SELECTING FOR MORE METHANE EFFICIENT SHEEP

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SUMMARY

A bioeconomic model was developed to predict outcomes of scenarios to select for methane efficiency in Merino sheep. The model determines economic values for trait improvement according to different breeding objectives. A selection index approach is used to predict response to selection, assuming knowledge or assumptions about genetic parameters, economic values of breeding objective traits and phenotypic measurement information used to select animals, including information from reference populations for genomic selection. Breeding objectives were based on profit per DSE, reduction in overall flock methane output and methane production per kg lamb produced (defined here as methane efficiency). Results showed that methane production to produce a certain amount of lambs is affected not only by methane production per head, but also by reproductive rate. Methane output per kg lamb produced can be decreased by 3.5% per annum, with the effect of improving production and reproduction efficiency being stronger than the effect of reducing methane production per head.

INTRODUCTION

In the need to reduce the production of enteric methane by ruminants breeding programs can be used to select for sheep that produce less methane. However, reducing methane emission per head might not be the most optimal strategy, as methane production is correlated to feed intake and productivity traits. Bio-economic modeling of sheep production systems can be used to determine breeding objectives and economic values of traits in multiple trait selection indices. An overall breeding goal is required and this can optimize profit per unit of production, e.g. profit per ha or profit per product. Equally we can minimize methane output, either per head or per kg product. How these various breeding objectives compare can be explored by deriving the index weights for the various traits in the breeding objective and predicting selection response when applying these weights. The purpose of the paper is to compare various selection strategies in sheep breeding programs with special emphasis on reducing overall methane output in sheep production systems.

MATERIALS AND METHODS

Increasing reproduction rate and other output traits for a fixed number of breeding ewes results in more lambs per breeding ewe and more feed requirement and more output overall. Therefore, it is relevant to calculate profit and output for a fixed amount of feed resource input, i.e. profit per dry sheep equivalent (DSE). The methane production of the flock was calculated for a fixed number of breeding ewes, in which case an increased reproductive rate increases the number of lambs produced by the flock, which increases the overall methane yield. However, the methane yield per kg lamb carcass produced could be lower, as fewer ewes are needed to produce the same number of lambs. Therefore, methane yield, assessed as the amount of CO_2 Eqvt (kg) produced per kg of lamb carcass is a relevant measure of measuring methane efficiency.

A production model was used to calculate profit and outputs based on the average phenotypic value of breeding objective traits. A model was based on a Merino flock with 100 breeding ewes, focusing on ten key traits that define profitability. Note that the flock size of 100 is just for convenience and actual size is not relevant as outputs are scalable per breeding ewe. All assumptions in the production model are initial ‘ballpark’ guesses with the aim to compare different breeding objectives and their associated selection response. The average methane production (MP) per mature ewe per day in the base situation was 24 g/day which was 8.76 kg/year. The MP of a slaughter lamb was assumed to be 90% of that of an adult ewe. The methane yield per breeding ewe, including the slaughter and young replacement ewes associated with each breeding ewe is then 15.35 kg/per breeding ewe per year which is 42.98 CO_2 Eqvt tonne per year for a flock with 100 breeding ewes. The MEMJ requirement for different periods in the life of lambs, replacement ewes and mature ewes were derived from Thompson *et al*. (1985), with a price of feed ($/MJME) between $0.01 and $0.03. It was assumed that 1 kg feed contains on average 10 MJME, with some variation in feed quality leading to differences in MJME cost for different ages. The price for lamb carcass was $6.50/kg whereas the wool price was $10/kg. The carbon price was assumed to be $40 per tonne CO_2 Eqvt. Variation in fleece weight and fibre diameter did not contribute to differences in methane production and neither was any variation in carcase fat and carcass eye muscle depth assumed to be related to feed requirement or methane production. It is important to note that a bioeconomic model for the purpose of deriving economic weights for genetic improvement requires partial derivatives of the profit, or any other objective, with respect to the trait means. This means that to calculate the economic value of one trait, only one trait at a time is changed, assuming that other traits are constant. This might seem counter-intuitive, e.g. for mature body weight, as typically one would expect more feed intake if animals become larger. However, these relationships are captured by the correlations applied in the selection index model that determines optimal trait responses for a given set of economic values and a given amount of information measured to select animals. Note that only changes in the mean of reproduction traits affect the methane production in the flock as for the same number of breeding ewes, more lambs per ewe will lead to more methane production. The ten breeding objective traits modelled are given in Table 2 along with their means in the base situation.

Economic values were calculated as partial derivative of a breeding objective criterion with respect to trait means. Breeding objective criteria were i): optimising profit per ewe for a fixed feed resource, i.e. per dry sheep equivalent (DSE) (BrObj1) ii) total methane production of a 100-ewe flock (BrObj2) and iii) the amount of methane (kg CO_2 Eqvt) produced per kg of lamb (BrObj3). Table 1 gives the results for economic weights of some objective traits for these three breeding objectives. The weights in BrObj2 suggest that to reduce methane, one should select against more reproductive ewes as fewer lambs per breeding ewe produce less methane per breeding ewe overall. The third breeding objective is more relevant where kg CH_4 per kg lamb carcase is minimized. This objective results in positive weights for slaughter weight and reproduction traits and a negative weight for methane production per ewe.

Table 1. Economic weight (standardized) for four different breeding objectives

	Profit per head for fixed DSE (BrObj1)	**Methane yield per ewe (BrObj2)**	**kg methane/ kg carcass (BrObj3)**
Slaughter Weight (9 mo)	$3.03	0.00	3.03
Fertility (pregnancy rate)	$146.03	-89.00	173.01
Lambing rate (lambs weaned/lambing)	$72.81	-44.50	85.48
Mature ewe Weight kg	$0.75	0.00	0.00
Daily DM Feed Intake (kg/day)	-$34.98	0.00	0.00
Methane production (g per ewe/day)	-$0.89	-6.29	-6.29

Selection response was calculated based on selection index theory. Genetic and phenotypic parameters were taken from Brown and Swan (2015) with parameters related to methane yield and feed intake largely based on Robinson *et al*. 2016. The genetic correlation between feed intake and methane production (MP) was assumed to be 0.8 and genetic correlations of MP with mature weight, fertility and lambing rate were 0.6, 0.10 and 0.10, respectively. Selection of breeding animals was optimised across age classes with information used for selection typical for traits routinely measured on-farm and MP and feed intake traits predicted from a reference population via genomic testing, assuming a reliability (accuracy-squared) of 0.10.

RESULTS AND DISCUSSION

Selection response per annum are given for breeding objective traits in Table 2. The results of genetic change in the MP per ewe, the MP per 100 ewe flock and MP per kg lamb are also given in Table 2. Results show that a breeding objective that maximizes profit per head for a fixed amount of DSE increases the methane output per breeding ewe because ewes have more lambs and there is a correlated response to selection for larger ewes and lambs. However, the methane yield per kg lamb carcase produced is about 2.7% lower than without selection.

Selecting only for lower MP per ewe in BrObj2 leads to lower methane production per ewe, but all traits respond negatively, such that profit decreases by \$5.52 per annum, rather than increasing by \$6.65 per annum. Note that BrObj2 only uses (negative) weights for reproduction traits and methane yield (Table 1), but these traits are correlated to weight traits. BrObj3 leads to the largest reduction in methane yield per kg lamb carcase produced. Under this scenario, the methane yield per breeding ewe increases because of an increase in mature size and because each breeding ewe produces more lambs, but the increase is about half of that when selection for profit (BrObj1). The increased productivity under BrObj3 means that every year of genetic improvement gives a 3.5 percent reduction in methane for the same amount of lamb meat. The profit increase due to genetic improvement is about 17% lower than under BrObj1. This indicates that the carbon price of \$40 per ton CO_2 Eqvt is not having a large effect on the selection response.

The predicted response under BrObj1 varies little between no price on carbon and a carbon price of \$400, with the response of MP changing most, from 0.22 to 0.14 g/day. A carbon price of ~\$900 would be required for zero response in MP under BrObj1. A very high carbon price would result in a similar response as BrObj2. In a scenario under BrObj3 where MP and feed intake are not measured in a reference population, the increase in MP would be 35% higher compared to results in Table 2, whereas the increase in feed intake would be 10% higher. This would also allow a slightly higher (~3%) response in production and reproduction trait responses, and the overall effect on methane output per kg lamb produced would be small. However, the effect on profit increase per annum would be 14% lower, mainly due to the higher cost of MP. Therefore, measuring MP and feed intake has a limited effect on methane/kg lamb, but it allows more improvement in productivity and reproduction traits while limiting and increase in methane output per kg lamb produced .

Knowledge of genetic parameters of feed intake and MP in sheep is still limited and a current MLA-EPA project aims to collect a lot more data on these traits. It is also unclear how methane production changes between lamb and ewe stages and whether the genetic correlation between MP measured in these different stages is close to 1. Therefore, results in this paper are preliminary. However, they already give a clear picture of the various perspectives from which methane efficiency breeding objectives can be based on. The paper has not considered functions of traits such as residual methane production (methane production adjusted for body weight and production traits) or methane yield (methane production per kg feed intake). Whereas breeding objectives can be defined as productivity ratios, it is not useful to define objective traits as function of traits. Especially ratios of traits have undesirable properties in selection index schemes as they tend to be less normally distributed and could give rise to non-linearity in the breeding objective.

Previous studies such as Robinson *et al.* (2016) and Gebbels (2022) have also shown that optimal breeding strategies do not aim to reduce methane production per ewe, as this tends to result in lower feed intake, lower growth rates and lower reproductive performance, hence overall reducing efficiency of lamb production. Therefore, sheep production systems that aim for less overall methane output should aim for genetic improvement resulting in increased productivity and reproductive performance. Including feed intake and MP in the breeding strategy is now possible due to genomic selection and the creation of reference populations. Such a strategy allows for maintaining selection for increase productivity while limiting the increase in methane production. In that aspect, this is akin to selection strategies to improve feed efficiency, where optimal genetic improvement will not result in lower feed intake per animal, but rather in improved productivity while limiting the correlated increase in feed intake.

Table 2. Breeding objective traits, their means before selection, their annual change with three different breeding objectives, and the effect on methane efficiency parameters

		Breeding Objective		
Breeding Objective Trait (units)		Profit / DSE	Reduce CH_4/ ewe	kg CO_2 Eqvt/ kg lamb
	Current mean	Annual change (trait units)		
Slaughter Weight (9 mo)	47.27	0.97	-0.79	0.77
Carcase Eye Muscle Depth (mm)	28.00	0.31	-0.17	0.12
Carcase Fat Depth (mm)	7.00	0.10	-0.05	0.00
Fleece Weight (kg)	4.00	0.01	-0.01	-0.01
Fibre Diameter (micron)	18.00	-0.04	0.00	0.03
Fertility (pregnancy rate)	0.75	0.01	-0.01	0.01
Lambing Rate (lambs weaned/lambing)	1.50	0.01	-0.01	0.01
Mature ewe Weight (kg)	55.00	1.27	-1.11	1.13
Daily DM Feed Intake (kg/day)	1.20	0.02	-0.02	0.01
Methane Production (g per ewe/day)	24.00	0.22	-0.28	0.10
Change in profit (p.a.)		$6.65	-$5.52	$5.47
Change in CH_4 output /ewe (% of mean)		0.92%	-1.16%	0.43%
100 ewe flock CO_2 Eqvt tonne/yr	53.33	101.8%	98.6%	100.8%
kg CO_2 Eqvt per kg lamb produced	28.04	97.3%	102.5%	96.5%

CONCLUSION

Breeding strategies to reduce the amount of methane produced in sheep production systems rely mainly on improving productivity and reproductive performance while measuring and selecting for methane production and feed intake allow increased productivity while limiting an increase in methane production and feed intake. The amount of methane produced per kg lamb product can be reduced via genetic improvement by about 3.5% per annum.

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