MODELLING THE EFFECT ON STOCKING RATE AND LAMB PRODUCTION OF ALLOWING EWES TO GRAZE A DUAL-PURPOSE WHEAT CROP.

S. R. McGrath[A,B,C,E], J. M. Virgona[B,D] and M. A. Friend[A,B,C]

[A]School of Animal and Veterinary Sciences, Charles Sturt University, PO Box 588, Wagga Wagga, NSW 2678, Australia.

[B]Graham Centre for Agricultural Innovation, Locked Bag 588, Wagga Wagga, NSW 2678, Australia.

[C]Future Farm Industries CRC, University of Western Australia, Crawley, WA 6009, Australia.

[D]Present address: Graminus Consulting Pty Ltd, 1 Heron Place, Wagga Wagga, NSW 2650, Australia.

[E]Corresponding author. Email: shmcgrath@csu.edu.au

Slow pasture growth rates during winter limit the potential gross margins from autumn and early winter lambing in southern New South Wales (NSW) by limiting stocking rates and/or increasing supplementary feed requirements. Dual-purpose crops can reduce the winter feed gap in mixed-farming systems by increasing the available feed in winter. The simulation software AusFarm was used to model a mixed-farming system at Wagga Wagga with Merino ewes joined to terminal sires and grazing lucerne-subterranean clover pasture over a 41-year period. A paddock of dualpurpose wheat was then added to the system, and ewes were allowed to graze the wheat crop when feed on offer reached 850 kg DM/ha and before GS31. Weaned lambs were sold after late August if lamb growth rates fell below 20 g/head.day, mean lamb weight reached 45 kg or production feeding of lambs was required. Lambing in June resulted in the highest median gross margin whether or not ewes were able to graze the wheat crop during winter. Grazing of a dual-purpose wheat crop resulted in greater proportional increases in gross margins as stocking rate was increased, increased lamb production and reduced supplementary feeding costs, and reduced interannual variability in gross margin returns.

INTRODUCTION

A range of lambing times are used across Australia and at a local level (Croker et al. 2009; McGrath et al. 2013). Lambing in spring in southern Australia generally allows the period of maximum demand of the ewe-lamb unit to be met by pasture, whereas lambing in autumn requires additional supplementary feeding to meet demands during winter when pasture growth rates are slow (Shallow 1996). Importantly, lambing in spring may allow higher stocking rates than autumn lambing (Trengove 1990) and stocking rate is a key driver of profitability (Warn et al. 2006). Despite this recommendation many producers continue to lamb in autumn (Croker et al. 2009). One reason for this, particularly in a meat-production system, is the opportunity for lambs to grow out to meet market requirements (Reeve and Sharkey 1980; Freer et al. 1994; Sackett and Francis 2006). Carrying capacity is affected by growing season length (Saul and Kearney 2002) and the optimal lambing time, in terms of gross margins, will depend on factors such as the length of the growing season and the sale policy used (Warn et al. 2006; Robertson et al. 2014, this issue).

Dual-purpose crops such as wheat (Triticum aestivum) are now an important part of the feedbase in mixed-farming systems in southern New South Wales (NSW; McMullen and Virgona 2009; McGrath et al. 2013) and can increase livestock production during the winter compared with lucerne (Virgona et al. 2008). Rather than replacing an area of sown pasture in mixed-farming systems, dual-purpose crops can increase the feed quantity available if a portion of the spring wheat is replaced by a dualpurpose wheat that is sown earlier and grazed during the winter (McMullen and Virgona 2009). The opportunity cost is therefore any reduction in grain yield from grazing the dual-purpose crop compared with the ungrazed spring wheat.

This modelling study sought to identify whether the time of lambing resulting in highest median gross margin was altered in southern NSW when ewes were able to graze a dual-purpose wheat crop sown in April. In this model, grazing of crops was considered opportunistic given that, if a spring wheat had been sown instead of a dual-purpose wheat, this area would not be available to graze; the ewe stocking rate was therefore calculated based on the area of pasture and excluding the cropped area. A lucerne-based pasture was modelled, being a widely used pasture in mixed-farming systems in the area, and with advantages for both nitrogen fixation and livestock production (Humphries 2012). A flexible selling system with no production feeding, where lambs could be grown out to heavier weights if seasonal conditions allowed, was modelled.

MATERIALS AND METHODS

Simulation modelling was conducted using AusFarm® version 1.4.7 (www.grazplan.csiro.au/, verified 10 July 2014), which allows the GRAZPLAN and APSIM models to simulate grazing and cropping systems, and included crop grazing (Moore et al. 2007; Moore 2009). The model was run using weather data for Wagga Wagga, NSW (GRAZPLAN weather database; 35100S, 147270E) from 1 January 1965 to 31 December 2011, with analysis of lamb birth and weaning data for calendar years 1970–2010, and gross margin, supplement feeding and lamb sales data for financial years ending July 1971–2011.Variables used were date of commencement of lambing in monthly increments from April to August and stocking rates of 6, 8 and 10 ewes/ha of permanent pasture. Separate simulations were run for whether or not sheep were allowed to graze the wheat crop.

Farm

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

An additional 350-ha paddock was added to the system in which a dual-purpose wheat crop was sown annually. The size of the wheat paddock provided a stocking rate when grazing crop similar to the average in producer surveys in the district and in local field experiments (McGrath et al. 2013; McGrath et al. 2014). Dual-purpose wheat (cultivar EGA Wedgetail) was sown each year during April following a cumulative rainfall total of 25mm over a 5-day period, or on 30 April if these conditions had not occurred. Wheat was sown at row spacing 17.5 cm and depth 25 mm with plant establishment density of 120 plants/m2.

Sheep flock

The livestock enterprise was a medium Merino ewe flock (breed standard reference weight 50 kg; breed reference fleece weight 4.5 kg) joined to Dorset rams (breed reference weight 55 kg) using a ram ratio of 0.01 and a 44-day joining period. Ewes were culled annually after shearing (before joining) at 6 years of age. Replacement ewes (age 19 months) were purchased annually on the day after cast-for-age ewes were sold to maintain flock size at the target stocking rate. Lambs were weaned at median age 12 weeks. Ewes and weaned lambs grazed crop concurrently if the conditions for crop grazing were met; otherwise ewes and weaned lambs grazed separate pasture paddocks until lambs were sold.

Grazing and supplementary feeding rules

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

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

Commodity and input prices

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

Selling rules

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

Analyses

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

Results

Pasture growth rates of lucerne and subterranean clover pastures were compared with those reported by Hall et al. (1985) at Wagga Wagga for the period 1975–1977 and considered acceptable. Pasture growth rates tended to peak in the spring, the lucerne component was able to respond to rainfall and soil moisture in the summer and autumn, and winter was typified by low pasture growth rates. Mean daily growth rates for wheat in the crop grazing model (July lambing flock at 8 ewes/ha) were 16, 22 and 15 kg DM/ha.day for June, July and August, respectively, which is lower than some other suggested growth rates (Anonymous 2008). The growth rate of ungrazed wheat in 2004 was 75 kg DM/ha.day in the model, compared with 71 kg DM/ha.day reported by Virgona et al. (2006) for a site north of Holbrook during the same period and with the same cultivar. The mean day that grazing of crops commenced was 30 June (median 9 July) in years when crop grazing occurred, and no crop grazing occurred in 1983 and 2007. The mean number of days grazing crop ranged between 49 and 50 days, except for April and May lambing at a stocking rate of 10 ewes/ha where crop grazing days averaged 44 days.

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

The amount of grain fed increased at higher stocking rates and was reduced with later lambing months and when ewes were able to graze the wheat crop; the proportion of years when more than 50 kg was fed per ewe followed a similar trend (Table 1).

The mean number of lambs sold annually increased and the mean sale weight of lambs across years was reduced as stocking rate increased. The increase in amount of lamb produced when crop grazing was permitted was proportionally greater for autumn lambing compared with later lambing at stocking rates of 8 or 10 ewes/ha (Table 1). The proportion of years when mean sale weight of lambs exceeded 39 kg liveweight increased at lower stocking rates and generally increased when crop grazing was permitted, with the effect being greatest for autumn lambing at the higher stocking rates (Table 1). In general, the mean sale date was not changed substantially by the inclusion of crop grazing for a given lambing month and stocking rate combination, although the sale date was slightly earlier for June lambing and slightly later for April and May lambing at higher stocking rates when crop grazing occurred compared with when it did not (Table 1).

The median gross margin was highest when lambing took place in June at a stocking rate of 8 ewes/ha regardless of whether crop was grazed or not (Fig. 1). Optimal stocking rate (in terms of median gross margin) was six ewes/ha for April and May lambing when no crop grazing was permitted, and the median gross margin was similar for six or eight ewes/ha for July and August lambing (Fig. 1a). The optimal stocking rate increased to eight ewes/ha for April and May lambing and 10 ewes/ha for August lambing when grazing crops were included, but did not change for June and July lambing (both 8 ewes/ha; Fig. 1b). The variability in the gross margins increased with stocking rate; however, this effect was reduced by the inclusion of crop grazing (Fig. 1). Varying the sale price of wool or lamb or the cost of supplement by 20% from the standard values affected mean gross margins, but did not have a major impact on the month with the highest mean gross margin (Table 2). Stocking rate at which the highest mean gross margin occurred for a given lambing month was affected by changes in commodity prices for some lambing months.

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

[A]Change in median gross margin when crop grazing included.
[B]From total grain fed.
[C]Proportion of years when amount of grain fed exceeded 50 kg/ewe joined (excluding grain fed to lambs).
[D]Proportion of years when mean lamb sale weight exceeded 39 kg/head.

Table 1. Effect on median gross margin, grain feeding and lamb production of varying lambing month, stocking rate and access to dual-purpose wheat grazing. Data are mean of 41 years

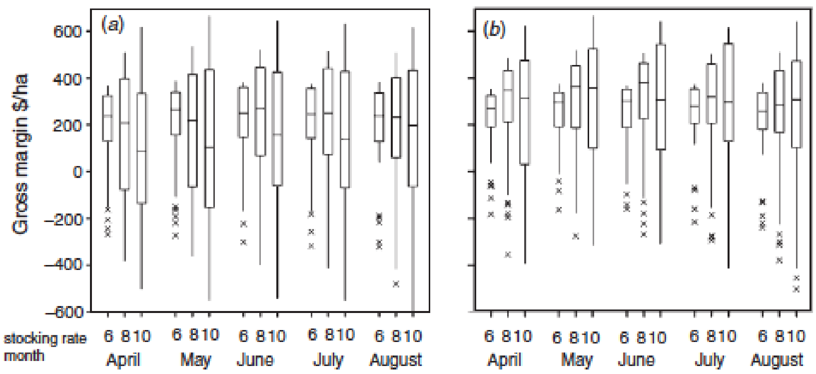

Fig. 1. Effect of lambing month on variation in gross margin (1971–2011) at stocking rates of 6, 8 and 10 ewes/ha for lambing months commencing April to August when (a) no grazing of dual-purpose wheat occurred, and (b) when ewes were able to graze the dual-purpose wheat crop. The box represents interquartile range with the median marked by the central line; whiskers show range of data, with outliers marked if exceeding 1.5 times the interquartile range beyond the quartiles (·).

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

Table 2. Highest mean gross margin (AU$) for each lambing month and crop grazing scenario at commodity prices 20% above or below standard rates and stocking rate at which this occurred (parentheses). See text for standard wool, lamb and grain prices used

DISCUSSION

The median gross margin for the first cross lamb enterprise on a lucerne-based pasture was increased by inclusion of dual-purpose wheat in the feedbase and the highest median gross margin was achieved with a June lambing date at eight ewes/ha for the sale policy used. Inclusion of crop grazing increased lamb production, reduced supplementary feeding and increased gross margins across lambing times and stocking rates (Table 1, Fig. 1).

Stocking rate is a key driver of profitability and the key benefit of optimising lambing time is by allowing stocking rates to be increased without an increase in the risk of needing to supplementary feed (Warn et al. 2006). Wool is a key component of the income but was not affected substantially by the lambing date in this model at an equivalent stocking rate, but contributed to the higher gross margins whenstocking rate was increased to levels that maximised the long-term gross margin (data not shown). Increasing stocking rate can increase income from lambs and wool, but may also result in higher supplementary feeding costs and greater year-to-year variation in gross margins (Table 1, Fig. 1), indicating greater risk (Warn et al. 2006). Dual-purpose winter crops such as wheat provide additional feed for livestock during the period when pasture growth rates can constrain production, and this model demonstrated that inclusion of dual-purpose wheat in the feedbase reduced risk by reducing supplementary feeding costs and interannual variability in income at a given stocking rate, allowing stocking rates to be increased for some lambing months. Inclusion of crop grazing affected lamb production as stocking rate increased; for April and May lambing, increasing stocking rate had a large impact on lamb production when crop grazing occurred compared with when it did not (Table 1). In comparison, crop grazing had little impact on the proportional change in lamb production with stocking rate for later lambing, although lamb production increased with stocking rate.

Given the lower price for lambs <18 kg carcass weight, there may be an advantage for lambing in months that allow turn-off of heavier lambs providing this does not reduce the number of ewes that can be run or greatly increase the cost of supplementary feeding. In the current model, lambing in June had lower supplementary feeding costs than April and May lambing, and a higher proportion of years where lambs achieved at least 39 kg liveweight at sale compared with July or August lambing (Table 1). This resulted in the highest median gross margin with inclusion of grazing crops occurring with June lambing. Increasing or decreasing the commodity prices did affect mean gross margins and stocking rate at which the highest mean gross margin occurred, with the highest mean gross margins occurring with May or June lambing across the different scenarios (Table 2). The sale policy used had the advantage of allowing lambs to be retained until they reached a target weight if pasture quality and availability allowed; however, the lambing month that optimised gross margins may change with sale policy (Robertson et al. 2014, this issue).

Lucerne is noted for its complementarity with other species by providing feed at different times of the year (Humphries 2012). Low pasture growth rates and, on occasion, digestibility of lucerne during the winter, resulted in high supplementary feeding costs during the winter in some years in the current model. A lucerne feedbase may therefore be a good fit with dual purpose cropping; conversely, the current model may overestimate the advantage of grazing the dual-purpose crop that would be achieved if other species with superior winter growth and quality are available for grazing by sheep. Further modelling with other pastures in combination or as an alternative to lucerne may be informative for producers considering the use of dual-purpose crops.

No gross margin for the cropping enterprise was included in the analysis. This enabled a more simplistic model to be used without requiring crop rotations and enabled us to demonstrate the benefits of allowing a crop to be grazed. Grazing of crops can negatively impact grain yields, although the effect can be minimised by good management, in particular the removal of livestock before Growth Stage 31, and in some circumstances grazing can increase grain yields compared with ungrazed crops (Virgona et al. 2006; Harrison et al. 2011). Modelling across regions in southern Australia suggested lower grain yields from dual-purpose wheat relative to spring wheat in the order of 3–17% (Moore 2009). Given only relatively small increases (<20%) in median gross margins were achieved at stocking rates of 6 ewes/ha in our model when crop grazing was permitted (Table 1), it may be considered riskier to graze crops if stocking rates are not increased. In contrast, the large increase in gross margins at higher stocking rates when utilising the crop for grazing would likely improve overall gross margins even if a small reduction in grain yield was incurred. For example, if June-lambing ewes stocked at eight ewes/ha are allowed to graze crop, the median gross margin increases by AU$112/ha for the sheep enterprise, or an additional AU$44 800. Assuming a net grain price of AU$250/MT and base yield of 3 MT/ha, any yield reduction less than 17% due to grazing would result in a profitable outcome. Further modelling considering grain yields of spring wheat cultivars compared with grazed dual-purpose cultivars at different sites will assist to determine the relative benefits over the long term. Additional inputs such as nitrogen applications to assist crop recovery post-grazing would also need to be considered when analysing the financial impact for the farm overall.

CONCLUSIONS

Allowing ewes access to some of the dual-purpose wheat sown on a mixed farm can increase gross margins from the sheep operation by increasing stocking rates and the amount of lamb and wool produced and reducing supplementary feeding requirements. Whether allowing ewes to graze a dual-purpose crop improves the farm economic performance depends on the effect on grain yield, along with the lambing time and stocking rate used.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of Neville Herrmann, Eric Zurcher and Andrew Moore (CSIRO) and Susan Robertson (CSU) for advice with setting up the model, and the financial contributions of Meat and Livestock Australia, Australian Wool Education Trust, NSW Rural Assistance Authority and Future Farm Industries CR

REFERENCES

Anonymous (2008) Grazing winter cereals in high rainfall regions. Available at http://lwa.gov.au/files/products/grain-and-graze/pn20685h/pn20685h. pdf [Verified 23 February 2012]

Croker K, Curtis K, Speijers J (2009) Times of lambing in Australian flocks – 2005 to 2007. Wool Desk Report – February 2009. Available at http:// www.agric.wa.gov.au/objtwr/imported_assets/content/aap/sl/wool/wool_ desk_report_no.10.pdf [Verified 5 November 2012]

Freer M, Donnelly JR, Axelsen A, Dove H, Fowler DG (1994) Prime lamb production in relation to time of mating. Australian Journal of Experimental Agriculture 34, 1–12. doi:10.1071/EA9940001

Hall DG, Wolfe EC, Cullis BR (1985) Performance of breeding ewes on lucerne–subterranean clover pastures. Australian Journal of Experimental Agriculture 25, 758–765. doi:10.1071/EA9850758 Harrison MT, Evans JR, Dove H, Moore AD (2011) Dual-purpose cereals: can the relative influences of management and environment on crop recovery and grain yield be dissected? Crop and Pasture Science 62, 930–946. doi:10.1071/CP11066

Humphries AW (2012) Future applications of lucerne for efficient livestock production in southern Australia. Crop and Pasture Science 63, 909–917. doi:10.1071/CP12140

McGrath SR, Lievaart JJ, Friend MA (2013) Extent of utilisation of dualpurpose wheat for grazing by late-pregnant and lambing ewes and producer-reported incidence of health issues in southern New South Wales. Australian Veterinary Journal 91, 432–436.

McGrath SR, Bhanugopan MS, Dove H, Clayton EH, Virgona JM, Friend MA (2014) Mineral supplementation of lambing ewes grazing dualpurpose wheat. Animal Production Science. doi:10.1071/AN13179

McMullen KG, Virgona JM (2009) Dry matter production and grain yield from grazed wheat in southern New South Wales. Animal Production Science 49, 769–776. doi:10.1071/AN09055

Moore AD (2009) Opportunities and trade-offs in dual-purpose cereals across the southern Australian mixed-farming zone: a modelling study. Animal Production Science 49, 759–768. doi:10.1071/AN09006

Moore AD, Holzworth DP, Herrmann NI, Huth NI, Robertson MJ (2007) The common modelling protocol: a hierarchical framework for simulation of agricultural and environmental systems. Agricultural Systems 95, 37–48. doi:10.1016/j.agsy.2007.03.006

Reeve J, Sharkey M (1980) Effect of stocking rate, time of lambing and inclusion of lucerne on prime lamb production in north-eastern Victoria. Australian Journal of Experimental Agriculture 20, 637–653. doi:10.1071/EA9800637

Robertson SM, Southwell A, Friend MA (2014) Modelling the risk of different lambing times and lamb sale policies. Animal Production Science 54, in press.

Sackett D, Francis J (2006) Integration of wool, meat and cropping systems. In ‘Proceedings of the 2006 Australian sheep industry CRC conference’, Orange, NSW, 16 February 2012. (Eds PB Cronje, D Maxwell) pp. 204–209. (Sheep CRC) Available at http://www.sheepcrc.org.au/files/pages/articles/wool-meets-meat–2006-conference-papers–enterpriseplanning/Integration_of_wool_meat_and_cropping_systems.pdf [Verified 16 February 2012]

Saul G, Kearney G (2002) Potential carrying capacity of grazed pastures. Wool Technology and Sheep Breeding 50, 492–498.

Shallow M (1996) Key issues that affect returns from merinos. Wool Technology and Sheep Breeding 44, 204–209.

Trengove CL (1990) ‘Opportunities for improvement in sheep and beef cattle production in the south east of South Australia.’ (Australian Society of Animal Production)

Virgona JM, Gummer FAJ, Angus JF (2006) Effects of grazing on wheat growth, yield, development, water use, and nitrogen use. Australian Journal of Agricultural Research 57, 1307–1319. doi:10.1071/AR06085

Virgona J, Martin P, Van der Rijt V, McMullen G (2008) Grazing systems for winter cereals. In ‘Global issues. Paddock action. Proceedings of the 14th Australian agronomy conference’, Adelaide, SA, 21–25 September 2008. (Ed. M Unkovich) Available at http://www.regional. org.au/au/asa/2008/plenary/cropping-livestock-systems/5669_virgonajm. htm#TopOfPage [Verified 13 November 2012]

Warn L, Webb Ware J, Salmon L, Donnelly J, Alcock D (2006) Analysis of the profitability of sheep wool and meat enterprises in southern Australia. Report to the Australian Sheep IndustryCRC,final report for project 1.2.6. Available at http://www.sheepcrc.org.au/files/pages/articles/analysis-ofthe-profitability-of-sheep-wool-and-meat-enterprises-in-southern-australia 2006/Analysis_of_Profitability_of_sheepmeat_and_wool.pdf [Verified 16 February 2012]

Zadoks JC, Chang TT, Konzak CF (1974) A decimal code for the growth stages of cereals. Weed Research 14, 415–421. doi:10.1111/j.1365- 3180.1974.tb01084.x