Modelling the effect of more lambs, faster growth and heavier carcasses on feed conversion efficiency and seasonality of demand

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Abstract

Feed conversion efficiency (FCE) and seasonality of feed demand were assessed within a demand-driven deterministic steady-state model of a sheep livestock system. Weekly animal feed demands were simulated within Excel™. Overall flock structure and seasonality of demand were then determined using linear programming. Key inputs were individual animal energy requirements (MJME) for maintenance, pregnancy, lactation and growth. Whole-of-system FCE was measured as grams of meat carcass per MJME. Overall system output was constrained by a fixed but arbitrary system limit of 10 million MJME. Increasing the lambing percentage from 110% to 170% increased FCE by 20%, with less total system feed required during the pregnancy period but with more feed required post-weaning. Increasing pre-weaning liveweight gain from 250 g/day to 450 g/day increased FCE by only 1%, but with a transfer of feed demand from post-weaning to pre-weaning. Increasing post-weaning liveweight gain from 100 g/day to 300 g/day increased FCE by 8% with earlier slaughter reducing overall post-weaning requirements. Increasing carcass weight from 12 kg to 24 kg increased FCE by 28%, with a major shift in feed demand from pre-weaning to post-weaning. Implications for improving pastoral sheep farm productivity and profitability are discussed.

Keywords: feed conversion efficiency; feed demand; sheep systems; lambing percentage; liveweight gain; carcass weight; linear programming

Introduction

The Red Meat Sector Strategy Report, commissioned by Beef and Lamb New Zealand and the Meat Industry Association of New Zealand, identified improved farm output per hectare as a major opportunity for improved profitability within the red meat sector (Deloitte 2011). This increase in output can come from increased feed production, or from more efficient use of feed by more productive animals, or from a combination thereof. In this paper, our focus is on animal-production parameters which affect the biological efficiency with which a fixed amount of feed energy is converted to carcass meat.

Given the pastoral nature of New Zealand sheep farming and the associated seasonality of feed supply, livestock strategies that improve feed conversion efficiency (FCE) also need to be evaluated in terms of feed demand seasonality. This requires a whole-of-system analytical framework. However, such analyses are inherently complex. Accordingly, while previous studies in New Zealand and elsewhere have evaluated biological efficiency of alternative animal performance levels and alternative livestock strategies (for example Large 1970; Spedding 1981; Geenty 1995; Cruickshank et al. 2008), these studies have typically focused on a sub-system level of analysis and have ignored some important system interactions. Further, no New Zealand studies have evaluated the interactions between FCE and seasonality of demand.

In this study, we approached these issues by first building a spreadsheet simulation model which calculates feed demand using linear and non-linear (i.e., exponential and logarithmic) biological relationships that link feed demand, animal growth and meat output at the individual animal level. The simulation outputs then become inputs to a linear programming model which provides the framework for determination of overall flock structure, incorporation of component interactions, and assessment of seasonality of demand. It is important to note that the linearity assumption within linear programming (Hillier & Lieberman 2005) means that individual animal requirements are scaled arithmetically to flock levels, but this does not constrain representation of within-animal non-linear biological complexity.

Our purpose in developing the model has been to provide guidance at the level of both individual farms and the overall industry. For individual farmers, the model provides a framework for understanding the impact of individual production parameters on overall animal system FCE, measured as grams of carcass per megajoule of metabolisable energy (g carcass/MJME) and also on seasonality of feed demand. At the industry level, the model provides a framework for system-based analyses (FCE and seasonality of demand) of specific research and development strategies that focus on particular system components.

The model presented here is a generic sheep livestock model which has relevance across all physical environments. However, it cannot provide optimal solutions for specific environments, each of which has its own unique feed supply conditions together with product pricing relationships which will change over time. We are currently developing such a model which can evaluate outcomes for different feed environments and economic conditions. In this paper, we further limit the analyses to four key parameters, these being lambing percentage (lambs tailed per ewe mated), pre-weaning lamb liveweight gain (g/day), post-weaning lamb liveweight gain (g/day) and the target carcass weight of lambs (kg). Other key parameters not presented here because of space constraints include ewe size, hogget lambing percentage, death rates and age of culling.

Materials and methods

To investigate how key parameters of the sheep livestock system impact on whole-of-system FCE and feed demand seasonality, a demand-driven deterministic steady-state enterprise level model of a sheep meat livestock production system was developed in Microsoft Excel™ 2010. Weekly feed demands were simulated in megajoules of metabolisable energy (MJME) for each class of livestock and performance level. Feed demand was expressed in terms of energy because, in pastoral systems, energy is typically the most limiting factor (Freer et al. 2007; Nicol & Brookes 2007). Equations used to calculate individual energy requirements are drawn from the generalised equations adopted by the Australian Standing Committee on Agriculture (Freer et al. 2007; SCA 1990) and are calculated using the factorial approach with total energy requirement being the sum of the MJME required for maintenance, liveweight gain (or loss), pregnancy, and the ewe and lamb lactation requirement.

At the level of the flock, the achieved pre-weaning growth rates are a function of the birth parity proportions (single, twin, triplets), the ages of the ewes (hogget, two-tooth and mature age), and the lamb gender ratio (assumed throughout as 1:1 ratio) (Loureiro et al. 2011; Thomson et al. 2004). Accordingly, and to avoid confusion arising from parameter interactions, input parameters for pre-weaning lamb growth are presented here as the growth of single lambs of mixed gender from mature-age ewes. In the baseline model this is set at 300 g live weight/day. Other categories of lambs grow at fixed proportions in relation to these single lambs from mature age ewes. For example, twin and triplet lambs grow respectively at 0.86 and 0.75 the rate of singles, while lambs from two-tooth ewes and hoggets grow at 0.93 and 0.86 the rate of lambs from mature aged ewes. This means that for any specific situation, there will be an input parameter for the pre-weaning growth rate of single lambs from mature age ewes, and there will be an achieved flock growth rate which will depend not only on this parameter but on other flock parameters relating to flock structure and lambing performance.

Post-weaning growth is assumed to be linear. However, modifiers were used to adjust weekly pre-weaning liveweight gains to account for growth rate changes associated with the stage of lactation (Geenty 1979; Litherland et al. 2000).

The simulation outputs then became inputs to the linear programming analysis using Frontline Systems Solver™, an add-in within Excel™. The objective function was maximisation of total meat carcass (lamb plus ewe mutton). Model outputs included flock structure, weekly and seasonal feed demand, and FCE measured as the grams of meat carcass produced per year per MJME. Lamb and ewe mutton carcass output were measured separately as well as combined. Rather than being linked to an absolute date, feed demand seasonality was calculated relative to ewe mating date and is reported here relative to key time periods within the annual breeding cycle, i.e., pregnancy (weeks 1-21), lactation (weeks 22-33) and post-weaning (weeks 34-52).

The linear programming framework was set up within Excel™ in matrix form according to the framework for modelling livestock enterprises (Dent et al. 1986). However, in contrast with supply driven models where animal numbers and their performance are determined by feed supply, following the approach used by Woodford (1997), total animal numbers and feed demand seasonality are determined endogenously within the model and are model outputs. To bound the model, total system feed demand was arbitrarily constrained to 10 million MJME which, under most New Zealand conditions, approximates the feed supplied from about 100 hectares of pastoral land.

The baseline model

In the baseline model, the livestock system represents a steady-state, self-contained breeding-finishing sheep system. Lambing date is 147 days after the date of mating. All ewes and 50% of hoggets are mated. Weaning occurs 12 weeks after lambing for ewes and 10 weeks after lambing for hoggets. Lambing percentage (lambs tailed per ewe mated) is 125% and hogget lambing (lambs tailed per hogget mated) is 64%, the approximate New Zealand national average for 2013 (Statistics New Zealand 2014). Birth-rank proportions were derived in reference to data from Amer et al. (1999). Lamb survival rates are related to birth rank (Everett-Hincks et al. 2007). For lambs born to mature age (MA) ewes, 90.3% of singles, 88.2% of twins and 85% of triplets survive to weaning. Ewe mortality rates are based on the Poukawa longevity trials (Cruickshank et al. 2008) and increase with ewe age. Ewes are culled cast-for-age after six lambings as a ewe. Rather than being sold at a fixed date, all lambs except ewe lamb replacements are sold when they reach target carcass weight. In the baseline model, this is 18 kg, the 2013 industry average slaughter weight (Beef and Lamb New Zealand Economic Service 2014). Dressing out percentage is related to live weight and sex (Kirton et al. 1984). For mature ewes, live weight at mating date is 65 kg with minimal liveweight fluctuation throughout the year. In the baseline model, the mixed gender pre-weaning lamb liveweight gain of singles lambs from MA ewes is 300 g/day prior to weaning and 200 g/day post-weaning.

Results

For the baseline model, breeding ewes numbered 1,318 at mating date, total meat carcass production was 31,192 kg, with 29% of annual feed demand required during pregnancy (weeks 1-21), 33% required during lactation (weeks 22-33) and 38% required during post-weaning (weeks 34-52). Given that total feed demand was pre-set at 10 million MJME, feed conversion efficiency was 3.12 g of carcass per MJME of feed.

The effect of increasing lambing percentage

When tested against the baseline model, increasing the number of lambs tailed per ewe mated by 10% (i.e., from 125% to 135%) increased FCE by 3.5%. The relationship between lambing percentage and feed conversion efficiency is curvilinear, with a further 10% increase in lambing to 145% increasing FCE by a further 3.1%. Increasing lambing percentage from 110% to 170% increased FCE by 20%. In relation to seasonality of feed demand, the major effect of increasing lambing percentage was to transfer feed demand from the pregnancy period to the post-weaning period (Fig. 1).

Increased FCE with higher lambing percentage is the result of spreading maternal overhead feed costs across more lambs. However, as the number of lambs per ewe increases, the marginal change in system FCE declines as a result of higher pre-weaning lamb death rates and lower lamb growth rates of twin and triplet lambs.

A key determinant of changed seasonality of feed demand is the greater number of twin and triplet lambs which grow slower and are therefore on-farm for longer. The increased number of lambs per ewe also impacts on the proportions of lamb and mutton carcass production. Across the assessed range of 110% to 170% lambing percentage, the percentage of lamb carcass relative to total meat carcass increases from 75%, at 110% lambing to 83% at 170% lambing.

The effect of lamb growth rate

To test the effect of lamb growth rate on FCE and seasonality of feed demand, the mixed gender pre-weaning and post-weaning growth rate of single lambs from MA ewes were adjusted while keeping the relative liveweight gains between lambs of different sex, birth rank and dam ages at baseline levels. Increasing pre-weaning lamb liveweight gain from 250 g/day to 450 g/day increased FCE by only 1%. It had minimal impact on flock structure and

Figure 1 The effect of lambing percentage (lambs tailed per ewe mated) at five example lambing rates (105% 125% (baseline) 140% 155% 175%) on whole-of-system feed demand seasonality, measured as the percentage of annual total feed demand (MJME) that is required each week starting from ewe mating date.

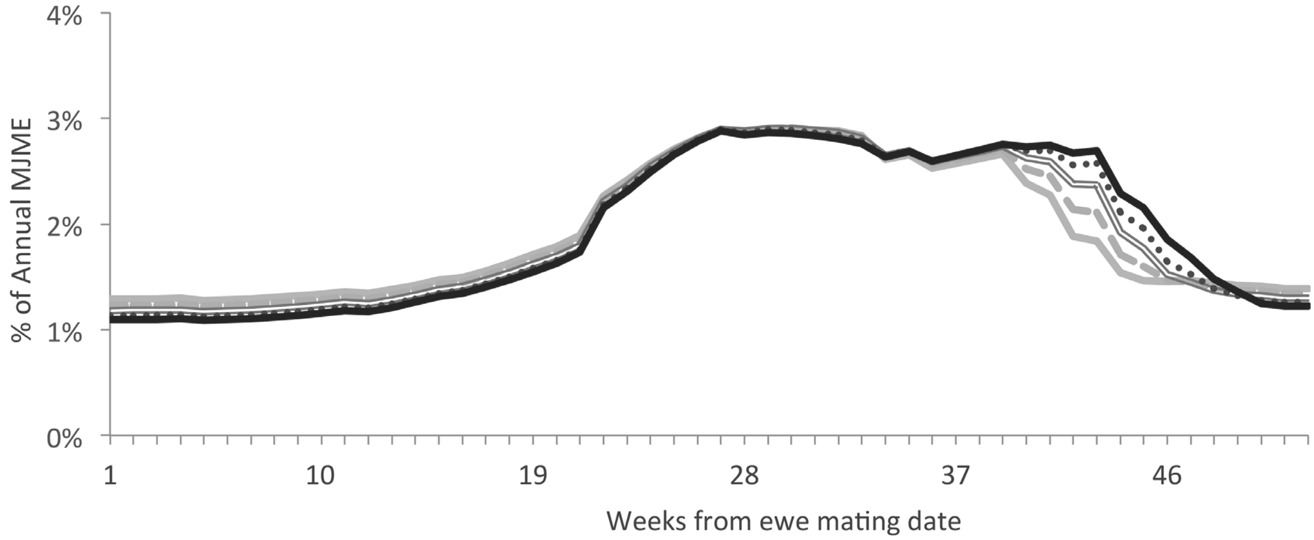


Figure 2 The effect of pre-weaning liveweight gain of lambs (250 g/day 300 g/day (baseline) 350 g/day 400 g/day 450 g/day) on whole-of-system feed demand seasonality, measured as the percentage of annual total feed demand (MJME) that is required each week starting from ewe mating date.

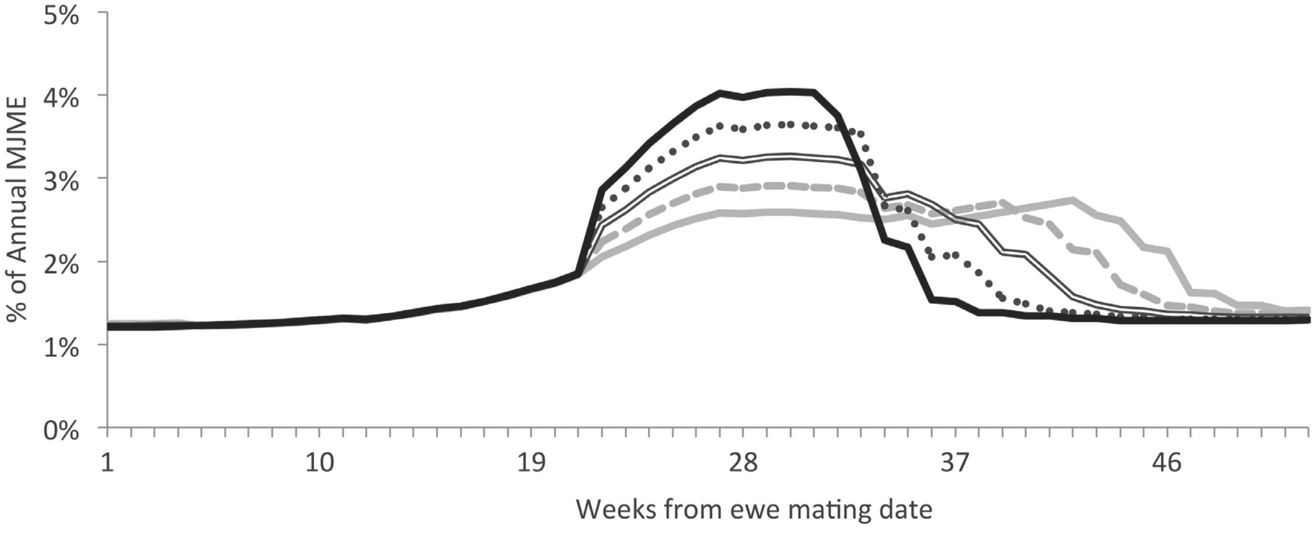
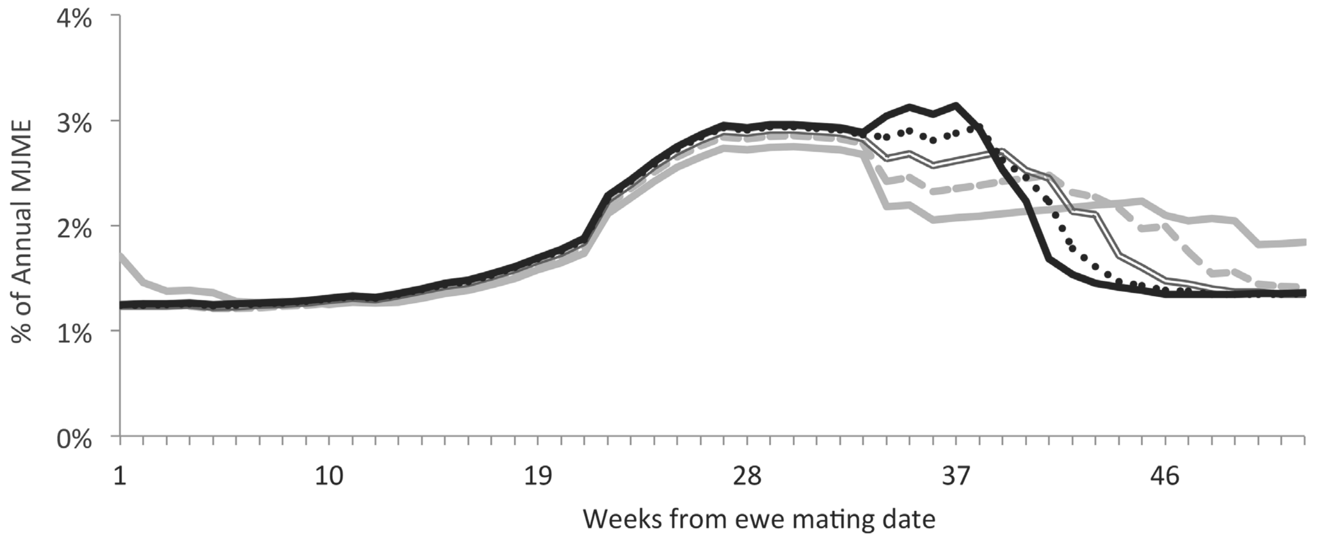


Figure 3 The effect of post-weaning liveweight gain (100 g/day 150 g/day 200 g/day (baseline) 250 g/day 300 g/day) on whole-of-system feed demand seasonality, measured as the percentage of annual total feed demand (MJME) that is required each week starting from ewe mating date.



no impact on the ratio of lamb to mutton carcass production but there was a major shift in feed demand from the post-weaning period to the lactation period (Fig. 2). The higher feed demand during lactation is the result of the increased energy demand for lamb maintenance and growth (including milk production). The lower feed demand during the post-weaning period is the result of earlier kill dates for lambs.

Assuming all other parameters remain at baseline levels, post-weaning liveweight gain has a curvilinear effect on FCE. Whereas FCE increased by 3.9% when post-weaning lamb liveweight gain increased from 100 g/day to 150 g/day, the increase was only 0.8% when these liveweight gains were increased from 250 g/day to 300 g/day. Overall, FCE increased by 8% when the post-weaning lamb growth rate was increased from 100 g/day to 300 g/day. Efficiency gains are a result of lower maintenance energy costs as a consequence of earlier kill dates and an increase in ewe numbers and hence lambs, which increase in direct proportion to the gain in FCE. There was no impact on the ratio of lamb to mutton carcass production.

Increasing post-weaning lamb liveweight gain from 100 g/day to 300 g/day increased whole-of-system feed demand 7.8% in lactation but decreased 6.5% post-weaning (Fig. 3). However, while overall feed demand in the post-weaning period reduced as a result of the earlier kill date of lambs, feed demand increased in the weeks immediately following weaning, as a result of higher lamb energy requirements for liveweight gain and maintenance.

The effect of carcass weight

When tested using the baseline values for all other parameters, increasing target carcass weight from 12 kg to 24 kg increased FCE by 28%. However, there were declining additional efficiency benefits from each additional kg increase. For example, a 1 kg increase from the current 18 kg average New Zealand carcass weight to 19 kg increased FCE by 1.9%. A further 1 kg increase to 20 kg increased efficiency by a further 1.6%. The primary reason why the marginal gain in FCE declines with each successive unit of carcass weight gain is a conseuqence of changes in the composition of liveweight gain and an associated increase in the energy requirement per kg of liveweight gain. A second reason is that the additional benefits of spreading the maternal overhead costs decline with each successive unit increase in carcass weight.

As carcass weight increases, and within a fixed total supply of feed energy, there is a decline in the number of ewes that can be carried. This relationship between carcass weight and ewe numbers is approximately linear with each kg increase in carcass weight requiring ewe numbers to decrease by approximately 2.4%.

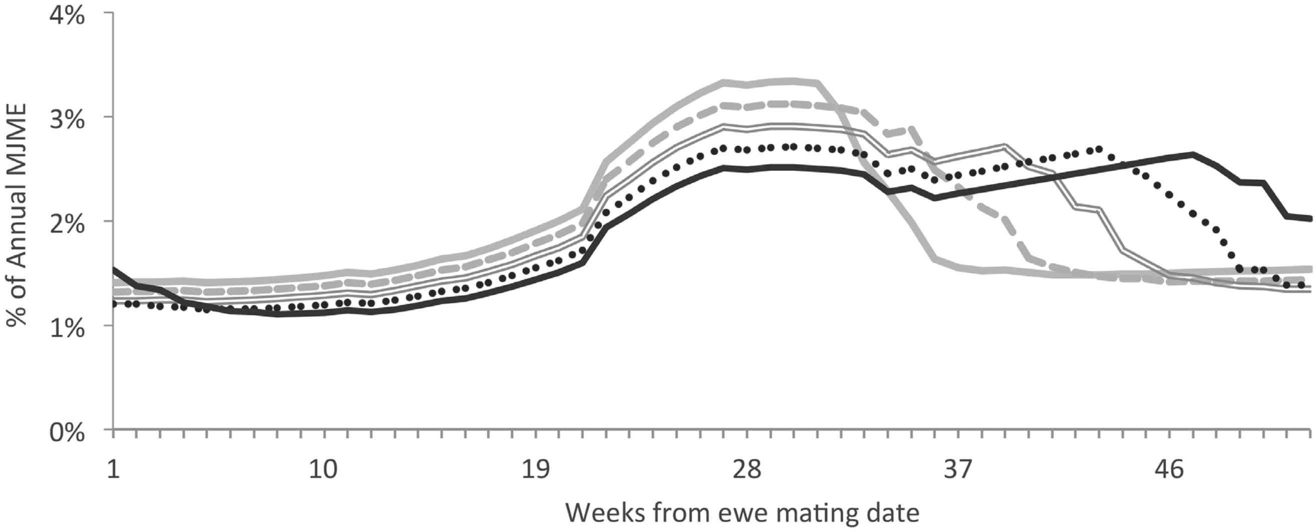
The major effect of carcass weight on seasonality is to decrease the proportion of feed required during the spring lactation period and to increase post-weaning requirements (Fig 4). Clearly this has particular implications for temperate pasture systems. At very high carcass weights, the feed requirements in early winter also increase as a consequence of delayed slaughter. However, later winter requirements decrease owing to the reduction in ewe numbers. In the post-weaning period, although feed demands are lower in the week immediately following weaning (as a result of reduced ewe and hence lamb numbers), higher carcass weights dramatically increase feed demand thereafter.

Combined effect

The combined effect of increasing all four parameters from the minimum to maximum levels reported earlier increases FCE by 60% and decreases ewe numbers by 34%. Feed demand decreased 32% during the pregnancy period but increased 18% during lactation and 15% post-weaning.

It is evident that system parameters generally have a multiplicative rather than additive effect on FCE and feed demand seasonality. For example, when target carcass weight is increased, higher liveweight gains have a greater impact on the average kill date and have a greater effect on FCE. Increasing carcass weight also increases the effect

Figure 4 The effect of lamb carcass weight (12 kg, 15 kg, 18 kg (baseline), 21 kg, 24 kg) on whole-of-system feed demand seasonality, measured as the percentage of annual total feed demand (MJME) that is required each week starting from ewe mating date.



of lambing percentage on FCE and the amount of feed required post-weaning.

Discussion

Feed requirements of breeding females make up a large component of total feed demands. These can be considered as an overhead cost. Accordingly, as lambing percentages and carcass weights increase, these maternal overheads are spread across more production with a consequent improvement in FCE. These principles have been understood for a long time, and the results in this paper are broadly consistent with previous findings from Large (1970) and Cruickshank et al. (2008). However, what is notable is the extent to which additional benefits decline for each additional increase in lambing percentage and carcass weight. Also, in relation to a fixed total supply of feed, the overall system benefits tend to be lower than is superficially apparent from consideration of system components. For example, whereas an increase in lambing from 110% to 170% increases the number of lambs per ewe by 54% (0.6÷1.10), the increase in overall system FCE is only 20%. Similarly, whereas increasing carcass weight from 12 kg to 24 kg increases lamb output per ewe by 100%, the system improvement in meat production is only 28%. Accordingly, it is clear that major productivity improvements require a focus on multiple parameters of the system.

In relation to increased lambing percentages, it can be argued that the seasonality impacts are not intuitively obvious. Increased lambing percentages means more twins which have lower growth rates, and in the absence of complementarity strategies relating to pre-weaning growth rates, then it is actually post-weaning where the overall system demand increases. In relation to carcass weight, the direction of shift in the seasonality of demands is intuitively obvious but the extent of the shift is remarkable. This has major implications for management of feed supply.

In contrast with the findings of Geenty (1995), who did not take a whole-of-system approach, it has been found here that lamb liveweight gain has only a small impact on the overall efficiency of meat production. This is because in a flock situation, lamb energy demands for maintenance, which on a per lamb basis decrease as growth rates increase consequent to earlier slaughter date, only make up a small proportion of total system energy requirements. However, pre-weaning growth rates do have a major impact on pre-weaning feed demands. Accordingly, and depending on the availability and cost of pre-weaning versus post-weaning feed, then increasing pre-weaning growth rates may still have a high impact on economic efficiency. This can only be assessed in relation to specific physical and economic environments.

In our model as presented here, high lamb growth rates actually have a negative FCE impact in relation to the breeding of female replacements. This is because these animals reach higher live weights at an earlier age, and hence, have higher maintenance requirements, but without any attributed benefits of enhanced reproductive performance. If we had assigned higher hogget mating and lambing percentages to these replacement animals then the benefits of higher lamb growth rates would have increased. Investigating such interactions between lamb growth rate and hogget lambing is feasible within the current model.

In drawing conclusions, first we emphasise that our focus here is limited to biological efficiency and seasonality of demand within the animal production system. The validity of the model for these purposes depends primarily on the validity of the energy equations, which are well established in the literature. Further, given that the findings relate to comparative efficiency of alternative system parameters rather than absolute efficiency, the generalised findings are robust in relation to particular energy equation coefficients. We also emphasise that this version of the model does not address issues of bio-economic optima for specific locations with their own unique and variable feed supply profiles.

With the above caveat, our key conclusion is the importance of assessing the impact of individual production parameters in relation to the overall animal production system rather than just to the specific component. A cautionary conclusion in relation to both specific on-farm strategies and R&D programs is that system improvements tend to be less than component improvements. A second cautionary conclusion is that improving individual performance parameters can also lead to major seasonality impacts which may not be intuitively obvious, but which need to be factored into both strategies and programs. These conclusions relate both to farm-level impacts of particular animal performance targets and policies, and as guidance for R&D programs.

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