.117	<.001
Final_Weight	Feed_Regime.Parity	0.364	0.856	0.015	0.514
Final_Weight	Feed_Regime.Parity.Sex	0.511	0.474	0.113	0.450
Final_Weight	Feed_Regime.Sex	0.237	0.072	0.983	0.788
Final_Weight	Lambing_Season	0.024	0.497	0.048	<.001
Final_Weight	Lambing_Season.Feed_Regime	0.418	<.001	0.061	0.382
Final_Weight	Lambing_Season.Feed_Regime.Parity	0.763	0.342	0.784	0.816
Final_Weight	Lambing_Season.Feed_Regime.Sex	0.801	0.233	0.602	0.084
Final_Weight	Lambing_Season.Parity	0.012	0.554	0.017	0.048
Final_Weight	Lambing_Season.Parity.Sex	0.636	0.839	0.985	0.287
Final_Weight	Lambing_Season.Sex	0.873	0.858	0.465	0.575

Final_Weight	Parity	<.001	<.001	<.001	<.001
Final_Weight	Parity.Sex	0.464	0.714	0.512	0.717
Final_Weight	Replicate	<.001	<.001	<.001	0.534
Final_Weight	Sex	<.001	<.001	<.001	<.001
GrowthRateBirth	Age_at_final_weigh	<.001	0.002	<.001	0.047
GrowthRateBirth	Drop	0.001	-	-	-
GrowthRateBirth	Drop.Feed_Regime	<.001	-	-	-
GrowthRateBirth	Drop.Feed_Regime.Parity	0.079	-	-	-
GrowthRateBirth	Drop.Feed_Regime.Sex	0.470	-	-	-
GrowthRateBirth	Drop.Lambing_Season	0.067	-	-	-
GrowthRateBirth	Drop.Lambing_Season.Feed_Regime	<.001	-	-	-
GrowthRateBirth	Drop.Lambing_Season.Parity	0.054	-	-	-
GrowthRateBirth	Drop.Lambing_Season.Sex	0.826	-	-	-
GrowthRateBirth	Drop.Parity	0.093	-	-	-
GrowthRateBirth	Drop.Parity.Sex	0.935	-	-	-
GrowthRateBirth	Drop.Sex	0.699	-	-	-
GrowthRateBirth	Feed_Regime	<.001	0.087	0.044	<.001
GrowthRateBirth	Feed_Regime.Parity	0.405	0.801	0.024	0.476
GrowthRateBirth	Feed_Regime.Parity.Sex	0.352	0.319	0.098	0.460
GrowthRateBirth	Feed_Regime.Sex	0.183	0.034	0.967	0.776
GrowthRateBirth	Lambing_Season	<.001	0.163	0.015	<.001
GrowthRateBirth	Lambing_Season.Feed_Regime	0.637	<.001	0.031	0.378
GrowthRateBirth	Lambing_Season.Feed_Regime.Parity	0.528	0.362	0.777	0.871
GrowthRateBirth	Lambing_Season.Feed_Regime.Sex	0.864	0.283	0.649	0.124
GrowthRateBirth	Lambing_Season.Parity	0.005	0.646	0.008	0.052
GrowthRateBirth	Lambing_Season.Parity.Sex	0.575	0.926	0.929	0.326
GrowthRateBirth	Lambing_Season.Sex	0.812	0.783	0.745	0.612
GrowthRateBirth	Parity	<.001	<.001	<.001	<.001
GrowthRateBirth	Parity.Sex	0.422	0.748	0.427	0.770
GrowthRateBirth	Replicate	<.001	<.001	<.001	0.624
GrowthRateBirth	Sex	<.001	<.001	<.001	<.001

GrowthRateWean	Age_at_final_weigh	<.001	<.001	<.001	0.988
GrowthRateWean	Drop	<.001	-	-	-
GrowthRateWean	Drop.Feed_Regime	<.001	-	-	-
GrowthRateWean	Drop.Feed_Regime.Parity	0.880	-	-	-
GrowthRateWean	Drop.Feed_Regime.Sex	0.063	-	-	-
GrowthRateWean	Drop.Lambing_Season	<.001	-	-	-
GrowthRateWean	Drop.Lambing_Season.Feed_Regime	<.001	-	-	-
GrowthRateWean	Drop.Lambing_Season.Parity	0.004	-	-	-
GrowthRateWean	Drop.Lambing_Season.Sex	0.674	-	-	-
GrowthRateWean	Drop.Parity	0.616	-	-	-
GrowthRateWean	Drop.Parity.Sex	0.936	-	-	-
GrowthRateWean	Drop.Sex	0.082	-	-	-
GrowthRateWean	Feed_Regime	0.310	0.028	<.001	<.001
GrowthRateWean	Feed_Regime.Parity	0.417	0.325	0.655	0.432
GrowthRateWean	Feed_Regime.Parity.Sex	0.990	0.410	0.887	0.509
GrowthRateWean	Feed_Regime.Sex	0.756	0.014	0.608	0.525
GrowthRateWean	Lambing_Season	<.001	<.001	<.001	<.001
GrowthRateWean	Lambing_Season.Feed_Regime	0.754	0.017	<.001	<.001
GrowthRateWean	Lambing_Season.Feed_Regime.Parity	0.051	0.089	0.423	0.245
GrowthRateWean	Lambing_Season.Feed_Regime.Sex	0.166	0.581	0.325	0.011
GrowthRateWean	Lambing_Season.Parity	0.608	0.078	0.505	0.010
GrowthRateWean	Lambing_Season.Parity.Sex	0.326	0.937	0.558	0.157
GrowthRateWean	Lambing_Season.Sex	0.666	0.598	0.535	0.590
GrowthRateWean	Parity	<.001	0.007	0.078	<.001
GrowthRateWean	Parity.Sex	0.361	0.894	0.792	0.969
GrowthRateWean	Replicate	<.001	<.001	0.002	0.432
GrowthRateWean	Sex	<.001	<.001	0.005	<.001
Marking_Weight	Age_at_marking	<.001	<.001	<.001	<.001
Marking_Weight	Drop	0.369	-	-	-
Marking_Weight	Drop.Feed_Regime	0.201	-	-	-
Marking_Weight	Drop.Feed_Regime.Parity	0.511	-	-	-

Marking_Weight	Drop.Feed_Regime.Sex	0.506	-	-	-
Marking_Weight	Drop.Lambing_Season	0.371	-	-	-
Marking_Weight	Drop.Lambing_Season.Feed_Regime	0.862	-	-	-
Marking_Weight	Drop.Lambing_Season.Parity	0.007	-	-	-
Marking_Weight	Drop.Lambing_Season.Sex	0.776	-	-	-
Marking_Weight	Drop.Parity	0.434	-	-	-
Marking_Weight	Drop.Parity.Sex	0.795	-	-	-
Marking_Weight	Drop.Sex	0.649	-	-	-
Marking_Weight	Feed_Regime	<.001	0.401	0.003	0.002
Marking_Weight	Feed_Regime.Parity	0.002	0.086	0.002	0.286
Marking_Weight	Feed_Regime.Parity.Sex	0.394	0.666	0.794	0.168
Marking_Weight	Feed_Regime.Sex	0.856	0.570	0.420	0.479
Marking_Weight	Lambing_Season	<.001	<.001	<.001	<.001
Marking_Weight	Lambing_Season.Feed_Regime	0.052	0.302	0.137	0.606
Marking_Weight	Lambing_Season.Feed_Regime.Parity	0.187	0.718	0.134	0.194
Marking_Weight	Lambing_Season.Feed_Regime.Sex	0.711	0.125	0.793	0.379
Marking_Weight	Lambing_Season.Parity	<.001	0.635	<.001	0.190
Marking_Weight	Lambing_Season.Parity.Sex	0.871	0.771	0.364	0.185
Marking_Weight	Lambing_Season.Sex	0.720	0.440	0.916	0.786
Marking_Weight	Parity	<.001	<.001	<.001	<.001
Marking_Weight	Parity.Sex	0.265	0.434	0.806	0.198
Marking_Weight	Replicate	0.57	0.376	0.003	<.001
Marking_Weight	Sex	<.001	<.001	0.002	0.223
Carcase_Weight	Age_at_final_weigh	<.001	<.001	0.175	0.218
Carcase_Weight	Drop	<.001	-	-	-
Carcase_Weight	Drop.Feed_Regime	<.001	-	-	-
Carcase_Weight	Drop.Feed_Regime.Lambing_Season	<.001	-	-	-
Carcase_Weight	Drop.Feed_Regime.Parity	0.009	-	-	-
Carcase_Weight	Drop.Feed_Regime.Sex	0.464	-	-	-
Carcase_Weight	Drop.Lambing_Season	<.001	-	-	-
Carcase_Weight	Drop.Lambing_Season.Parity	0.102	-	-	-

Carcase_Weight	Drop.Lambing_Season.Sex	0.471	-	-	-
Carcase_Weight	Drop.Parity	0.541	-	-	-
Carcase_Weight	Drop.Parity.Sex	0.937	-	-	-
Carcase_Weight	Drop.Sex	0.420	-	-	-
Carcase_Weight	Feed_Regime	<.001	0.068	0.064	<.001
Carcase_Weight	Feed_Regime.Lambing_Season	0.712	0.579	0.005	0.088
Carcase_Weight	Feed_Regime.Lambing_Season.Parity	0.416	0.251	0.284	0.322
Carcase_Weight	Feed_Regime.Lambing_Season.Sex	0.880	0.065	0.786	0.807
Carcase_Weight	Feed_Regime.Parity	0.819	0.071	0.008	<.001
Carcase_Weight	Feed_Regime.Parity.Sex	0.601	<.001	0.013	0.556
Carcase_Weight	Feed_Regime.Sex	0.111	0.213	0.922	0.888
Carcase_Weight	Lambing_Season	0.770	0.416	0.375	0.243
Carcase_Weight	Lambing_Season.Parity	0.041	0.528	0.027	0.086
Carcase_Weight	Lambing_Season.Parity.Sex	0.980	0.907	0.596	0.690
Carcase_Weight	Lambing_Season.Sex	0.568	0.68	0.62	0.168
Carcase_Weight	Parity	<.001	<.001	<.001	<.001
Carcase_Weight	Parity.Sex	0.47	0.778	0.453	0.748
Carcase_Weight	Replicate	<.001	<.001	<.001	0.345
Carcase_Weight	Sex	<.001	<.001	<.001	<.001
Ratio	Age_at_final_weigh	<.001	<.001	<.001	0.325
Ratio	Drop	<.001	-	-	-
Ratio	Drop.Feed_Regime	0.474	-	-	-
Ratio	Drop.Feed_Regime.Lambing_Season	0.237	-	-	-
Ratio	Drop.Feed_Regime.Parity	0.020	-	-	-
Ratio	Drop.Feed_Regime.Sex	0.666	-	-	-
Ratio	Drop.Lambing_Season	<.001	-	-	-
Ratio	Drop.Lambing_Season.Parity	0.964	-	-	-
Ratio	Drop.Lambing_Season.Sex	0.379	-	-	-
Ratio	Drop.Parity	0.664	-	-	-
Ratio	Drop.Parity.Sex	0.986	-	-	-
Ratio	Drop.Sex	0.730	-	-	-

Ratio	Feed_Regime	<.001	0.066	0.135	<.001
Ratio	Feed_Regime.Lambing_Season	0.227	0.522	0.063	0.003
Ratio	Feed_Regime.Lambing_Season.Parity	0.226	0.315	0.553	0.370
Ratio	Feed_Regime.Lambing_Season.Sex	0.306	0.391	0.506	0.732
Ratio	Feed_Regime.Parity	0.304	<.001	0.012	<.001
Ratio	Feed_Regime.Parity.Sex	0.933	0.902	0.023	0.491
Ratio	Feed_Regime.Sex	0.227	0.467	0.588	0.268
Ratio	Lambing_Season	0.002	0.763	0.191	0.179
Ratio	Lambing_Season.Parity	0.949	0.956	0.885	0.678
Ratio	Lambing_Season.Parity.Sex	0.486	0.640	0.218	0.161
Ratio	Lambing_Season.Sex	0.079	0.349	0.863	0.007
Ratio	Parity	0.002	0.149	0.001	0.204
Ratio	Parity.Sex	0.648	0.861	0.500	0.936
Ratio	Replicate	0.017	0.385	<.001	0.565
Ratio	Sex	0.108	0.557	0.298	0.019
Value	Age_at_final_weigh	<.001	<.001	0.107	0.001
Value	Drop	<.001	-	-	-
Value	Drop.Feed_Regime	<.001	-	-	-
Value	Drop.Feed_Regime.Parity	0.023	-	-	-
Value	Drop.Feed_Regime.Sex	0.182	-	-	-
Value	Drop.Lambing_Season	<.001	-	-	-
Value	Drop.Lambing_Season.Feed_Regime	<.001	-	-	-
Value	Drop.Lambing_Season.Parity	0.204	-	-	-
Value	Drop.Lambing_Season.Sex	0.727	-	-	-
Value	Drop.Parity	0.434	-	-	-
Value	Drop.Parity.Sex	0.866	-	-	-
Value	Drop.Sex	0.663	-	-	-
Value	Feed_Regime	<.001	0.119	0.015	<.001
Value	Feed_Regime.Parity	0.572	0.479	0.007	0.344
Value	Feed_Regime.Parity.Sex	0.520	0.426	0.248	0.425
Value	Feed_Regime.Sex	0.533	0.045	0.469	0.758

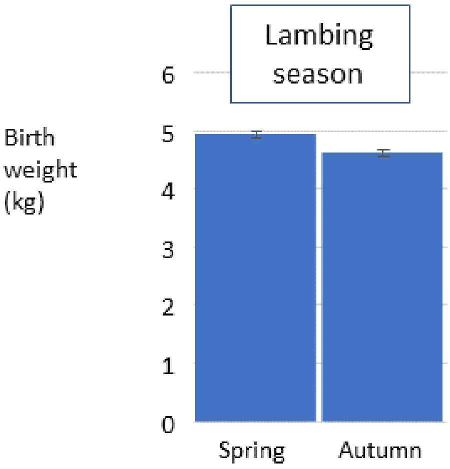
Value	Lambing_Season	<.001	0.875	0.018	<.001
Value	Lambing_Season.Feed_Regime	0.496	0.003	0.010	0.290
Value	Lambing_Season.Feed_Regime.Parity	0.347	0.366	0.689	0.816
Value	Lambing_Season.Feed_Regime.Sex	0.572	0.721	0.187	0.591
Value	Lambing_Season.Parity	0.014	0.820	0.019	0.106
Value	Lambing_Season.Parity.Sex	0.705	0.993	0.908	0.527
Value	Lambing_Season.Sex	0.126	0.429	0.595	0.105
Value	Parity	<.001	<.001	<.001	<.001
Value	Parity.Sex	0.16	0.683	0.147	0.925
Value	Replicate	<.001	<.001	<.001	0.923
Value	Sex	<.001	<.001	<.001	<.001
Weaning_Weight	Age_at_weaning	<.001	0.011	<.001	<.001
Weaning_Weight	Drop	<.001	-	-	-
Weaning_Weight	Drop.Feed_Regime	<.001	-	-	-
Weaning_Weight	Drop.Feed_Regime.Parity	0.023	-	-	-
Weaning_Weight	Drop.Feed_Regime.Sex	0.650	-	-	-
Weaning_Weight	Drop.Lambing_Season	<.001	-	-	-
Weaning_Weight	Drop.Lambing_Season.Feed_Regime	<.001	-	-	-
Weaning_Weight	Drop.Lambing_Season.Parity	0.110	-	-	-
Weaning_Weight	Drop.Lambing_Season.Sex	0.422	-	-	-
Weaning_Weight	Drop.Parity	0.014	-	-	-
Weaning_Weight	Drop.Parity.Sex	0.860	-	-	-
Weaning_Weight	Drop.Sex	0.397	-	-	-
Weaning_Weight	Feed_Regime	<.001	0.128	<.001	<.001
Weaning_Weight	Feed_Regime.Parity	0.060	0.337	<.001	0.719
Weaning_Weight	Feed_Regime.Parity.Sex	0.391	0.999	0.045	0.750
Weaning_Weight	Feed_Regime.Sex	0.181	0.804	0.779	0.462
Weaning_Weight	Lambing_Season	<.001	<.001	<.001	0.012
Weaning_Weight	Lambing_Season.Feed_Regime	0.160	0.002	<.001	<.001
Weaning_Weight	Lambing_Season.Feed_Regime.Parity	0.187	0.542	0.231	0.188
Weaning_Weight	Lambing_Season.Feed_Regime.Sex	0.247	0.038	0.80	0.877

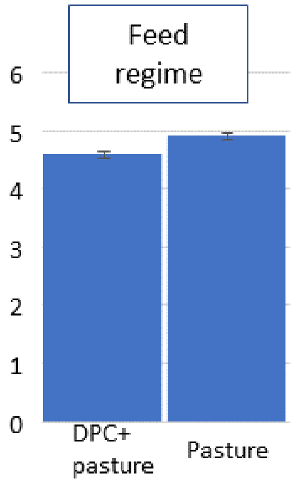
Weaning_Weight	Lambing_Season.Parity	0.003	0.343	<.001	0.491
Weaning_Weight	Lambing_Season.Parity.Sex	0.790	0.843	0.594	0.801
Weaning_Weight	Lambing_Season.Sex	0.412	0.703	0.227	0.540
Weaning_Weight	Parity	<.001	<.001	<.001	<.001
Weaning_Weight	Parity.Sex	0.863	0.783	0.450	0.467
Weaning_Weight	Replicate	0.023	0.228	<.001	0.049
Weaning_Weight	Sex	<.001	<.001	0.003	0.278

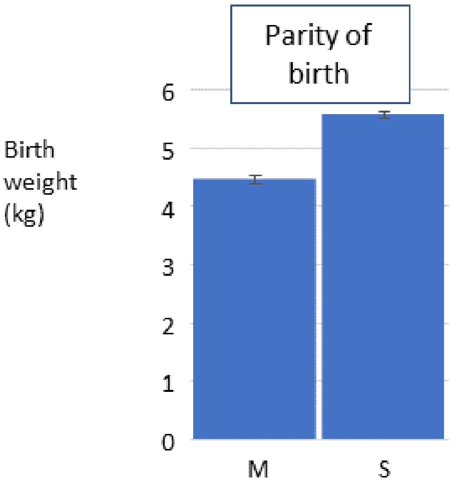
Graphs

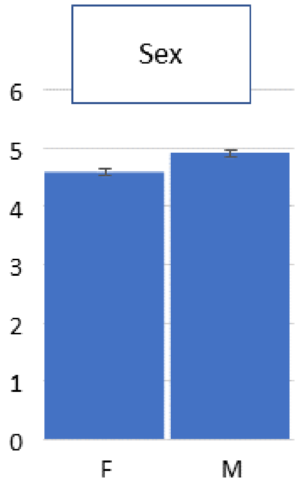
The following graphs represent means from the ANOVA statistical model
Error bars are the standard error differences, and they are the mean standard error differences for those with more than 2 groups
DPC is used in some graphs as an abbreviation for DPC+pasture because of space limitations
For sex, m=castrated males, f=females
For parity of birth, m=multiple birth lambs (twins or triplets), s=single born lambs

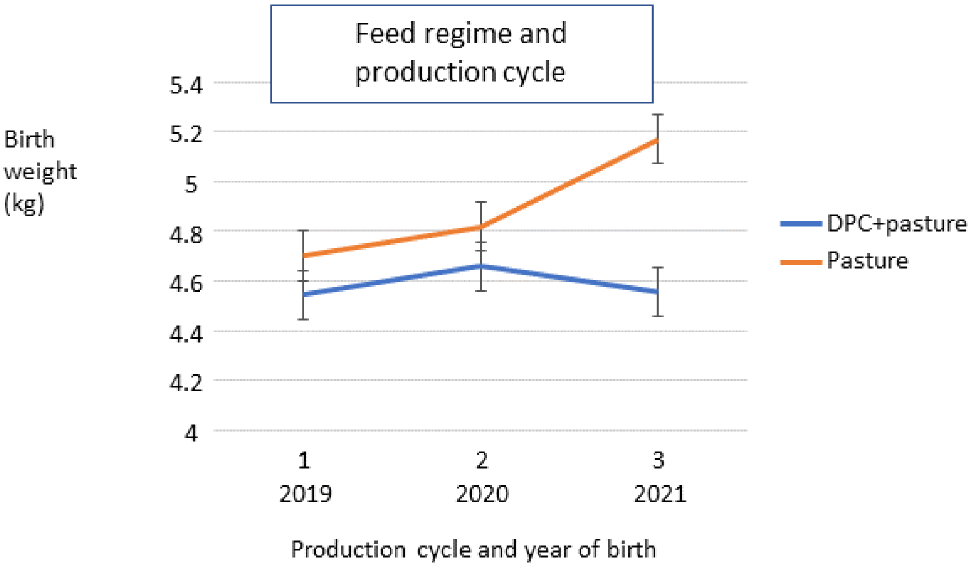
Significant factor effects for Birth Weight



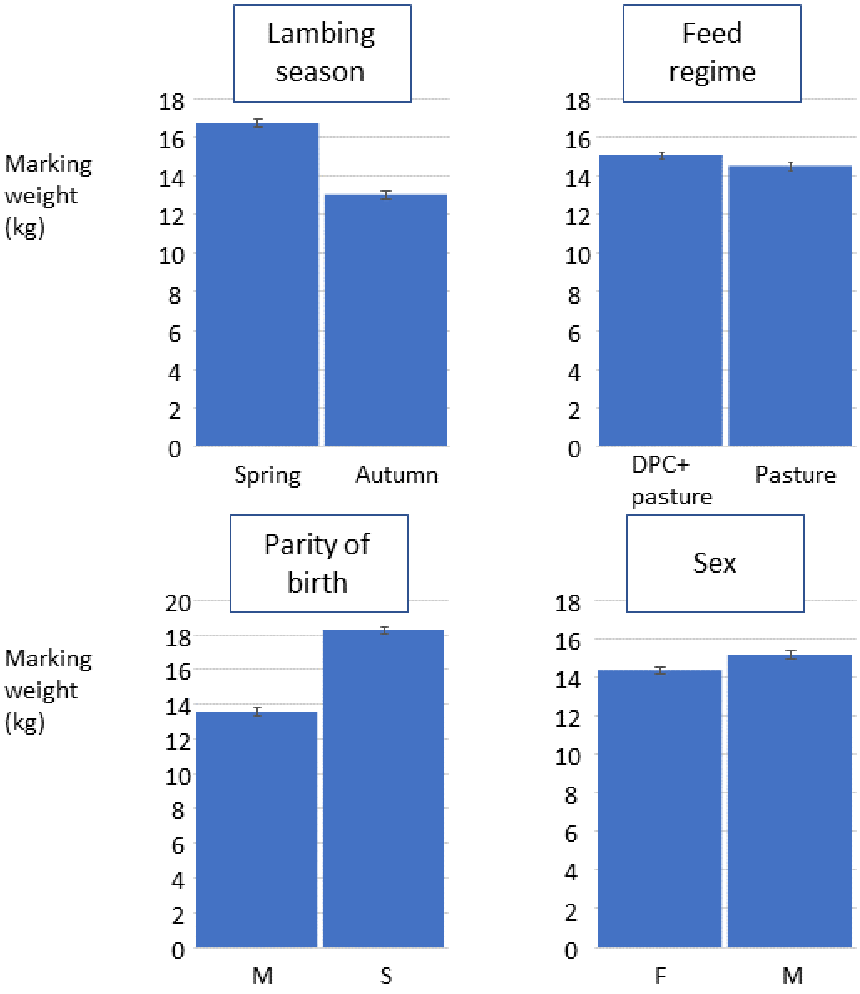


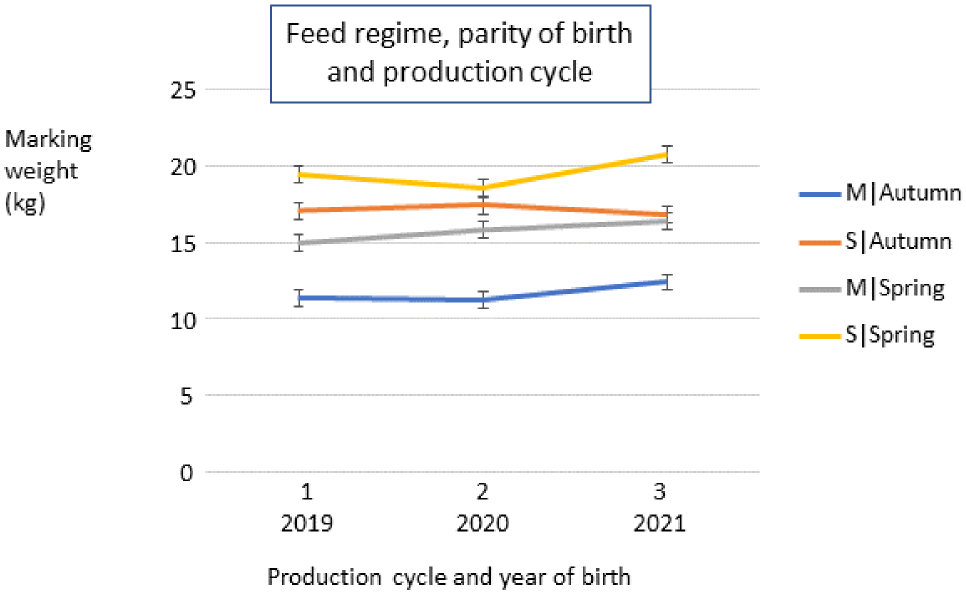


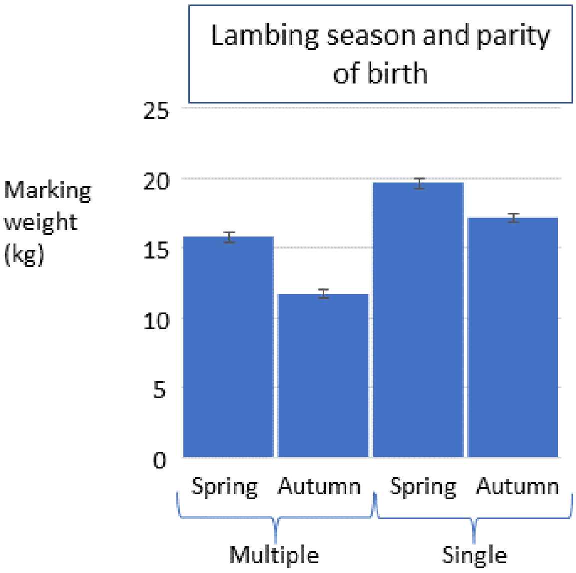


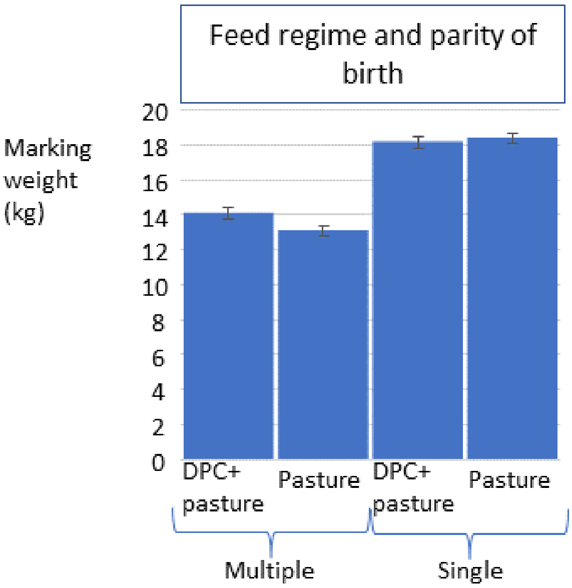


Significant factor effects for Marking Weight

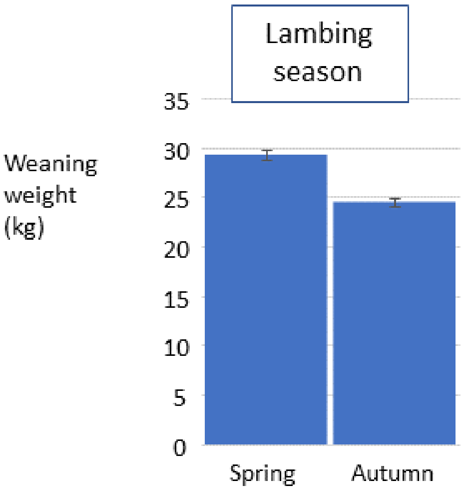


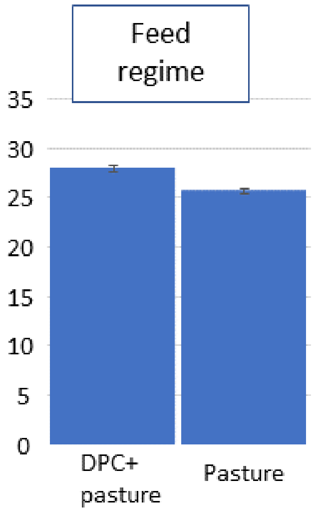


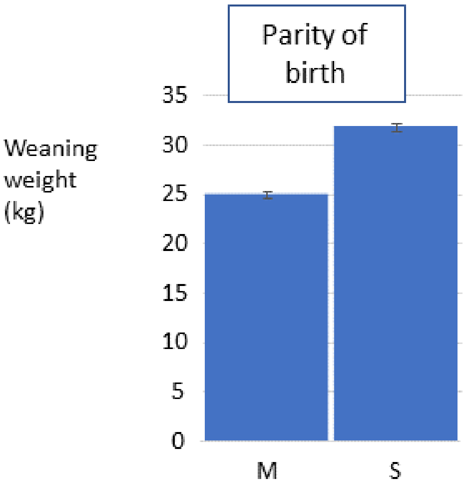

Lambing season and parity of birth
Marking weight (kg)
25
20
15
10
5
0
Spring
Autumn
Spring
Autumn
Multiple
Single

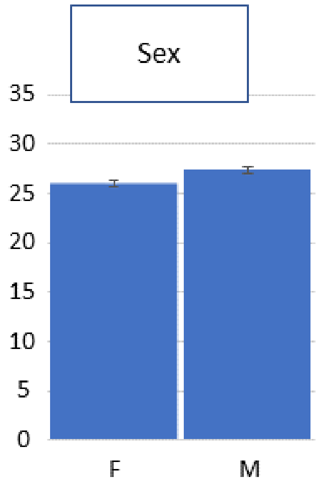

Feed regime and parity of birth
Marking weight (kg)
20
18
16
14
12
10
8
6
4
2
0
DPC+ pasture
Pasture
DPC+ pasture
Pasture
Multiple
Single

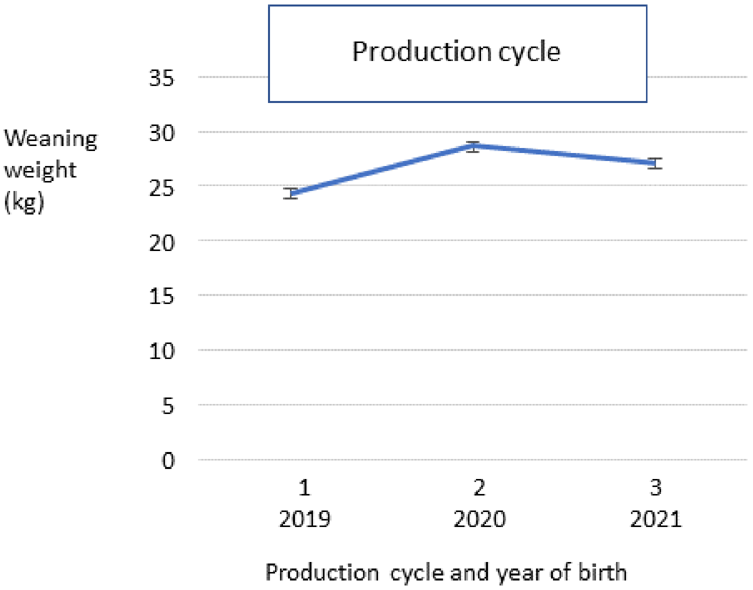
Significant factor effects for Weaning Weight

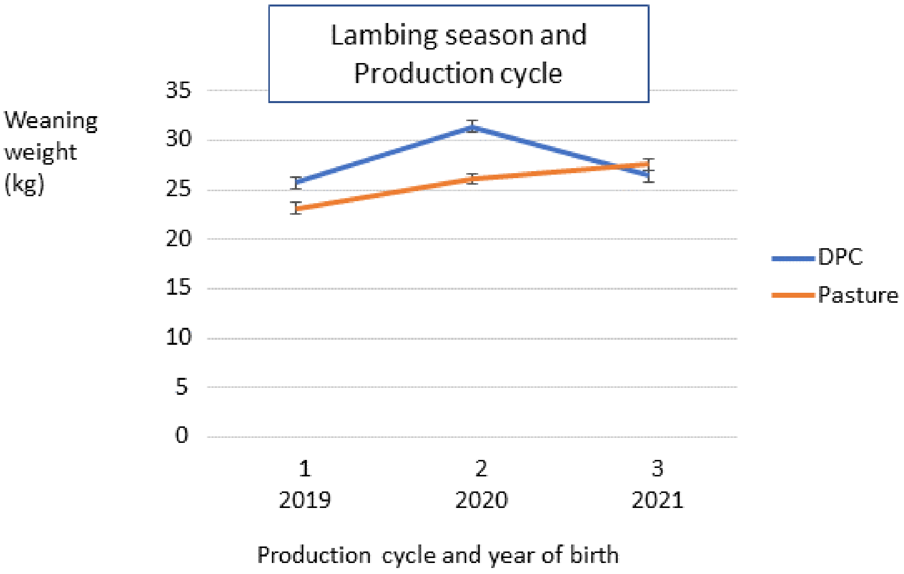


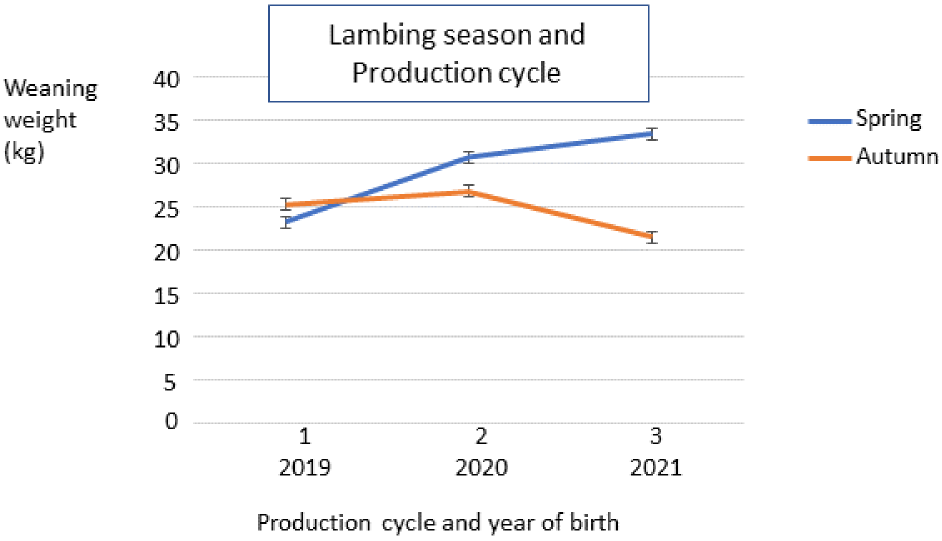


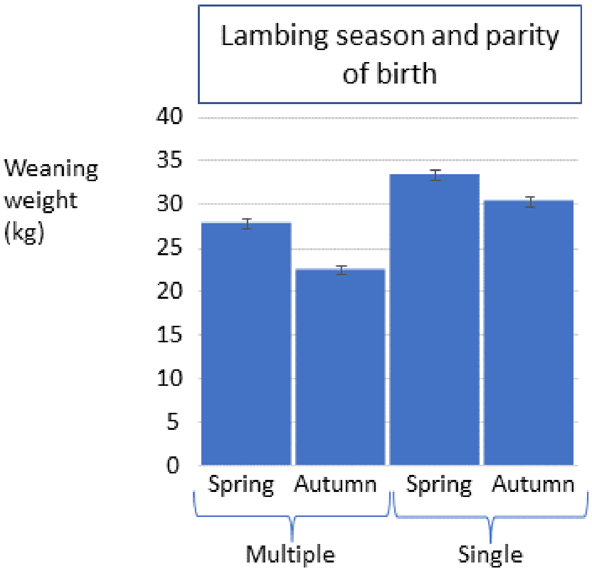


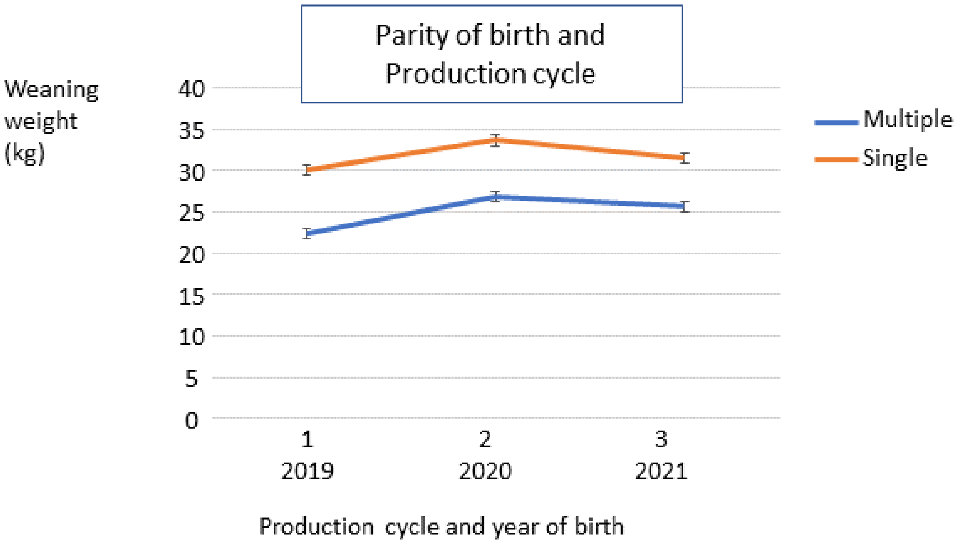


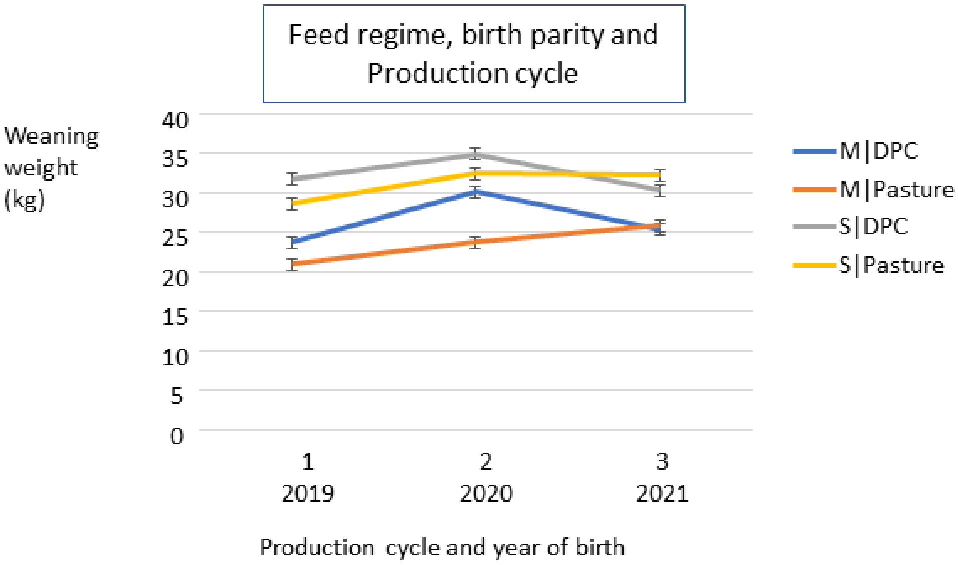


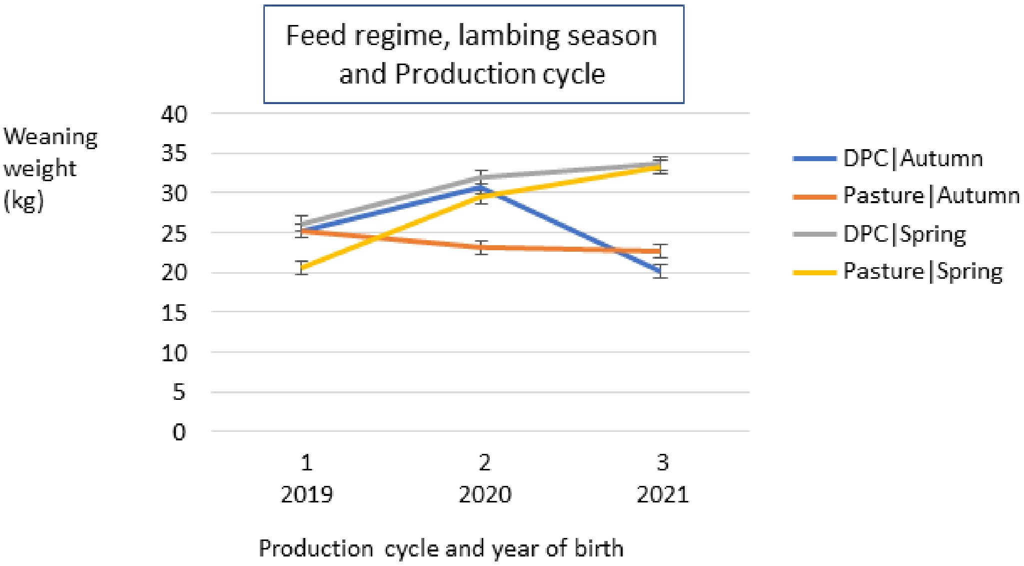

Lambing season and Production cycle
Weaning weight (kg)
35
30
25
20
15
10
5
0
1
2019
2
2020
3
2021
Production cycle and year of birth
DPC
Pasture


Lambing season and Production cycle
Weaning weight (kg)
40
35
30
25
20
15
10
5
0
1
2019
2
2020
3
2021
Production cycle and year of birth
Spring
Autumn

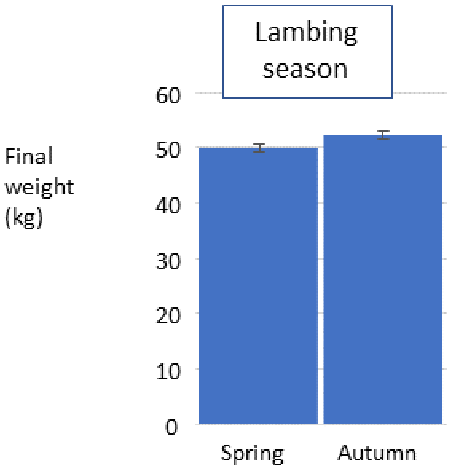

Lambing season and parity of birth
Weaning weight (kg)
40
35
30
25
20
15
10
5
0
Spring
Autumn
Spring
Autumn
Multiple
Single

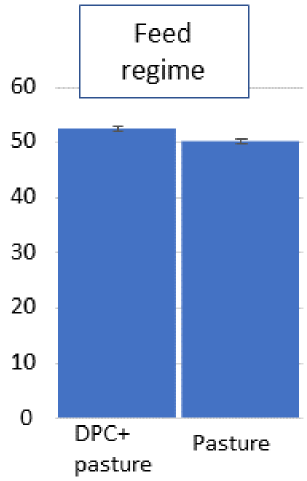

Parity of birth and Production cycle
Weaning weight (kg)
40
35
30
25
20
15
10
5
0
1 2019
2 2020
3 2021
Production cycle and year of birth
Multiple
Single

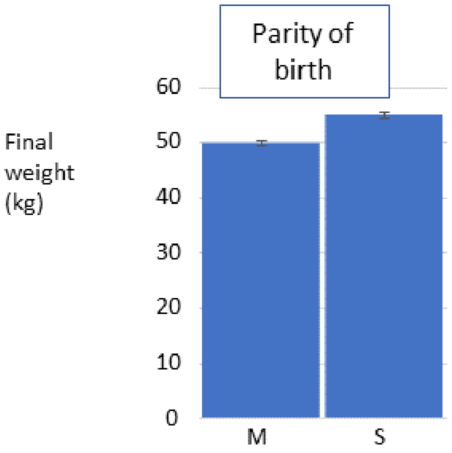

Feed regime, birth parity and Production cycle
Weaning weight (kg)
40
35
30
25
20
15
10
5
0
1
2019
2
2020
3
2021
Production cycle and year of birth
M|DPC
M|Pasture
S|DPC
S|Pasture

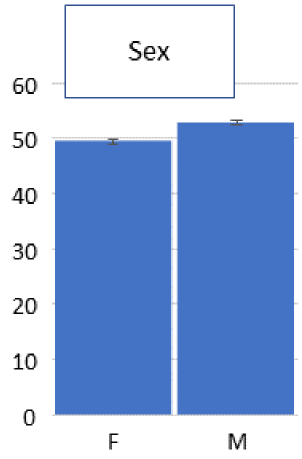

Feed regime, lambing season and Production cycle
Weaning weight (kg)
40
35
30
25
20
15
10
5
0
1
2019
2
2020
3
2021
Production cycle and year of birth
DPC|Autumn
Pasture|Autumn
DPC|Spring
Pasture|Spring

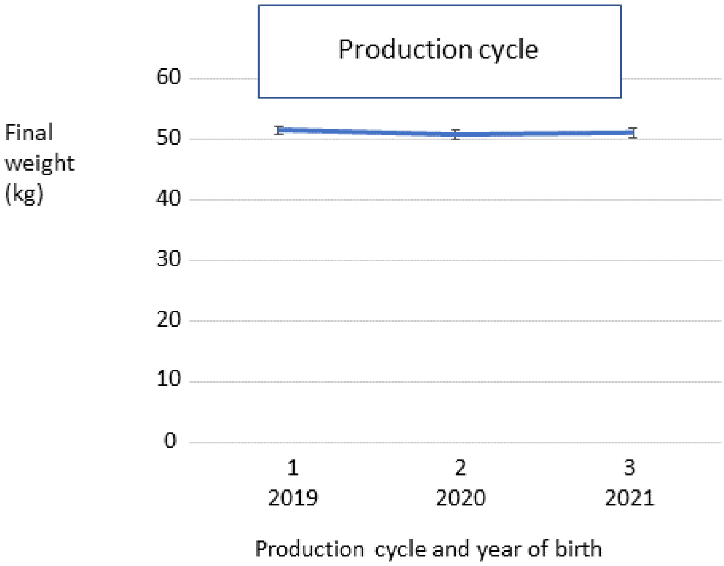
Significant factor effects for Final Weight

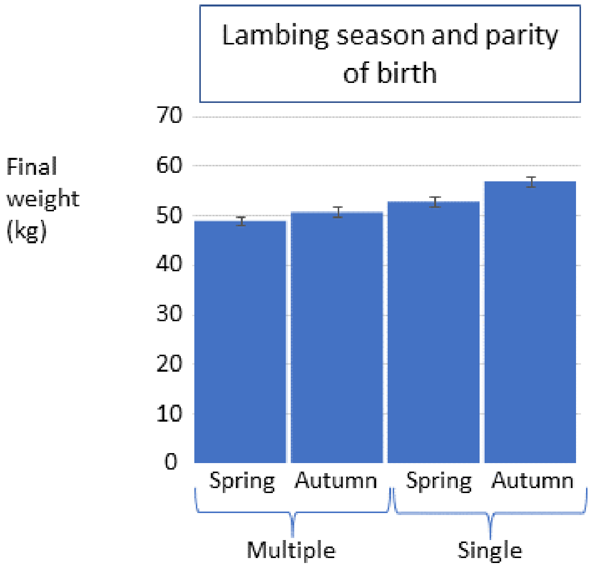


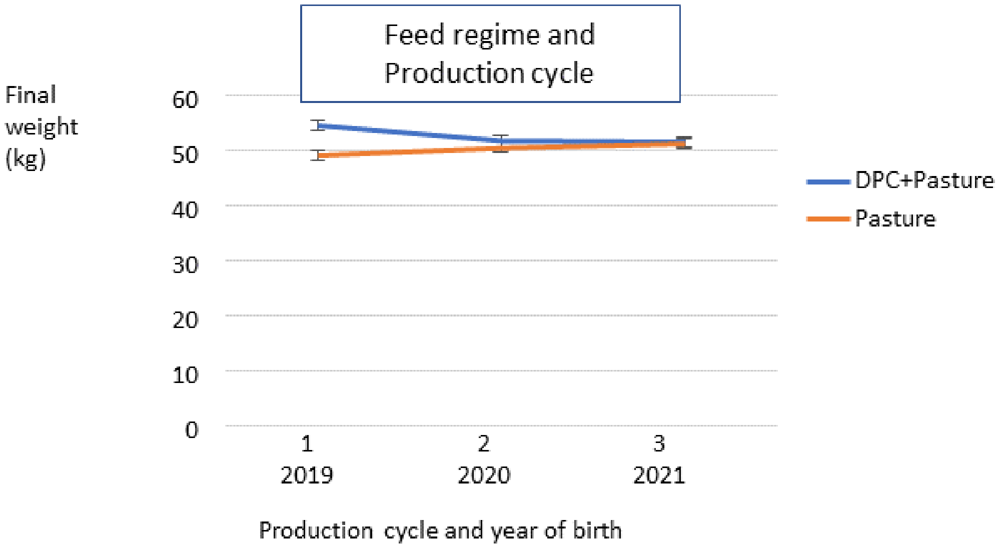


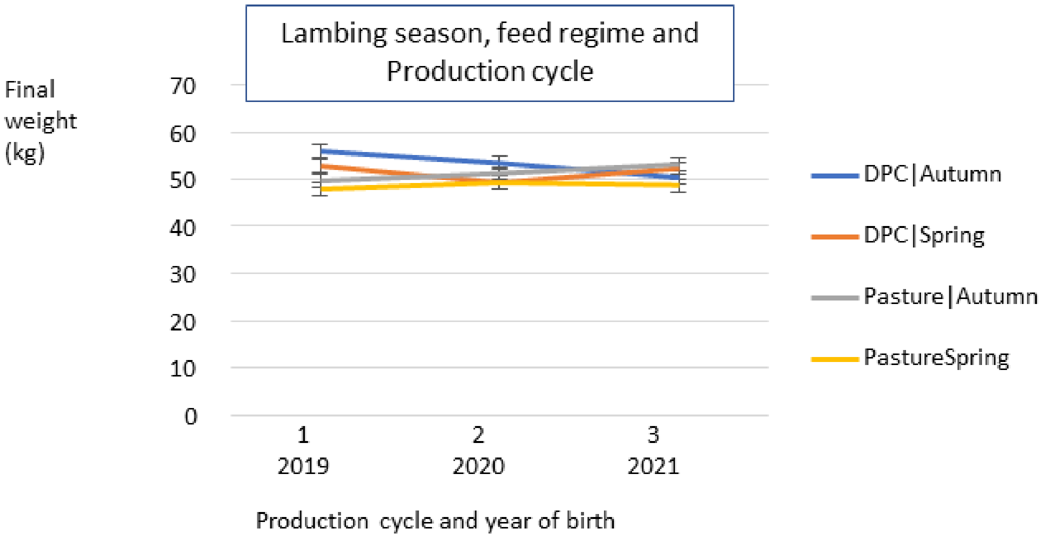




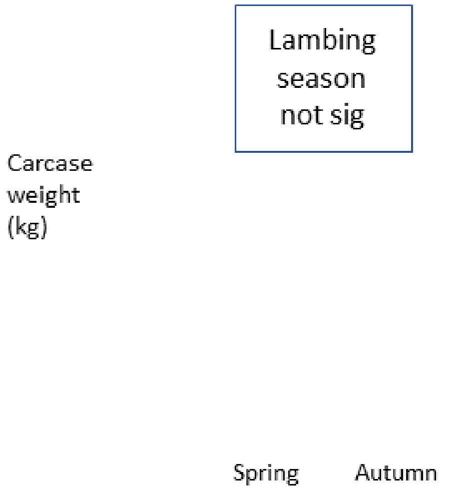


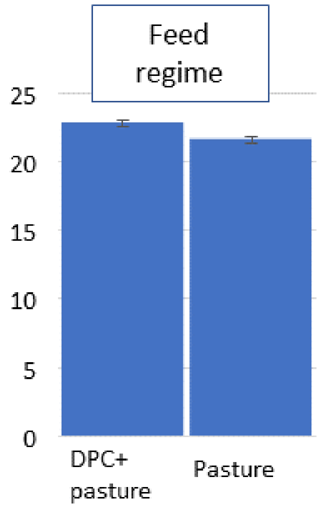

Lambing season and parity of birth
Final weight (kg)
70
60
50
40
30
20
10
0
Spring
Autumn
Spring
Autumn
Multiple
Single

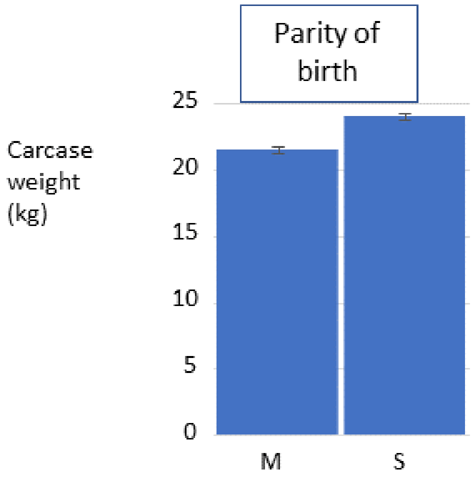

Feed regime and Production cycle
Final weight (kg)
60
50
40
30
20
10
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC+Pasture
Pasture

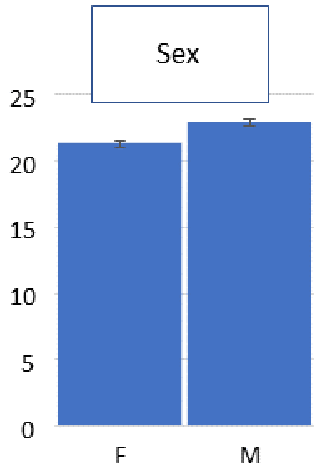

Lambing season, feed regime and Production cycle
Final weight (kg)
70
60
50
40
30
20
10
0
1
2019
2
2020
3
2021
Production cycle and year of birth
DPC|Autumn
DPC|Spring
Pasture|Autumn
PastureSpring

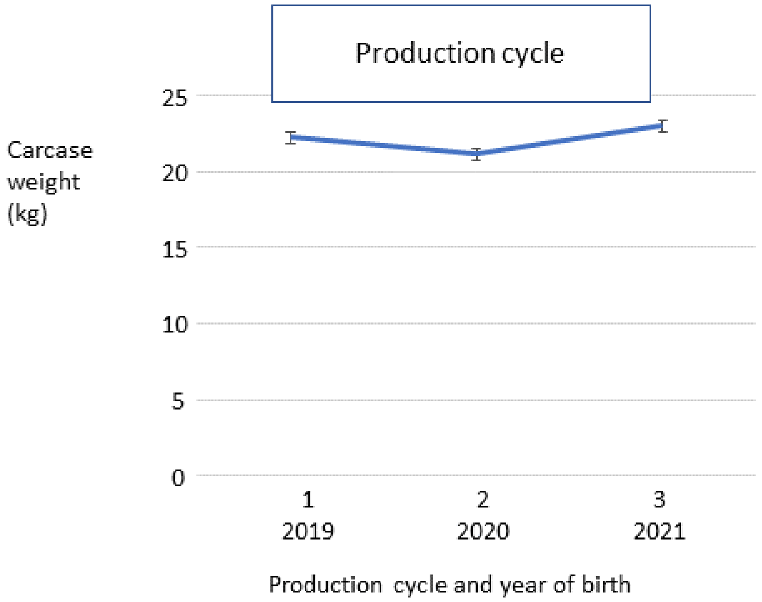
Significant factor effects for Carcase Weight

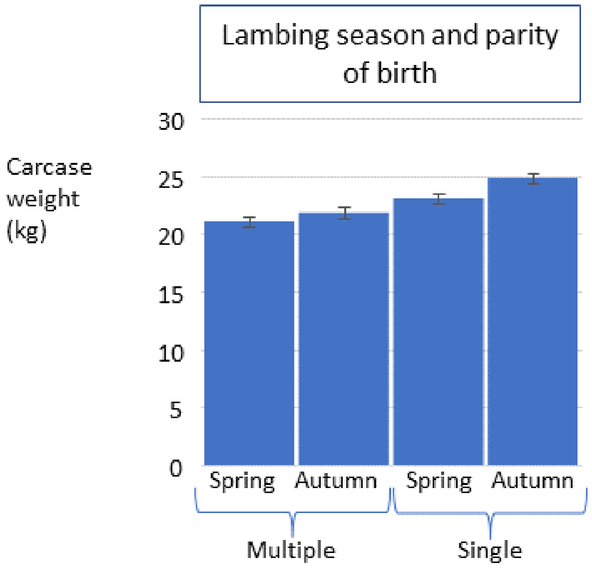


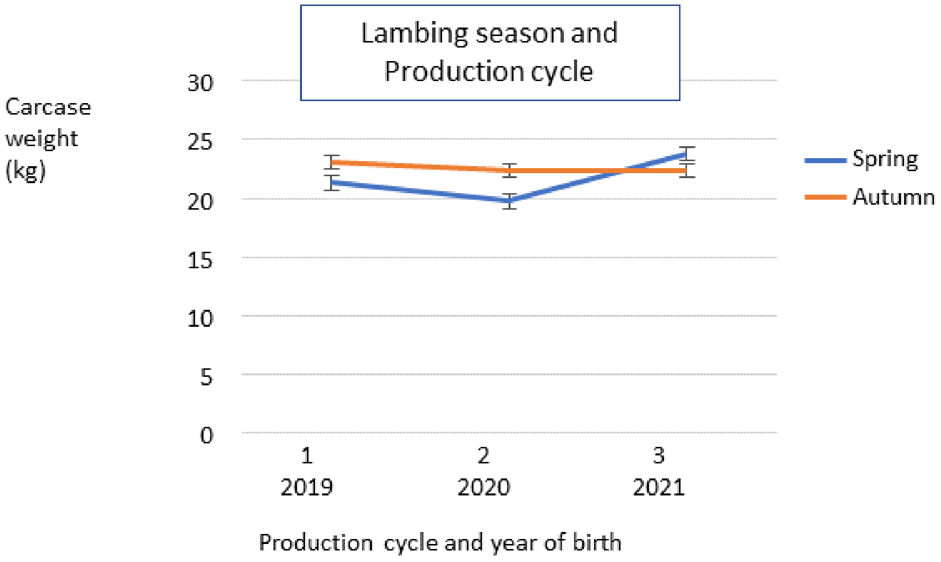


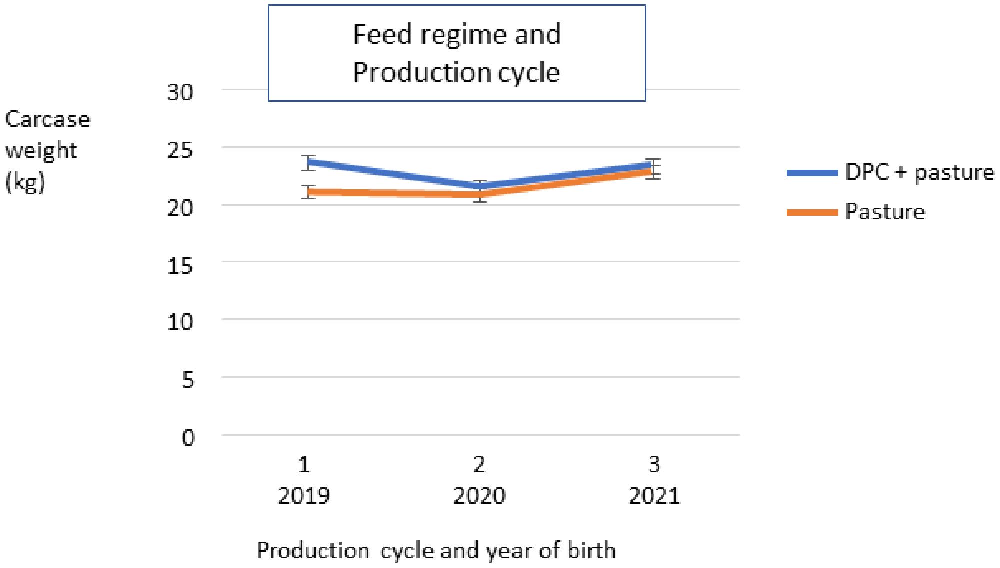


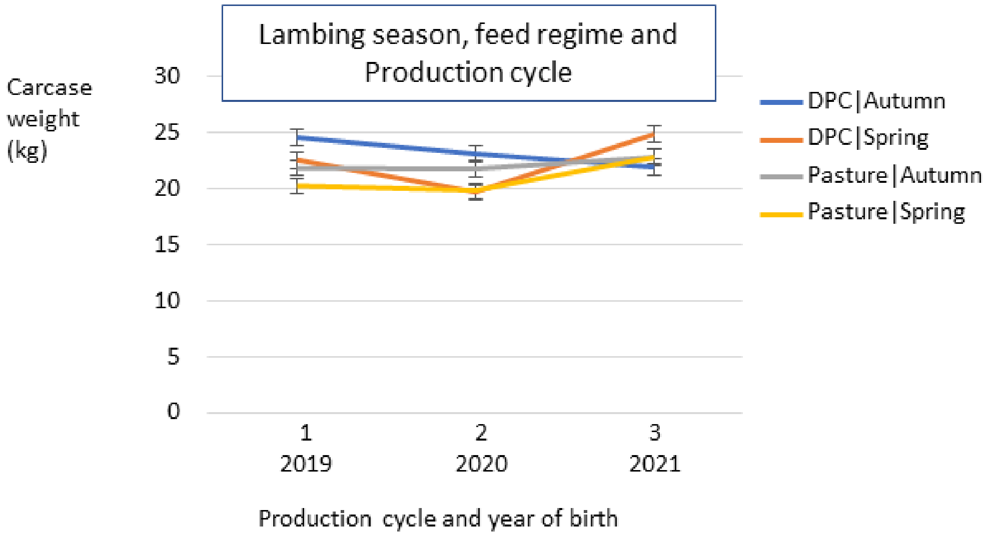


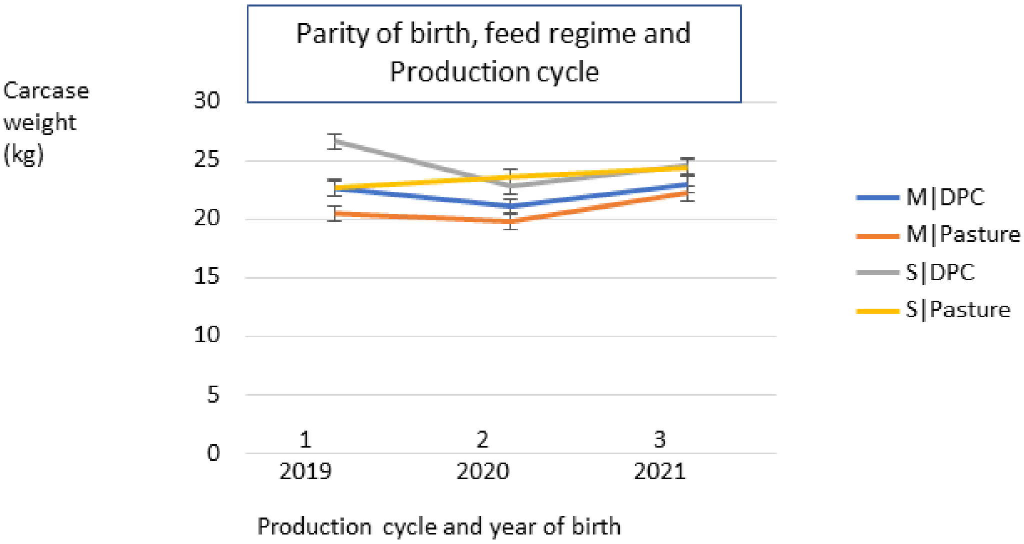



Lambing season and parity of birth
Carcase weight (kg)
30
25
20
15
10
5
0
Spring
Autumn
Spring
Autumn
Multiple
Single

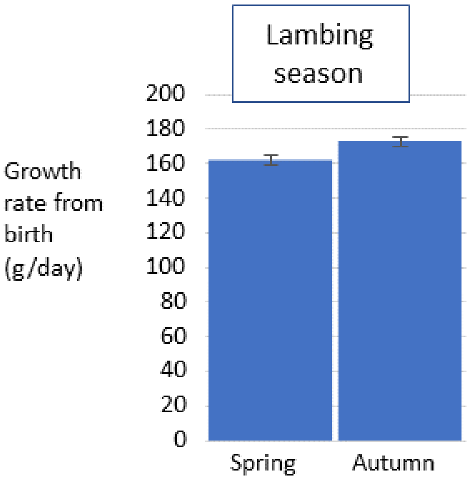

Lambing season and Production cycle
Carcase weight (kg)
30
25
20
15
10
5
0
1
2019
2
2020
3
2021
Production cycle and year of birth
Spring
Autumn

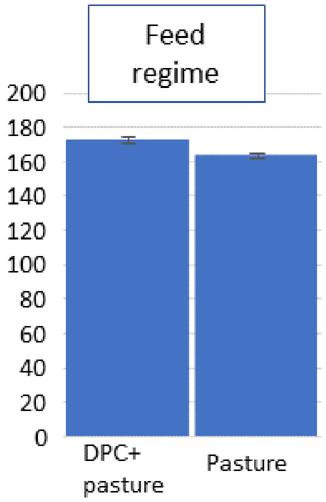

Feed regime and Production cycle
Carcase weight (kg)
30
25
20
15
10
5
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC + pasture
Pasture

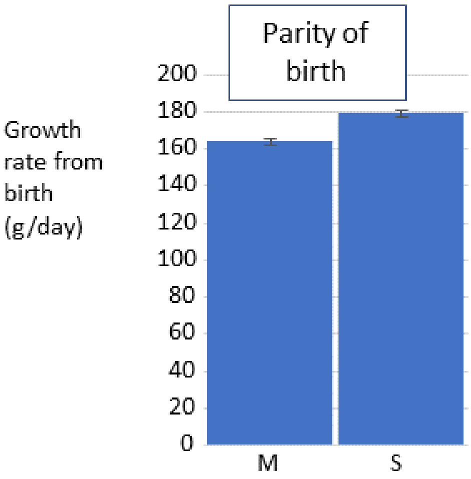

Lambing season, feed regime and Production cycle
Carcase weight (kg)
30
25
20
15
10
5
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC|Autumn
DPC|Spring
Pasture|Autumn
Pasture|Spring

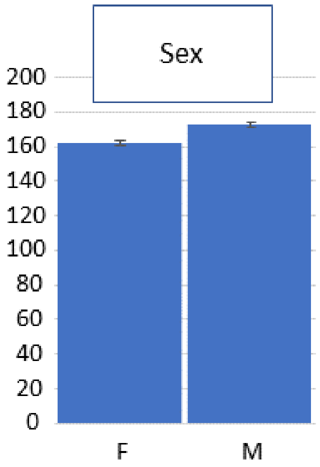

Parity of birth, feed regime and Production cycle
Carcase weight (kg)
30
25
20
15
10
5
0
1 2019
2 2020
3 2021
Production cycle and year of birth
M|DPC
M|Pasture
S|DPC
S|Pasture

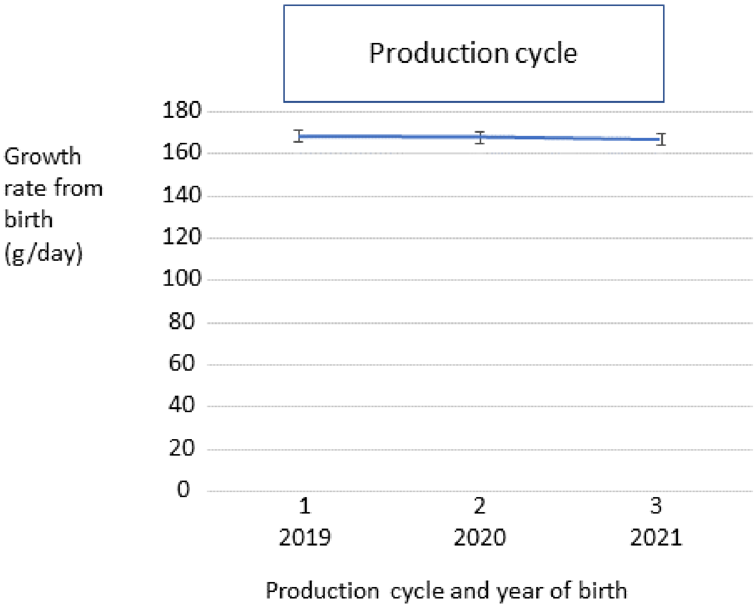
Significant factor effects for Growth Rate from Birth

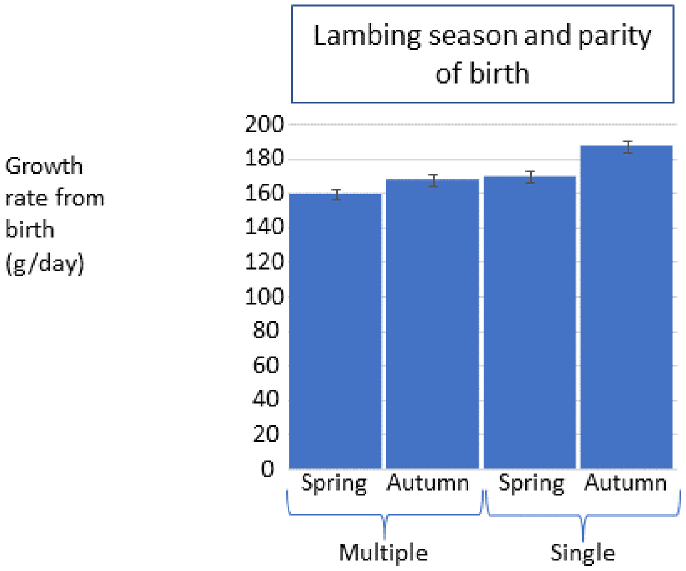


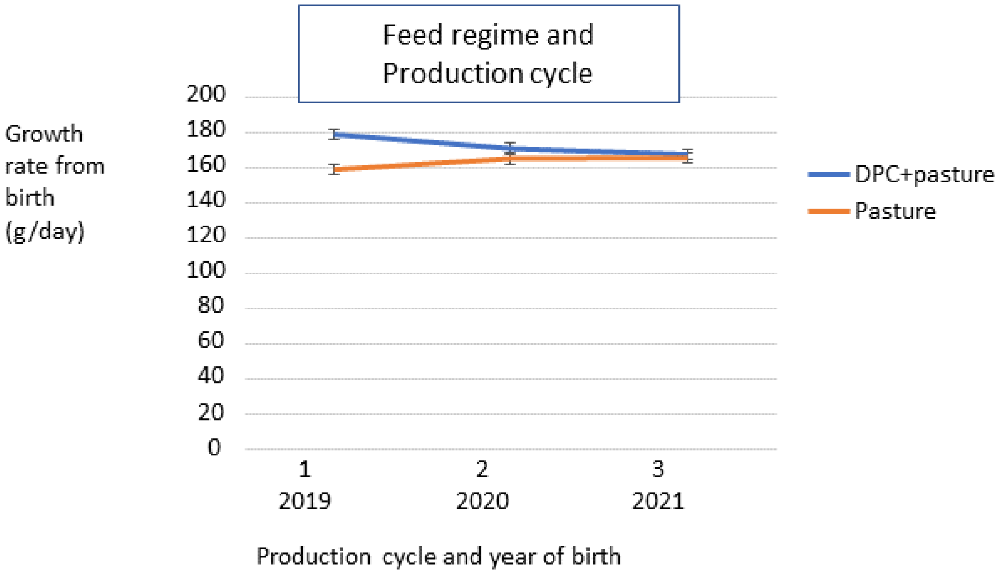


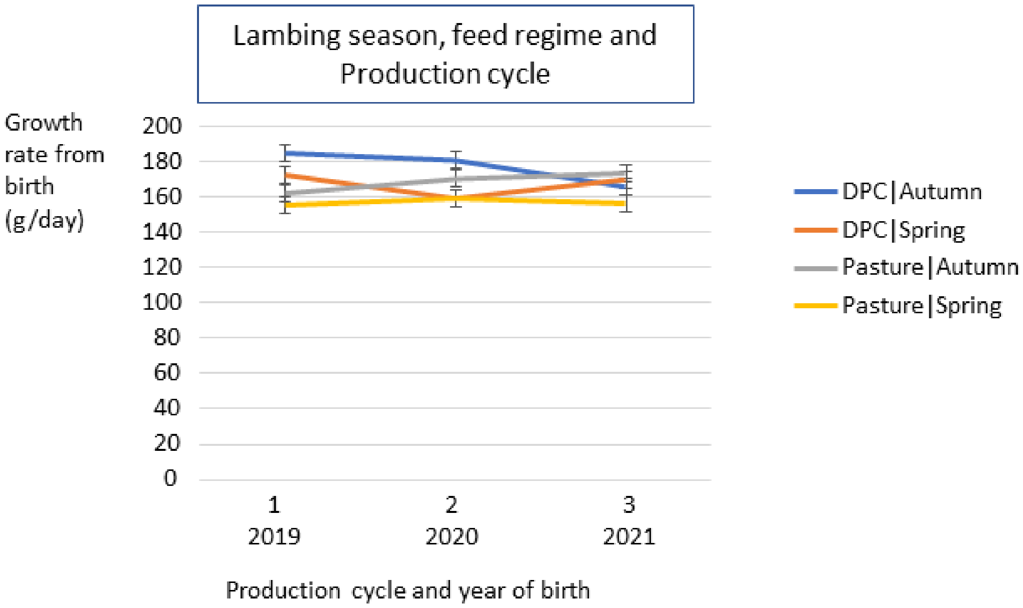




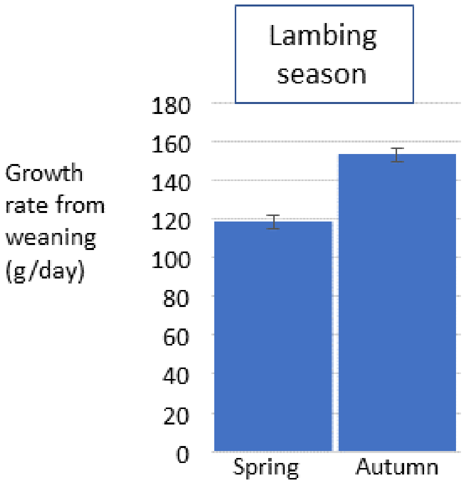


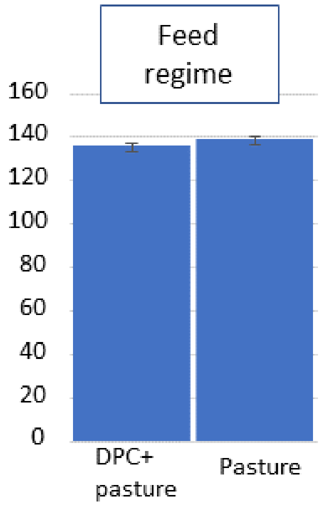

Lambing season and parity of birth
Growth rate from birth (g/day)
200
180
160
140
120
100
80
60
40
20
0
Spring
Autumn
Spring
Autumn
Multiple
Single

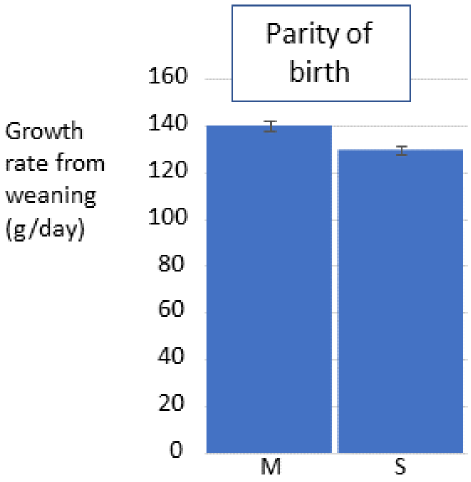

Feed regime and Production cycle
Growth rate from birth (g/day)
200
180
160
140
120
100
80
60
40
20
0
1
2019
2
2020
3
2021
Production cycle and year of birth
DPC+pasture
Pasture

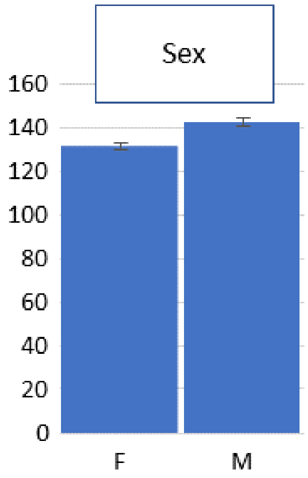

Lambing season, feed regime and Production cycle
Growth rate from birth (g/day)
200
180
160
140
120
100
80
60
40
20
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC|Autumn
DPC|Spring
Pasture|Autumn
Pasture|Spring

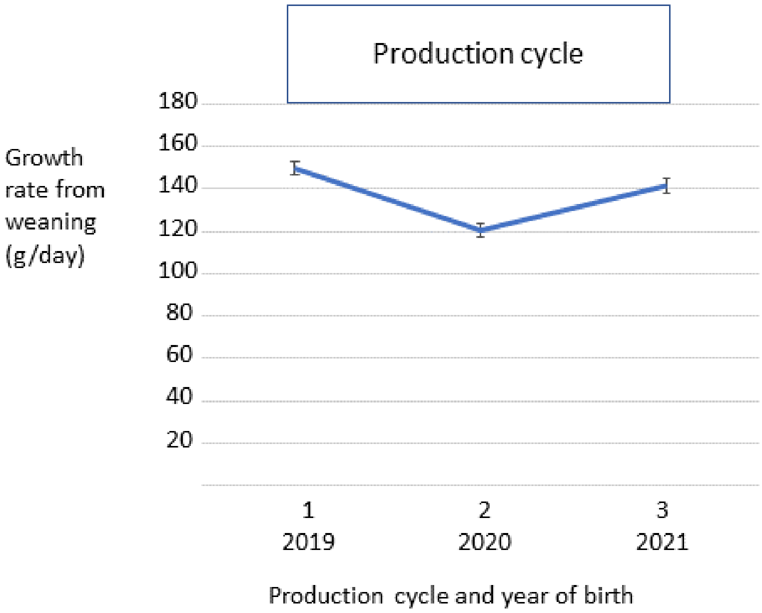
Significant factor effects for Growth Rate from Weaning

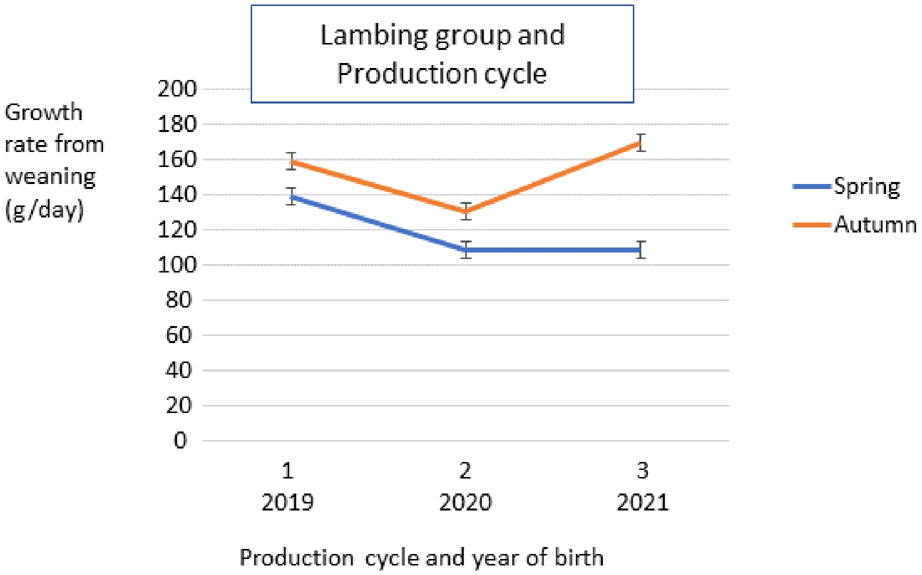


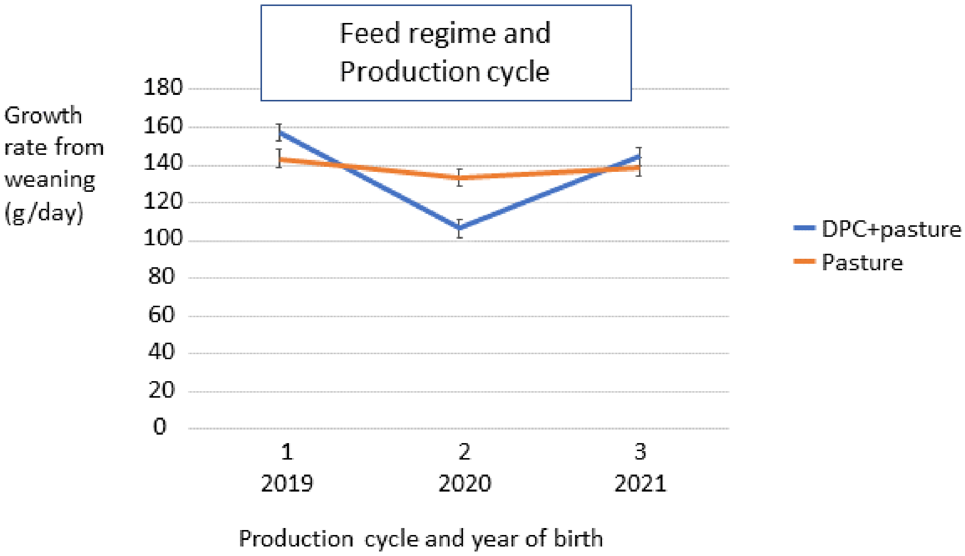


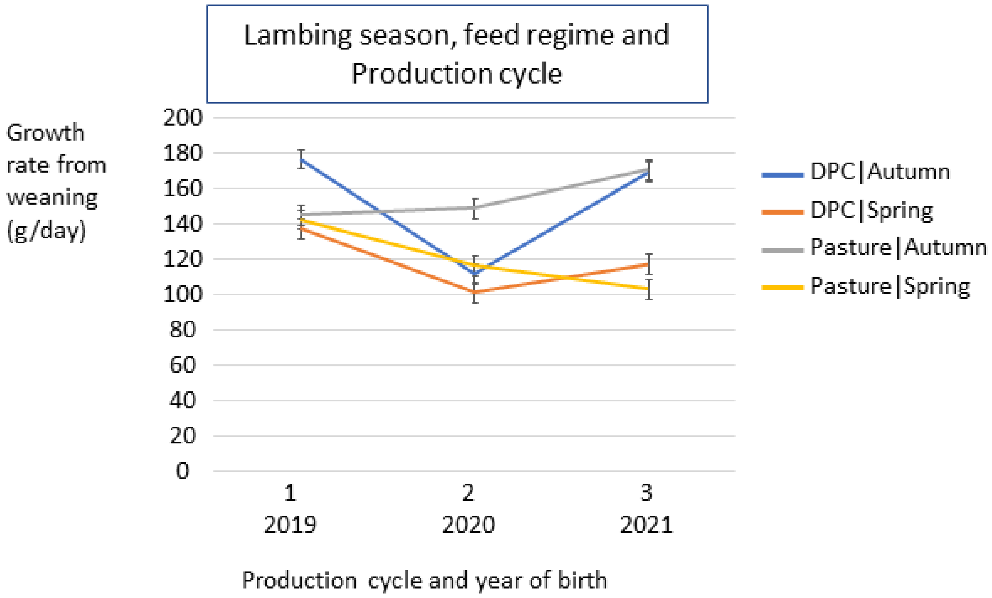


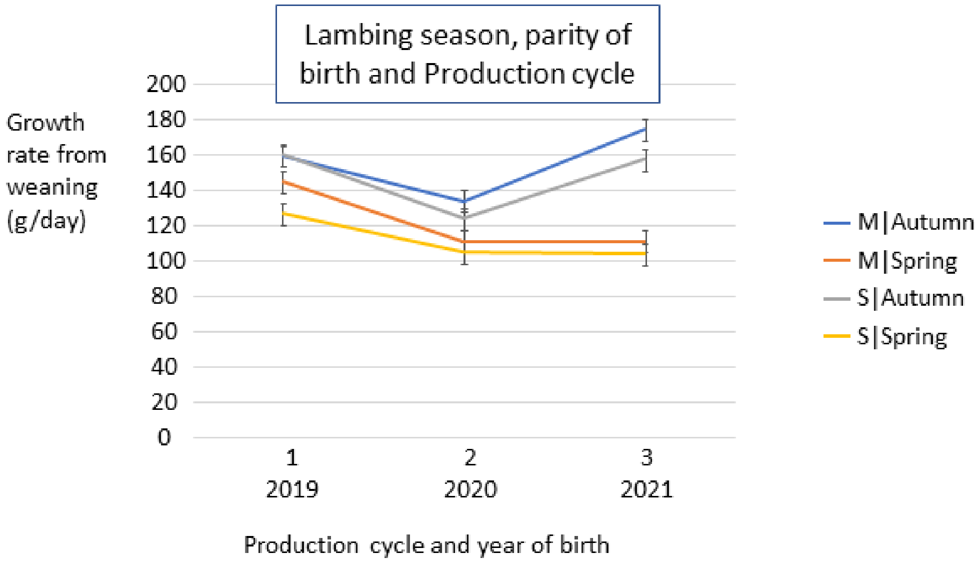




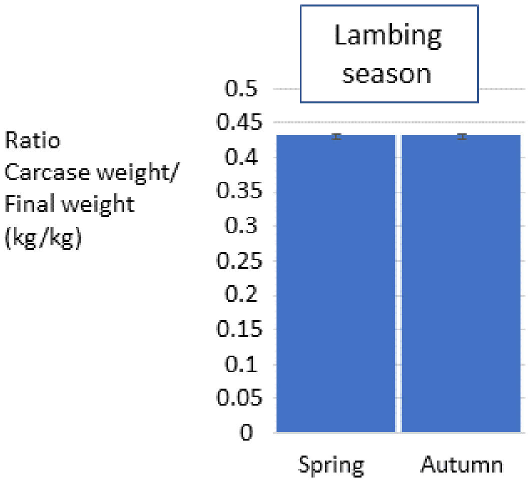

Lambing group and Production cycle
Growth rate from weaning (g/day)
200
180
160
140
120
100
80
60
40
20
0
1 2019
2 2020
3 2021
Production cycle and year of birth
Spring
Autumn

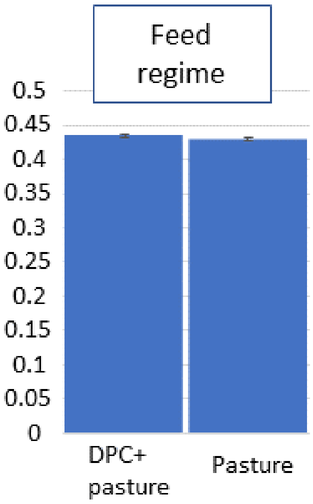

Feed regime and Production cycle
Growth rate from weaning (g/day)
180
160
140
120
100
80
60
40
20
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC+pasture
Pasture

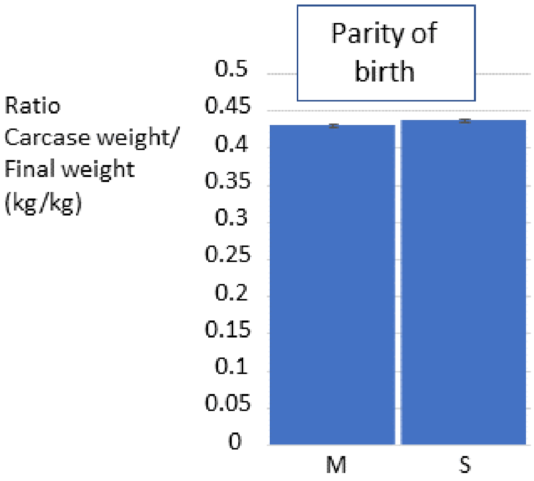

Lambing season, feed regime and Production cycle
Growth rate from weaning (g/day)
200
180
160
140
120
100
80
60
40
20
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC|Autumn
DPC|Spring
Pasture|Autumn
Pasture|Spring


Lambing season, parity of birth and Production cycle
Growth rate from weaning (g/day)
200
180
160
140
120
100
80
60
40
20
0
1 2019
2 2020
3 2021
Production cycle and year of birth
M|Autumn
M|Spring
S|Autumn
S|Spring

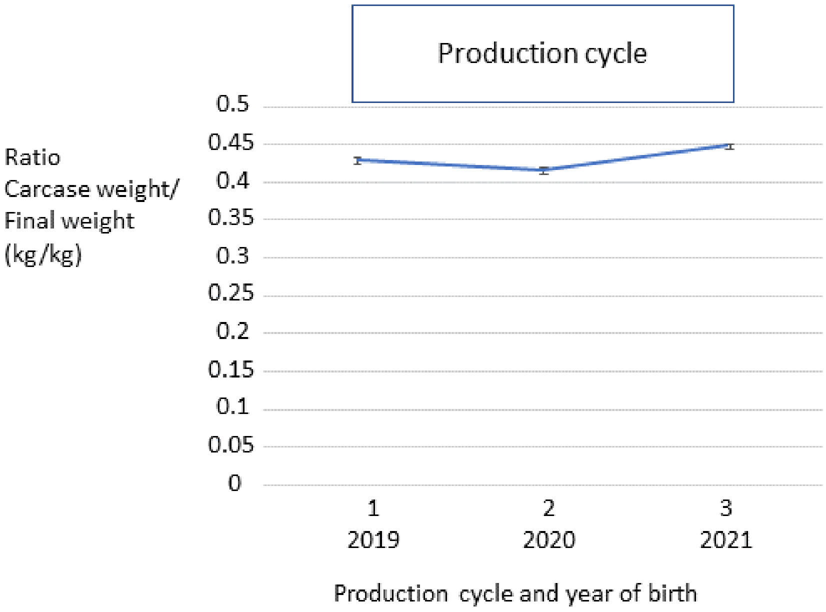
Significant factor effects for Ratio of carcase weight to final weight

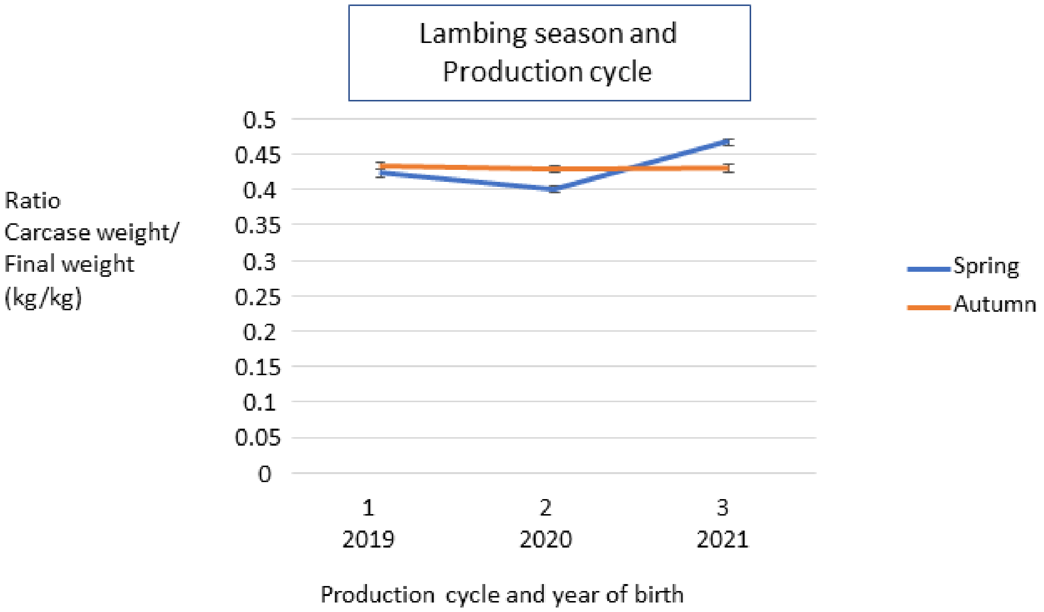


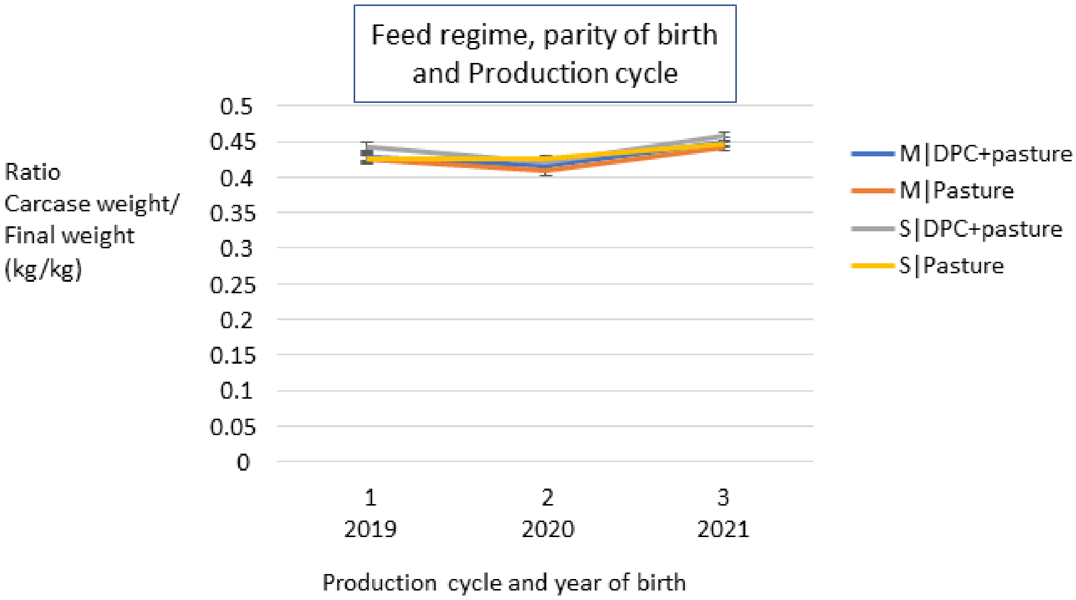




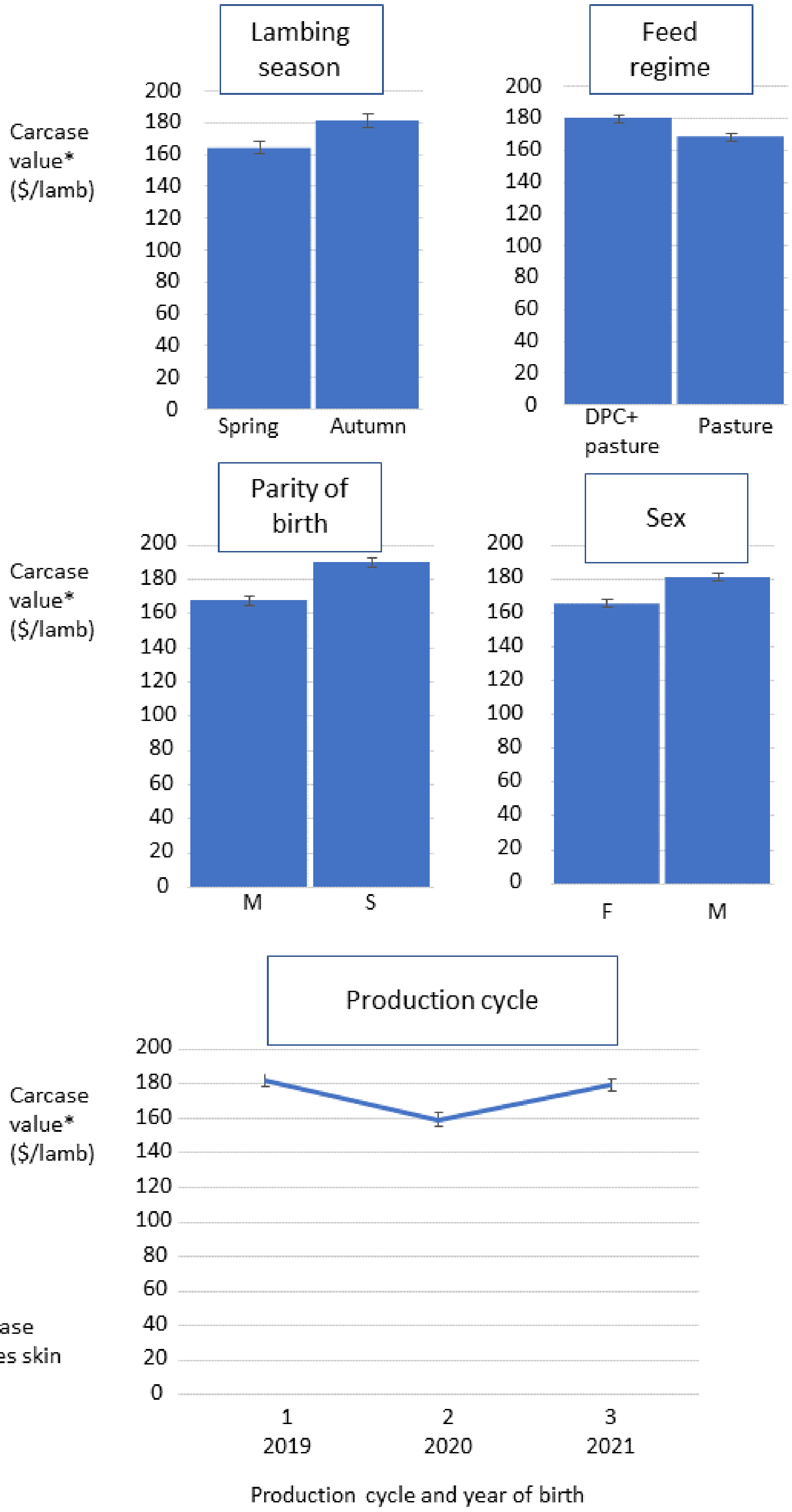
Sex
Not sig



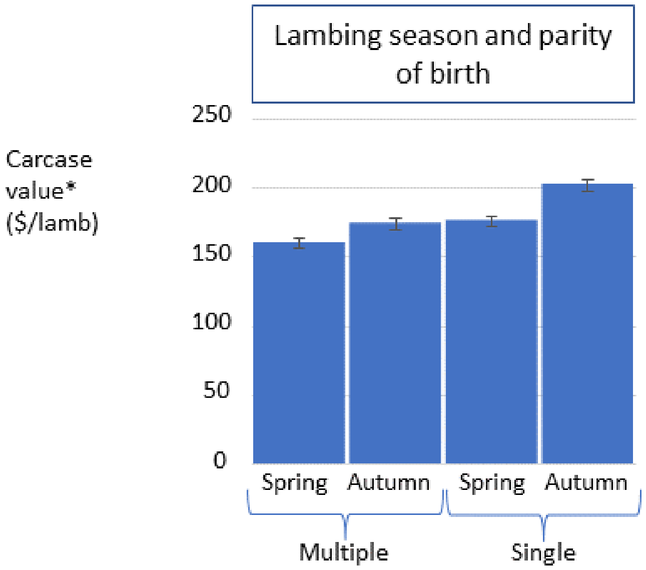

Lambing season and Production cycle
Ratio Carcase weight/ Final weight (kg/kg)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2019
2 2020
3 2021
Production cycle and year of birth
Spring
Autumn

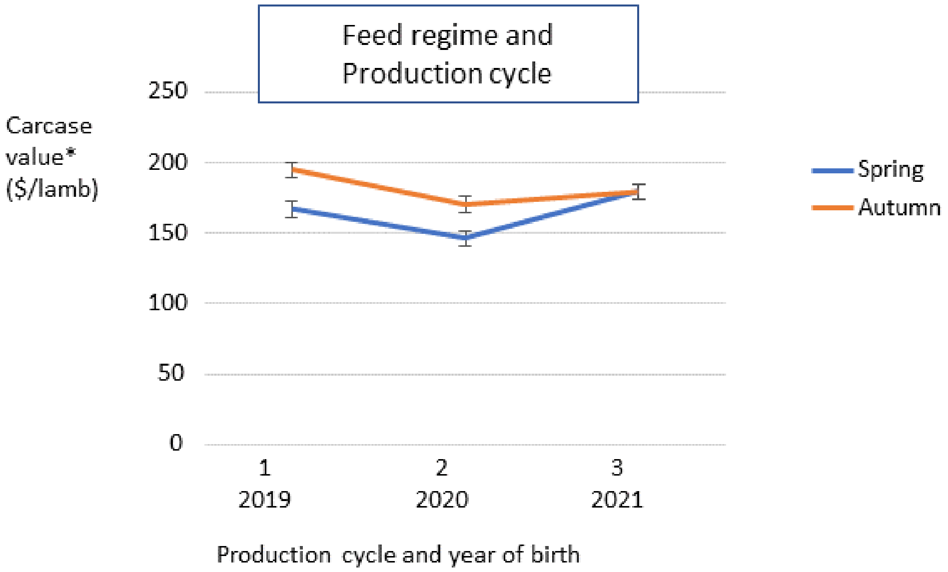

Feed regime, parity of birth and Production cycle
Ratio Carcase weight/ Final weight (kg/kg)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2019
2 2020
3 2021
Production cycle and year of birth
M|DPC+pasture
M|Pasture
S|DPC+pasture
S|Pasture

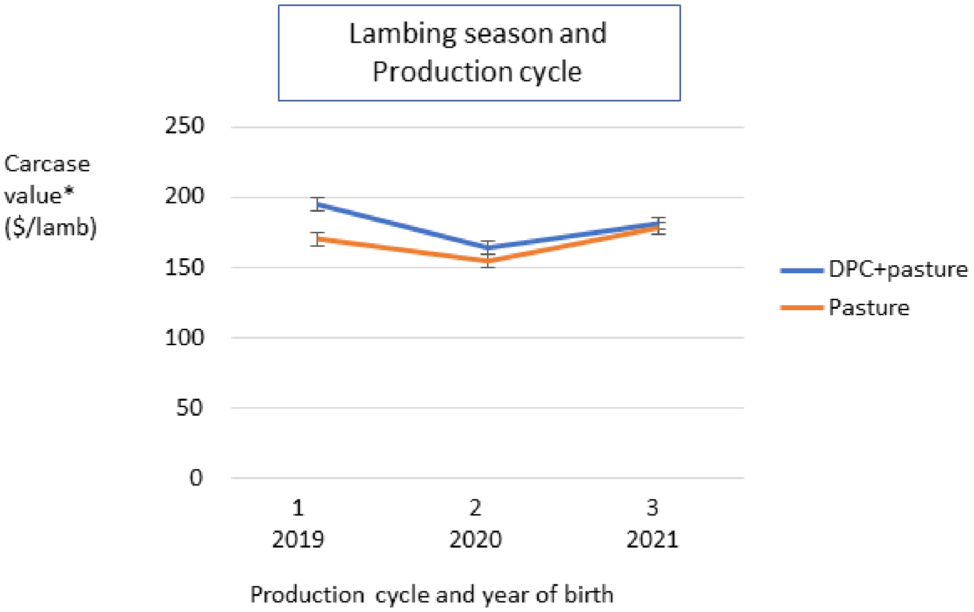
Significant factor effects for Carcase Value

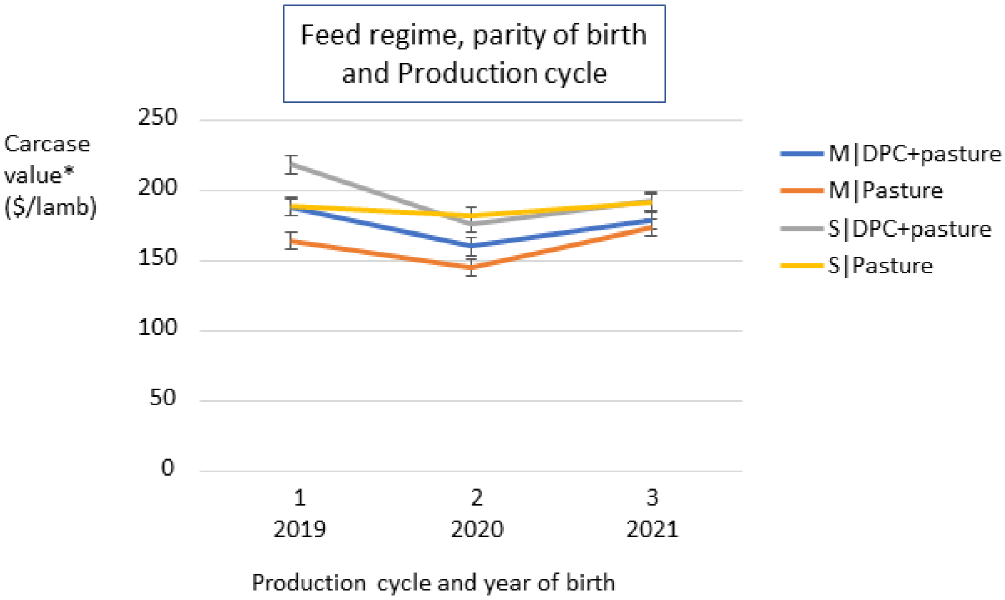


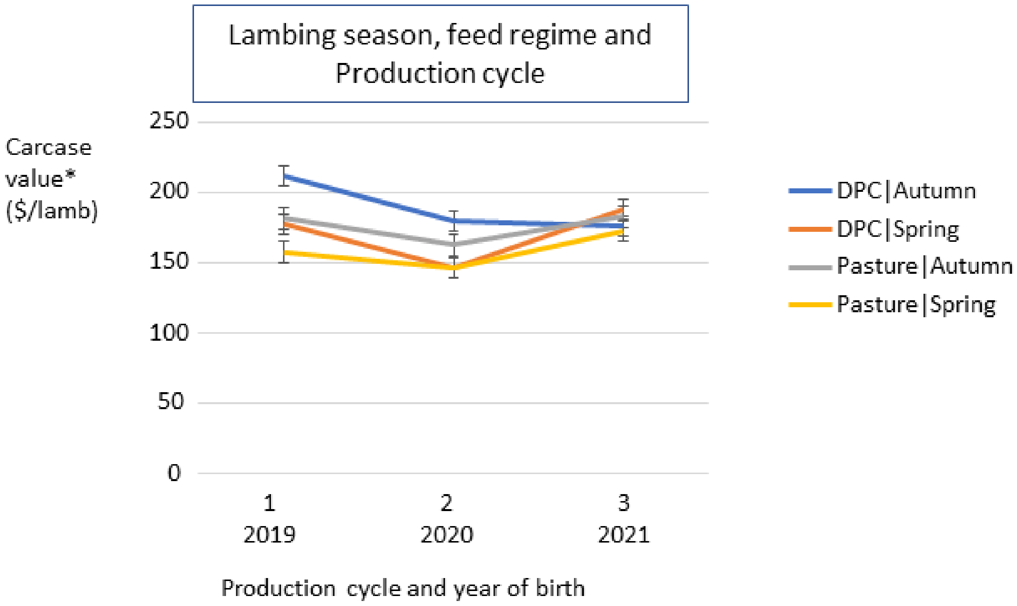
* Mean carcase value includes skin value


Lambing season and parity of birth
Carcase value* ($/lamb)
250
200
150
100
50
0
Spring
Autumn
Spring
Autumn
Multiple
Single


Feed regime and Production cycle
Carcase value* ($/lamb)
250
200
150
100
50
0
1
2019
2
2020
3
2021
Production cycle and year of birth
Spring
Autumn


Lambing season and Production cycle
Carcase value* ($/lamb)
250
200
150
100
50
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC+pasture
Pasture


Feed regime, parity of birth and Production cycle
Carcase value* ($/lamb)
250
200
150
100
50
0
1 2019
2 2020
3 2021
Production cycle and year of birth
M|DPC+pasture
M|Pasture
S|DPC+pasture
S|Pasture


Lambing season, feed regime and Production cycle
Carcase value* ($/lamb)
250
200
150
100
50
0
1 2019
2 2020
3 2021
Production cycle and year of birth
DPC|Autumn
DPC|Spring
Pasture|Autumn
Pasture|Spring