POTENTIAL FOR NEW ZEALAND FARMERS TO REDUCE SHEEP GREENHOUSE GAS EMISSIONS THROUGH GENETIC SELECTION TOOLS

Cameron Ludemann, Tim Byrne, Jude Sise and Peter Amer
AbacusBio Ltd, Dunedin, New Zealand

Abstract

This research examined and quantified the effect on farm profit and emissions per kilogram of lamb product and per ewe when using different potential genetic selection tools.
A new selection tool was designed for farmers to select animals that produce fewer greenhouse gas (GHG) emissions while maintaining an 'acceptable' level of genetic progress in traits which enhance farm profitability.

Selection of sheep based solely on farm profit could potentially improve emission reductions per unit of product by 0.190 kg CO_2e/kg lamb carcass weight (CWT). This is equivalent to a 0.61% reduction in total lamb emissions per annum (pa). Selection of sheep based solely on improving GHG emissions efficiency rather than farm profitability could potentially improve emission reductions per unit of product to 0.250 kg CO_2e/kg lamb CWT per annum; equivalent to a 0.8% reduction in total emissions pa. However, doing this would come at the cost of 27 cents per breeding ewe reduction in annual genetic progress for farm profitability, due to sub-optimal emphasis on traits which enhance farm profits.

A selection tool would not be adopted by farmers if it caused an unacceptable level of farm profit progress to be lost. Altering the relative cost of each unit of carbon equivalents (CO_2e) in the selection tool enabled the balance between GHG emissions per unit of product and farm profit progress to be changed.

A workshop involving key New Zealand sheep industry members was organised to discuss what an acceptable trade-off would be between progress made in farm profit and that in reducing GHG emissions per kilogram of product. A \$25/t CO_2e cost was deemed to provide an 'acceptable' trade-off. The acceptable trade-off produced an annual 0.199 kg CO_2e/kg lamb CWT reduction in GHG emissions. This was predicted to achieve a 0.64% pa reduction in total emissions or 79.6% of the total possible reduction in GHG emissions using selection index tools, while still achieving 99.8% of the potential gains in farm profit progress.

Keywords: Greenhouse gases sheep genetic selection

Subtheme: The environment

Introduction

The decisions farmers make on which animals to breed from can be simplified by the use of a selection index. Selection indexes define the relative weighting of a range of animal traits which allow comparisons to be made between animals (Hazel 1943). Altering the relative weighting of each trait can cause a re-ranking of individual selection candidates in a breeding program. This in turn may impact on the overall progress made in a breeding program.

Genetic improvement goals in New Zealand in the past have generally focussed on improving traits which add profit to the farmer's operation. As a consequence, the productivity of the New Zealand sheep industry has increased significantly (Young & Amer 2009). Between 2000 and 2006 the average carcase weight (CWT) breeding value (BV) of performance recorded sheep participating in the Sheep Improvement Limited Advanced Central Evaluation (SIL-ACE) national genetic evaluation analysis increased by 0.9 kg. Over the same 7 year period, the number of lambs born (NLB) per ewe lambing BV increased by approximately 5 percentage points (Young & Amer 2009). The selection decisions farmers make based on selection index values (whether they are breeders selecting stud sires or breeding ewes or commercial farmers buying rams) are not only important with respect to farm profitability, but can also have environmental impacts in the form of changed farm greenhouse gas emissions.

This paper describes the impact sheep selection decisions by New Zealand farmers may have on farm profitability as well as greenhouse gas (GHG) emissions per unit of product (based on kg lamb carcass) and per breeding ewe. The potential for further GHG emission efficiency improvements through the use of a new selection index tool was also examined.

Methodology

GHG emission calculations

Current New Zealand sheep selection indexes have economic weights assigned to each trait, based on how a unit change in the trait impacts on farm profitability. The relative weightings have an impact on how much genetic progress is made in each trait. A calculation of the implications of a unit change in each trait on GHG emissions was required to determine what affect sheep selection decisions were having on GHG emissions.

The main GHG emissions associated with lamb production include Methane (CH_4) and Nitrous Oxide (N_2O). A life cycle analysis by Ledgard et al. (2010) for example stated that 80% of emissions associated with New Zealand lamb products consumed in the UK market were attributable to on-farm emissions. Seventy two percent of the on-farm emissions were either CH_4 or N_2O from the sheep. This study was therefore limited to CH_4 and N_2O emissions when dealing with the costs of GHG emissions. Table 1 outlines assumptions regarding major farm performance factors impacting on CH_4 and N_2O emissions from sheep.

Table 1: Performance parameters which form base farm model assumptions.

Performance parameter	Assumption
Ewe prolificacy (lambs born per ewe lambing)	1.45
Average lamb survival (birth to tailing)	0.91
Average lamb survival (tailing to slaughter)	0.98
Average weaning weight averaged across sexes (kg)	28
Average lamb CWT (kg)	17
Average lamb dressing proportion	0.45
Ewe mature weight (kg)	65
Age at which mature weight reached (years)	2
Replacement rate (proportion of the flock as 2-Tooths)	0.25
Average (across birth ranks) days to slaughter	162

Emission factors were required to predict the weight (in grams) of CH_4 and N_2O produced per kilogram of dry matter consumed (Table 2). These factors were based on the 2010 New Zealand GHG inventory submission to the Intergovernmental Panel on Climate Change (IPCC) (Ministry for the Environment 2010). The resultant GHG emission outputs were multiplied by the global warming potential of CH_4 (21) and N_2O (310) respectively, to calculate the emissions in grams of Carbon Dioxide equivalents (CO_2e) per unit of dry matter intake per unit change in the trait. An increase in feed requirements on a farm would require more feed to be made available either as supplements or pasture, at a GHG emission cost. Alternatively, a change in a trait which reduces feed demand would allow a farmer to reduce GHG emission levels.

Table 2: Methane and nitrous oxide emission factors, based on the Ministry for the Environment (2010).

Class of stock	Grams of CH_4 per kg dry matter consumed	Grams of direct N_2O per kg dry matter consumed	Grams of indirect N_2O per kg dry matter consumed
Lambs (birth to slaughter)	16.8[1]	0.0489	0.0135
Replacement sheep (birth to maturity)	18.9[1]	0.0489	0.0135
Mature sheep	20.9	0.0489	0.0135

[1]Lambs were assumed to not produce methane until they were 8 weeks of age as stated by Clark (2008).

Workshop

As part of this study a one day workshop was organised involving 20 knowledgeable and influential people from the sheep industry, including sheep breeders, commercial farmers, academics and other representatives from industry bodies. Discussion at the workshop focussed on:

- how the GHG emission values and weights should be calculated,
- what price should be put on carbon to accurately reflect likely cost to farmers and;
- methods for incentivising farmer usage of a new index to enhance GHG emission reductions

Participants were presented with the predicted rates of GHG emission and farm profit progress with alternative indexes. Workshop participants were then asked what their preferred level of trade-off would be between farm profit and GHG efficiency progress if a new selection index became available to farmers.

Methodology for reporting emissions

Two methodologies for reporting GHG emissions were investigated.
The 'GHG Gross' weights were calculated using a methodology which predicted the change in GHG emissions per breeding ewe with a unit change in each trait, using the relationship between changes in feed demand and GHG emission factors previously described.

'GHG Intensity' weights, predicted the change in GHG emissions per kg of lamb CWT, with a unit change in each trait. The GHG emission weights per kg lamb CWT were translated to a per ewe lambing basis, to align with existing selection indexes for sheep in New Zealand, using scaling constants (Amer et al. 2010).

Development of indexes

Selection indexes are used in genetic improvement programs to simplify management of tradeoffs among traits competing for selection effort. It is very rare for a single animal to rank best for all traits. Therefore, some sort of prioritisation is required, so that weaknesses within a selection candidate for one trait can be offset by strengths within other traits. The relative weighting applied to traits is typically based on economic principles and a goal of improving farm profit is common in the formulation of selection indexes. However, in this study indexes which also take account GHG emissions have been included for comparison. Increasing the relative selection index weighting for one trait results in faster genetic progress in that trait, but less genetic progress in other traits as trait selection effort among a pool of candidates is limited in total. Tradeoffs are modest for traits that are favourably correlated, but can become quite severe when traits are unfavourably correlated.

An existing economic index is presented in Table 3, along with three additional indexes, all of which incorporate GHG emissions.

The index which maximises gains in farm profit progress is defined as the Dual Purpose Overall (DPO) index. This index is anticipated to be implemented for national sheep genetic improvement in New Zealand in the near future (Amer et al. 2010).

The GHG gross index utilised gross weights, the GHG intensity index utilised intensity weights and the 'Dual Purpose Environment' (DPE) index included a combination of the DPO and GHG emission weights. Workshop participants voted on their most preferred method for calculating GHG emissions (Gross or Intensity) based on predicted farm profit and GHG emission progress made. The most preferred methodology for calculating GHG emissions was combined with the DPO weights by converting the GHG emission weights (in kg CO_2e) to a monetary value by multiplying by several prices of carbon. Calculating the DPE at several prices of carbon ($15, $25, $50, $75 and $100/t CO_2e) allowed quantification of carbon price effect on genetic progress for both farm profit and GHG emissions.

The relative weightings between traits influence the level of progress made in each trait in a selection index. Increasing the weight relative to other traits will increase genetic progress in the trait, while decreasing the relative weighting will reduce progress. For example, the DPE relative weight for NLB (2120 cents) is 408 cents higher than the DPO relative weight (1712 cents). Increasing NLB has a favourable effect on GHG emissions per unit of product and emissions costs are considered part of the cost of the trait in the DPE index. Increasing the price of carbon increases the carbon component of the trait weight thus increasing that traits weighting. The DPE index therefore has greater weighting on the NLB trait relative to the DPO index because NLB reduces GHG emissions to a greater extent than other competing traits in the index.

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Table 3: Objective trait names, description, response units, and economic weights used in the modelling of responses to selection

			DPO	**DPE**	**GHG Intensity**	**GHG Gross**
Name	**Trait description**	**Response unit**	Cents/breeding ewe	Cents/breeding ewe (at \$25/t CO_2e)	Kg CO_2e /breeding ewe adjusted for production	Kg CO_2e /br'd ewe unadjusted for prod'n
NLB	Number of lambs born	lambs	1712	2120	163.2	-186.4
WWT	Weaning weight	kg	144	153	3.9	3.9
CWT	Carcass weight		348	372	9.7	1.4
HFW	Hogget fleece weight		113	113	0.0	0.0
LFW	Lamb fleece weight		423	423	0.0	0.0
EFW	Ewe fleece weight		327	327	0.0	0.0
FEC1	Fecal egg count	eggs $gram^{-1}$	-4.7	-4.8	-0.03	-0.01
FEC2			-4.7	-4.8	-0.03	-0.01
AFEC	Adult fecal egg count		-3.5	-3.6	-0.2	-0.005
SUR	Lamb survival	lambs	8476	10299	729.4	-259.5
Lean Yield	Carcass lean meat	kg	532	532	0.0	0.0
EweWT	Ewe mature weight		-150	-164	-5.5	-5.5
WWTmat	Maternal weaning weight		121	129	3.1	3.1
Longevity	Ewe longevity	% of 2 tooth's	-16664	-17372	-283.4	-371.9

Genetic trends were predicted by modelling the trait responses to selection using each of the contrasting index methods. The modelling predicted the annual rates of genetic progress per breeding ewe, for each of the sets of trait weights (i.e. in each index), as described by Amer et al. (2010).

The trends in progress made across the range of carbon prices in the DPE index were described to workshop participants. They then voted on the price of carbon they believed produced the most acceptable trade-off between farm profit and GHG emission genetic progress.

Results

Using emission factors listed inTable 1, and further methodology explained by Amer et al (2010), the total GHG emissions for lamb products (for comparison with the genetic responses in traits) was calculated to be 31.31 kg CO_2e/kg lamb CWT.

The genetic responses in individual traits for each index are shown in Table 4. This provides an indication of the sheep characteristics which will be emphasised in future years of breeding. The DPE index for example was predicted to result in more genetic progress in NLB compared to the DPO index with 0.008 and 0.005 extra lambs born per ewe lambing pa, respectively. Selection based on the DPE index would also lead to greater annual progress in WWT but less progress made in CWT relative to selection on the DPO index. In contrast, selection using the GHG Gross index would result in NLB and CWT genetic progress to become negative (reducing average NLB and CWT), while also making less genetic progress in WWT relative to the three other indexes.

Table 4: Annual genetic responses made in sheep traits when using different sets of index weights

	DPO	DPE	GHG Intensity	GHG Gross
Trait	Genetic progress made (in trait units pa.)			
NLB	0.005	0.008	0.012	-0.016
WWT	0.230	0.233	0.129	0.036
CWT	0.167	0.161	0.093	-0.003
HFW	0.028	0.026	0.015	0.007
LFW	0.004	0.004	0.002	0.001
EFW	0.024	0.022	0.013	0.005
FEC1	0.239	-0.739	0.123	0.115
FEC2	0.275	-0.984	0.141	0.132
AFEC	0.307	-1.100	0.158	0.148
SUR	0.001	0.001	0.002	-0.001
Lean Yield	0.024	0.021	0.005	0.008
EweWT	0.115	0.116	0.065	-0.045

Table 5 shows the overall GHG emission and farm profit progress levels when all traits are combined.

In relation to overall lamb emissions, using the DPO index was predicted to reduce GHG emissions per unit of product by 0.61% pa. For the DPE index there was a 0.64% pa reduction. The GHG Intensity index had the greatest potential for reducing GHG emissions per unit of product (by 0.8% pa). However, the GHG Intensity index had 26.5 and 26.65 cents/breeding ewe pa lower genetic progress for farm profit compared to the DPE and DPO indexes respectively. The Gross index was predicted to cause a 19.2 cents/breeding ewe reduction in farm profit progress, while increasing GHG emissions per kilogram of lamb CWT by 0.50%. However the total emissions per breeding ewe would reduce by 3.62 kg CO_2e.

Table 5: GHG emission and farm profit genetic progress predicted for a range of index weights.

Index methodology	**DPO**	**DPE**	**Intensity**	**Gross**
Genetic progress made in farm profit (cents/breeding ewe pa)	112.60	112.45	85.80	-19.20
Genetic progress made in GHG emission efficiency (kg CO_2e/kg lamb CWT pa)	-0.190	-0.199	-0.250	+0.166
Annual reduction (%) in GHG emissions relative to average total lamb emissions²	-0.61	-0.64	-0.80	+0.50
Genetic progress made in GHG emissions (kg CO_2e/breeding ewe pa)	+0.725	+1.25	+2.45	-3.62

² Based on 31.31 kg CO_2e/kg lamb CWT (Amer et al. 2010).

Calculating the GHG emissions on an 'intensity' basis was backed by unanimous agreement from participants of the workshop, who also believed that the formulation of the hybrid DPE index was desirable. Preference was given to the intensity method as it was predicted to have 105 cents higher annual farm profit and 0.416 kg CO_2e/kg lamb CWT higher rate of gain in reducing GHG emissions relative to the Gross method (Table 5).

Figure 1 depicts the trade-off between genetic progress in farm profits and progress in reducing GHG emissions per kg lamb CWT as the assumed price of carbon equivalents is increased. The DPO index provides the highest farm profit genetic progress (112.6 cents/breeding ewe pa) while the GHG intensity index was predicted to have 85.8 cents genetic progress. As the price of carbon in the DPE index increased, the rate of farm profit progress reduced. At the same time, the rate of GHG emission per kilogram of lamb CWT progress became more negative meaning a greater reduction in emissions per unit of product resulted.

The DPE index at $25/t CO_2e was predicted to produce 112.45 cents farm profit progress per breeding ewe pa while contributing to a 0.199 kg CO_2e/kg CWT reduction in emissions. The trade-off for the DPE at a $25 carbon price was therefore 99.8% of the potential farm profit progress made by the DPO, and 79.6% of the potential progress (relative to the GHG intensity index) in reducing GHG emissions per kg lamb CWT. At a $100 price of carbon, farm profit progress reduced to 110.5 cents/breeding ewe with a 0.218 kg CO_2e/kg lamb CWT reduction in GHG emissions predicted.

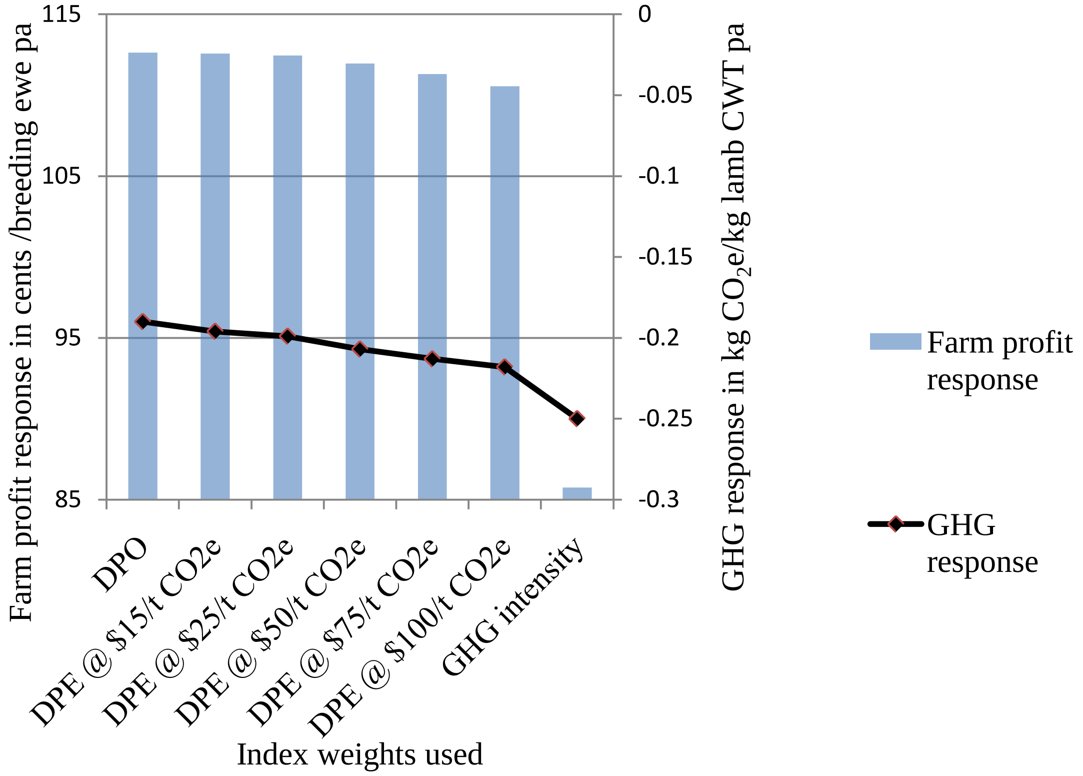

Figure1: Farm profit responses per breeding ewe and GHG emission responses per kilogram of lamb CWT across a range of selection indexes.

Ninety three percent of workshop participants voted for the DPE at a carbon price of $25/t CO_2e as being the 'most acceptable' trade-off between farm profit and GHG emission efficiency progress.

Discussion

Genetic progress made by selecting animals based on selection index weightings can provide cumulative and permanent improvements toward achieving a farmer's goal (Simm 1998). In the past, New Zealand sheep farmers have focussed on improving farm profitability (Young & Amer 2009). However, the New Zealand Government's plan to include agriculture in a regulatory framework to put a cost to GHG emissions produced (the Emissions Trading Scheme) may bring about a change in the goals farmers' base their sheep selection decisions on, to include reducing GHG emissions. Fortunately, focussing on traits which improve farm profitability may also facilitate progress in reducing GHG emissions per kilogram of lamb CWT.

The workshop carried out in this study highlighted the sheep industry representative's preference for reducing GHG emissions per unit of product rather than per breeding ewe, owing to the potential for greater farm profit progress. As a result of this, the DPE index incorporated the 'GHG Intensity' methodology for calculating GHG emissions. The GHG Intensity method takes into account the GHG emissions dilution effect of changes in traits which effect lamb CWT production. NLB for example may on a per breeding ewe (Gross) basis have increased GHG emissions as a result of additional pregnancy and lactation energy requirements associated with another lamb born. However, the extra lamb born also contributes to an increase in lamb CWT which may dilute the additional GHG emissions to an extent which actually reduces GHG emissions per kilogram of CWT. The GHG Intensity method thus selected for improvements in efficiency in terms of GHG emissions per unit of lamb CWT and so had 105 cents per ewe pa higher predicted annual farm profit progress compared to the GHG Gross method.

The environmental and economic benefits to farmers using the DPE index will not be obtained unless farmers adopt the DPE index. The workshop was organised to allow an influential and representative section of the sheep industry to provide feedback in the development of the index. Workshop participants suggested their most preferred level of trade-off between economic and environmental progress. This is important for the uptake of the index because increasing the carbon price in the DPE index increases GHG efficiency but comes at a cost in terms of farm profit progress. A higher carbon price places greater emphasis on traits that improve GHG efficiency. Although improving GHG efficiency can also improve farm profit (as it also selects for efficiency of feed use), there is not a 1.0 correlation between GHG efficiency and farm profit. Some traits which increase GHG efficiency will therefore be emphasised, which do not provide optimal farm profit responses, hence the lower farm profit progress at higher carbon prices relative to the DPO.

A carbon price of $25/ t CO_2e used in the DPE was regarded as being the most acceptable trade-off by workshop participants, achieving 99.8% of farm profit progress and 79.6% of potential GHG efficiency. This suggests that the workshop participants were unwilling to forsake farm profit progress for additional GHG efficiency with DPE weights at higher carbon prices, which is understandable given the fact that they have a strong desire to improve profitability. In addition, under the proposed Emissions Trading Scheme, farmers may not be able to receive any financial benefit for their reductions in ruminant emissions they make at an 'on-farm' level. This is because the point of obligation is proposed to be at the meat processor level and will use New Zealand average GHG emission factors rather than emission factors that alter according to changes made on individual farms.

New Zealand sheep farmers would require tangible benefits, in order for them to use an environmental index which would result in a reduction in the annual rate of genetic progress for farm profit. A premium would need to be extracted from the market in order to overcome the financial cost to the farmer of selecting on the environmental index. One way to extract a premium for the reduced emissions alluded to in the industry workshop by participants was the need for a lamb supplier group to be set up. A supplier group of sheep farmers could prove they are more GHG efficient relative to other producers and extract a benefit for this, either in the form of lower GHG emission factors applied to their stock when they are slaughtered. Or by extracting a price premium through lamb marketing campaigns via their meat processor based on suppliers taking steps to reduce their GHG emissions.

Conclusion

Genetic progress can be made to reduce GHG emissions per unit of lamb CWT by using a traditional selection index focussed on improving farm profitability. This is because it also selects for more efficient animals. Greater GHG emission progress could be made by selecting only on GHG efficiency.

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However, this comes at a cost in the form of lost genetic progress made in traits which improve farm profits. It may also lead to higher emissions per ewe.

The DPE index proposed here based on industry consultation provides a selection tool for farmers to capture nearly all (99.8%) of farm profit progress while obtaining most (79.6%) of the potential GHG emission reductions per kg of lamb CWT. For farmers to use indexes with stronger weightings placed on GHG emissions, they would need to be assured the benefits of selecting sheep based on a DPE index outweigh lost farm profit progress. This might be achieved by having a specific lamb supplier group to extract a premium from the market for taking steps to reduce their emissions.

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