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The value of genetic fatness in Merino ewes differs with production system and environment

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Abstract. Selection against fatness in the Australian sheep industry has been a priority, but defining the true value of fat requires an understanding of the effects it has on both the value of lamb carcasses and on sheep productivity. A Merino flock with 10 years of reproduction data was used to analyse the correlation between breeding values for fatness at yearling age (YFAT) and the number of lambs born per ewe mated (NLB). In 2 production years, NLB was related ($P < 0.01$) to YFAT resulting in an extra 14 or 24.5 lambs born per 100 ewes mated per mm of YFAT. Based on these relationships, bio-economic modelling was used to assess the whole-farm value of YFAT for different sheep production systems and for years representing a low, medium and high response of NLB to YFAT. The changes in whole-farm profitability for a 1-mm increase in YFAT varied from $1000 (2%) for a wool enterprise with a low response up to $44 000 (25%) for a lamb enterprise with a high response. Appropriate carcass value discounts for higher YFAT were investigated but were not evident because of the small change in GR fat depth associated with the range of YFAT investigated. In most years there is no impact of YFAT on NLB and therefore profitability, yet in years where Merino ewes with higher YFAT produce higher NLB, ewes with an extra 1 mm of YFAT will be up to 25% more profitable. Therefore, care is required in determining the appropriate selection pressure to be placed on YFAT in Merino selection.

Introduction

The amount of fat stored in all fat depots in sheep can be changed in a desired direction by selection for subcutaneous fat depth (Kadim *et al*. 1989; Hegarty *et al*. 2006; Hopkins *et al*. 2007). However, determining the correct approach to selection of fatness in Australian Merino sheep is complex. Defining the true value of fat requires an understanding of the effect it has on the value of lamb carcasses as well as its effects on the productivity of the sheep production system in different environments. Reducing the fatness of lamb to improve its consumer appeal has been a priority in the Australian sheep industry (Russell *et al*. 2005; Pethick *et al*. 2006). This trend towards leaner lambs is reflected in the price grids offered by lamb processors: discounts are often applied to lambs that are too fat. However, because of the processing efficiencies and eating qualities associated with an optimum level of fat, discounts also apply to lambs that are too lean. Therefore, to maximise lamb carcass value, producers must deliver lambs that are neither too lean nor too fat. From a genetic perspective, this has resulted in a general focus on selection for less fat in Australian sheep breeds (Fogarty 2009) to improve carcass value, processing efficiency and consumer appeal of lamb.

Fat not only has potential effects on the carcass value of animals but fat accumulation is the key mechanism by which all mammals store energy (Pond 1992). Fat is stored during favourable times and then mobilised to provide energy for fundamental functions when requirements exceed supply, such as during periods of limited nutrition or during late pregnancy and lactation (Pethick *et al*. 2005). Fat also plays an essential role in the reproductive process and sufficient fat reserves are necessary for animals to ovulate and successfully reproduce (Friggens 2003). This association has been demonstrated in sheep as a positive correlation between fatness and fertility (Gunn *et al*. 1969). Therefore, selection against fatness could compromise an animal's ability to reproduce. The negative effects of selection against fatness on reproductive capacity may exceed the potential value of improved carcass value in breeds that are used as the maternal base for lamb production. The analysis reported in this paper tests the hypothesis that in some production years or environments, selection against fatness in the Merino will

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result in lower farm profitability because of negative effects on reproduction.

Materials and methods

Analyses of maternal effects of genetic fatness

In this study, we used information collected by Merinotech (WA) Pty Ltd from their nucleus flock based at 'Yarrak' near Kojonup in south-west WA. Some of the data were reported previously (Ferguson *et al*. 2007). A total of 4845 records from 10 production years (2000–09) were analysed. The analysis included ewes aged between 2 and 9 years. Ewes were mated in February–March and lambed in July–August. Ewes were pregnancy scanned by ultrasound after mating. The number of fetuses present in pregnant ewes was recorded and confirmed by closely monitoring ewes at lambing and recording the number of lambs born (NLB).

The ewes had both full pedigree and Australian sheep breeding values (ASBV) for yearling fat depth (YFAT) measured by ultrasound over the eye muscle (*M. longissimus lumborum*) on the 12th rib, 45 mm from the midline (C site). The YFAT values used in this analysis were generated in a MERINOSELECT run on 21 November 2009. The range of YFAT in the dataset was –1.4 to 2.0 mm. For the purposes of analysis, ewes aged greater than 6 years were combined with the 6-year-old group because of small numbers in these age groups. The variate NLB was defined as ewes that did not get pregnant (0), ewes that gave birth to one lamb (1) and ewes that gave birth to multiple lambs (2). NLB was analysed for the effect of ewe YFAT using a generalised linear model with a multinomial distribution and logit link function and adjusted for ewe age and year. All analyses were conducted using GENSTAT 11.1 software (VSN International 2008) and second-order interactions were included in the original models and removed if non-significant.

Valuing lamb carcasses and the effect of fatness

Lamb value was based on a lamb of 42 kg liveweight with a carcass weight of 19.5 kg. Effects of YFAT on dressing percentage were considered but because the correlation was not consistent or strong, it was not included in this study. However, YFAT did have an effect on GR tissue depth (total tissue depth over the 12th rib 110 mm from the midline) and this effect was considered. The GR tissue depth was estimated from a combination of carcass weight (0.79 mm GR tissue depth per kg carcass weight) and YFAT (0.53 mm GR tissue depth per 1 mm YFAT) based on correlations derived from the Information Nucleus Flock dataset for lambs born in 2007 (Gardner *et al*. 2010). This resulted in lambs with 9.9–10.5 mm of tissue at the GR site across the range of YFAT analysed in this study (–0.5 to +0.5 mm). These GR values are well within the range of 5–15 mm, which is the range for which lamb value is maximal on most lamb price grids. Based on this analysis, all lambs were assigned the same carcass value across the range of YFAT ASBV.

Analyses of whole-farm value of fatness

A modelling approach was used to analyse the potential value of changes to YFAT across a whole farm. Three YFAT values were modelled (–0.5, 0 and +0.5 mm). The analysis used the Hamilton EverGraze MIDAS bio-economic model (Young *et al*. 2004) of a 1000-ha farm sown to perennial ryegrass-based pastures that were moderately productive. MIDAS is an optimising model that can efficiently examine the effects of altering the management of a flock. It includes a powerful feed budgeting module that accounts for the changes in the energy requirement of the flock when production potential is altered and it optimises animal and pasture management across the whole farm.

The analysis was based on a Merino genotype that had the capacity to produce both meat and wool (described by Thompson and Young 2002). Three production systems were compared: (i) Wool – a self-replacing Merino flock in which surplus ewes are sold as hoggets and all wethers are sold as store lambs off shears in March; (ii) Self-replacing – a Merino flock in which surplus ewe hoggets are mated to terminal sires; and (iii) Lamb – a prime lamb-producing flock in which replacement Merino ewes are bought and all ewes are mated to a terminal sire. The correlations between YFAT and NLB identified in the Merinotech WA dataset were used to assess the whole-farm value of YFAT. As the correlations between YFAT and NLB differed between production years (Table 1), the analyses were undertaken using correlations between YFAT and NLB from three separate production years representing low, medium and high responses of NLB to YFAT. The 3 years used in modelling were selected to demonstrate the large fluctuation in the impact of YFAT on profit. Two of the 3 years selected were those when a significant positive impact of YFAT on NLB occurred.

The MIDAS model was calibrated so that the proportion of dry, single- and twin-bearing ewes was equal to the level achieved in the datasets from each of these 3 years. Survival of single- (92%) and twin-born lambs (76%) was not altered and was based on birthweight. The ewe fleece weight and wool fibre diameter varied depending on the proportion of pregnant and lactating ewes with singles and twins. Lambing time was in August–September and shearing in March for all systems tested. Within the analysis, cull-for-age ewes were valued at $45. In the lamb production systems, lambs were sold at 42 kg

Table 1. Number of ewes mated, mean Australian sheep breeding value for yearling fat depth (YFAT) of those ewes, the number of lambs born (NLB) per 100 ewes mated at YFAT of 0 mm and the regression coefficients between NLB and YFAT across 10 production years

*, significant regression ($P < 0.05$) between YFAT and NLB

Year	Number of ewes	Mean YFAT of ewes (mm)	NLB/100 ewes at 0 mm YFAT	NLB/100 ewes/mm YFAT
2000	436	0.2	134	–2.0
2001	433	0.2	139	14.5*
2002	456	0.2	130	–4.5
2003	464	0.2	136	4.4
2004	468	0.2	130	–1.6
2005	489	0.2	138	2.8
2006	517	0.3	129	9.2
2007	538	0.3	134	2.7
2008	516	0.3	125	4.7
2009	528	0.3	110	24.5*

liveweight and 19.5 kg carcass weight and valued at $67 or $3.44 per kg carcass weight. In the Wool production system, wethers were sold at 50 kg and valued at $62.

The model identified the optimum stocking rate, supplementary grain feeding and flock structure and the maximum profit for a 1000-ha farm for each of the YFAT scenarios (–0.5, 0 and 0.5 mm), animal production systems (Wool, Self-replacing and Lamb) and years (low, medium and high correlation between YFAT and NLB). The level of discount on carcass value that would be needed to outweigh the positive influence of YFAT on reproduction was calculated by dividing the change in profit by the weight of lamb carcass sold in each scenario.

Rainfall and pasture growth data

Monthly rainfall data was acquired from the Bureau of Meteorology for the closest weather station to the property (weather station number 010582, Kojonup, WA) and summed to calculate an annual rainfall in the season preceding mating. The rainfall that had fallen in the summer preceding mating (November–February) was also calculated due to its negative impacts on feed quality over summer. In addition, for each of the study years the annual production of pasture DM was estimated for the property by 'Pastures from Space' using historical satellite images of the farm (Edirisinghe *et al*. 2000).

Results

The average NLB across all fat levels differed between years as a result of seasonal fluctuations (Table 1). The NLB per ewe mated was related ($P < 0.01$) to YFAT in 2001 and 2009 and the slope of the relationship differed ($P < 0.01$) between years. The effect of YFAT on NLB ranged from –4.5 to +24.5 lambs born per 100 ewes mated per mm YFAT (Table 1).

There was considerable variation in the amount of rain that fell in the 12 months preceding the mating period for each year. Total production of pasture reflected these differences in rainfall (Table 2). Summer rainfall also varied considerably between years.

Table 2. Annual rainfall and 'Pastures from Space' predicted total pasture production in the year preceding the mating period and summer rainfall (November–February) in the summer preceding the mating period for each of the 10 years

Year	Summer rainfall (mm)	Total rainfall in previous year (mm)	Pasture production in previous year (kg DM/ha)
2000	153	493	8362
2001	15	349	6154
2002	108	393	7616
2003	39	417	8890
2004	57	508	9284
2005	42	378	5986
2006	67	597	9388
2007	32	326	4322
2008	45	502	6997
2009	117	511	7385

The optimum management system for the Wool, Self-replacing and Lamb systems for the base scenario of 0 mm YFAT is presented in Table 3. At standard wool and sheep prices, the Lamb system was $45/ha more profitable than the Self-replacing system and $110/ha more profitable than the Wool system ($170 versus $125 versus $60/ha, respectively). The wool income was similar across all three systems but sale sheep income was substantially higher from the Lamb and Self-replacing systems than the Wool system because of a slightly higher stocking rate and a greater percentage of ewes in the flock.

The analysis of the effects of YFAT on whole-farm profit via changes in NLB revealed that increasing NLB is more valuable for a flock producing more prime lambs and greater income from sheep sales than a flock focussed on wool production. The increase in profit for a farm with a genotype with +0.5 mm for YFAT compared with a farm with an equivalent genotype but with –0.5 mm for YFAT ranges from $1000 for a wool enterprise with a low response up to $44 000 for a lamb enterprise with a high response (Table 4).

The amount that could be sacrificed in lamb carcass value to achieve the increase in reproductive rate and maintain

Table 3. Production and management parameters for a 1000-ha farm across the three sheep production systems for the scenario of 0 mm yearling fat depth and a medium response year (2001)

Parameter	Unit	Wool	Self-replacing	Lamb
Farm profit	$/ha	60	125	170
Number of ewes	–	4200	4950	6000
Stocking rate	DSE/WG ha[A]	8.3	8.7	9.1
Supplementary feeding	kg/DSE	23	32	57
Percentage of ewes in flock	%	76	86	100
Pasture growth	t/ha.year	7.1	7.2	7.2
Pasture utilisation	%	41	41	43
Wool income	$/ha	206	206	211
Sale sheep income	$/ha	144	239	350

[A]Dry sheep equivalent per winter-grazed hectare.

Table 4. Change in farm profit from altering the Australian sheep breeding value (ASBV) for yearling fat depth (YFAT) across three production years for Wool, Self-replacing and Lamb production systems

Year	YFAT ASBV (mm) –0.5	0	+0.5
	Wool		
2001	–2920	0	3729
2005	–689	0	346
2009	–6495	0	6585
	Self-replacing		
2001	–9046	0	15 440
2005	–2543	0	1286
2009	–19 379	0	21 563
	Lamb		
2001	–11 206	0	13 620
2005	–2942	0	1474
2009	–22 915	0	21 241

profitability was dependent on the production system and the increase in reproduction achieved by increases in YFAT (Table 5). For the 2001 scenario, in which there was a medium relationship between NLB and YFAT, a reduction in carcass value of \$0.09 or \$0.19/kg for the Lamb flock and the Self-replacing flock would negate the value of the higher reproductive rate resulting from increasing YFAT by 0.5 mm. These discounts equate to ~2.6 and 5.5%, respectively.

Discussion

Sheep flocks based on Merino ewes with higher YFAT breeding values produced more lambs than those based on leaner ewes in 2 out of 10 years. In the other 8 years, the relationship between YFAT and NLB was not significant. We therefore accept our hypothesis that YFAT will only affect NLB under some scenarios. The regression coefficients between YFAT and NLB were used to model the impact of YFAT on whole-farm profitability under scenarios where YFAT was correlated with NLB. The modelling showed that under scenarios where there is a large positive influence of YFAT on NLB, a 1-mm increase in YFAT would result in an increase in farm profit of up to 25% (\$44 000). The size of the difference in profitability differed considerably with the sensitivity of the response of NLB to YFAT. The scale of the difference in profitability associated with YFAT also changed considerably with the production system with a much larger impact on profit in lamb focussed than wool production systems. It is important to note that these increases in profitability were calculated based on a lamb price of \$3.44/kg carcass; the effects of YFAT on farm profit are considerably greater (up to 75% increase in farm profit) if prices of \$5.00/kg carcass are used (J. Young, unpubl. data). This study shows that in most years there is no impact of YFAT on NLB, yet in years where Merino ewes with higher YFAT produce higher NLB, high YFAT ewes will be up to 25% more profitable.

The positive correlation between YFAT and NLB in 2 out of 10 years is an important finding for the Australian sheep industry that has potential ramifications for breeding decisions. The strong correlations in 2001 and 2009 resulted in 15–25 extra lambs born per 100 ewes mates per mm YFAT. However, these positive correlations are contrary to the negative genetic and phenotypic correlations between fat and reproduction traits in merinos reported by Safari *et al*. (2008). In addition, selection for increased fatness resulted in lower conception rates and lower NLB in Coopworth sheep (McEwan *et al.* 2001). However, in that study the increase in fatness was associated with a reduction in mature ewe size, which may be the causative mechanism. In light of the findings of the present work, the differences in nutritional environments between studies may contribute to contrasting findings. In support of these findings Gernand *et al*. (2008) found a positive genetic correlation between fat depth and reproduction when nutrition at mating was restricted, yet found a negative correlation between fat and reproduction when ewes were mated under favourable conditions. Importantly, a preliminary analysis of almost 44 000 records from Merino ewes within the national MERINOSELECT database (Brown *et al*. 2007) showed a positive regression coefficient across all years between YFAT and NLB similar to but slightly greater than that in 2001 in our study (M. Ferguson, unpubl. data). The positive correlation between fatness and reproduction is supported by studies on pigs in which improvements in litter size resulted in higher levels of ultrasound-measured back fat and carcass fat and associated reductions in carcass lean content compared with an unselected control line (Estany *et al*. 2002*a*, 2002*b*). Divergent selection lines for fatness in mice also resulted in higher fecundity as a result of higher ovulation rate and neonatal survival in a fat line compared with a lean line (Hastings *et al*. 1991). The contrasting effect of fatness on reproduction between years in this study and the difference between this study and others means that care is required in determining the appropriate selection pressure to be placed on YFAT in Merino selection programs.

The economic analysis shows that increasing reproductive rate is more valuable for flocks producing more prime lambs that have greater income from sheep sales. This finding is supported by Warn *et al*. (2006) and Young *et al*. (2010), who also showed a greater value of improving reproductive rate in flocks focussed more on lamb than wool production per hectare. The increase in farm profit in lamb-focussed flocks is realised through higher prices for sale stock as well as the ability to sell sheep at a younger age and to reduce stocking rate over the summer–autumn period. The value of YFAT is therefore greater in flocks that are focussed on lamb production than those that are focussed on wool production.

The differences in the responses of NLB to YFAT between production years and the difference between our findings and those of Safari *et al*. (2008) requires further investigation because of the potentially large differences in whole-farm profitability associated with them. As the correlations were based on an analysis of a historical dataset, it is difficult to define causative mechanisms to the differences in responses between years. Anecdotally, it is known that there was very little high-quality paddock feed in the summer–autumn period leading up to the 2009 mating as a result of 117 mm of summer rainfall. This year had the lowest average reproductive rate and was associated with the highest regression coefficient between NLB and YFAT. However, the other year where the correlation between NLB and YFAT was significant, there was the highest average reproductive rate and very little summer rainfall. However, in that year annual rainfall and total pasture production in the year preceding mating was lower than average. Therefore, historical pasture production and rainfall data was not helpful in identifying a common theme between the sensitivity of the relationship between YFAT and NLB and ewe nutritional environment. Ewe nutritional environment would have been

Table 5. Change in lamb carcass value (\$/kg) that would erode the benefits of increased reproductive rate associated with altering yearling fat depth Australian sheep breeding value of ewes by 0.5 mm

n.a., not applicable

	Breakeven change in carcass value (\$/kg)		
	2001	2005	2009
Wool	n.a.	n.a.	n.a.
Lamb	0.09	0.02	0.20
Self-replacing	0.19	0.03	0.77

strongly impacted on by the level of supplementary feeding and the availability of cereal or pulse stubbles, however this information is not available for this dataset. It is important to further understand the scenarios that result in a strong response of NLB to YFAT in the future. It is possible that the higher responses were the result of poorer nutritional environments in those years. If that is the case, selection for higher fatness (up to a threshold) in low nutritional environments could be advocated to enhance reproduction, whereas in better environments selection to maintain or reduce fatness may be a preferred option.

There was no effect of YFAT on carcass value in the scenarios examined in this study. The positive effect of YFAT on GR fat depth was not significantly strong to change carcass value at the carcass weight used in this study. In other circumstances or with improvements in payment methods for lean meat yield, YFAT may change carcass value and therefore affect whole-farm profit. Further analysis of profit values calculated in this study shows that a price discount of \$0.02–\$0.77 per kg of carcass weight for each 0.5 mm increase in YFAT would need to be applied to erode the benefits found in reproduction, depending on the scenario examined. This equates to a discount of between \$0.08 and \$2.90 per kg of carcass weight for each 1-mm increase in GR fat depth on the carcass, compared with the typical discount of between \$0.02 and \$0.10 per kg for each mm of GR fat that is currently applied by processors. Although YFAT did not affect carcass value in the scenarios examined here, different methods of valuing carcasses may result in penalties for high YFAT animals. Such discounts would need to be large to counteract the positive effect of YFAT on whole-farm profit in scenarios where YFAT and reproduction are positively correlated.

The definition of the whole-farm value of selection traits depends on the means by which they are calculated. In this study, we used a whole-farm systems approach to define the value of YFAT because of the complexity of accommodating the energy requirement changes that occur whenever a trait affects reproductive potential. Importantly, the MIDAS whole-farm systems model accounts for the change in energy requirements of ewes that are dry, pregnant with singles or twins or lactating with singles or twins. The model also accounts for the change in ewe wool production and fibre diameter that results from pregnancy and lactation with different numbers of progeny, including ewes that bore a lamb that died soon after birth. Furthermore, the model accounts for the lower wool production and higher fibre diameter of retained ewes born and raised as twins. These various complexities result in a whole-farm value for YFAT that has taken into account the less obvious costs of enhanced reproduction.

The present analysis only includes the effect of YFAT on reproduction and carcass value. It does not consider potential differences in physiology and metabolism that may be associated with a higher level of fatness. Importantly, the analysis did not take into account potential differences in ewe resilience associated with changes in YFAT. Preliminary modelling by the authors has shown that if YFAT affects ewe resilience and feed requirements over the summer period, then the differences in profitability between high and low YFAT animals will be much greater than those reported in the current study. Further work is required to define associations between YFAT and other ASBV and ewe resilience to nutritional stress.

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