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investment. As long as it is profitable, grain will be included in ruminant diets in many countries, and the use of palm kernel expeller in New Zealand is no different. Although beef and sheep meat are associated with a high Ei, as long as consumers pay the price, production will be ongoing. However, if mitigation of GHG from agriculture became a high priority, only dairy animals would be retained to graze pastures, and our diets would be dominated by vegetables and grains (Waghorn & Hegarty, 2011) with pork and chicken.

CONCLUSION

Although agriculture accounts for only 9-14% of global GHG, within New Zealand it accounts for about 48% of our total emissions, and we are obligated to reduce these. Consensus amongst researchers suggests reductions in both CH_4 and N_2O yields (g/kg DMI) are unlikely to exceed 15-20%, but Ei can be reduced substantially whilst retaining or increasing profitability, by farming efficiently. This can be achieved by adoption of best practice for feed production, utilisation and animal aspects of farming. Efficient farming will maintain food production, but what processes will be required for measuring compliance? Farmers are likely to be faced with increased legislation to ensure environmental sustainability. This may include some form of GHG accounting. Farmers and industry leaders need to work with policy makers to ensure their views are heard and to influence decisions, rather than reacting to legislation drafted by persons with limited knowledge of farming. More efficient farming can increase livestock production without increasing GHG emissions. This will be good for farmers, governments and especially people, because we all need food and have a right to choose food that we like.

The role of breeding in reducing sheep GHG intensity

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ABSTRACT

Historic and potential future greenhouse gas (GHG) emission reductions resulting from genetic selection decisions in sheep have been quantified. Historic genetic trends in number of lambs born in maternal breeds and growth in terminal sire breeds were estimated to have reduced GHG emissions per kilogram of lamb carcass weight by 0.45% and 0.09% per year of genetic change, respectively. The implications of future selection using different indexes were also examined. Selection based solely on farm profits could lead to emission reductions per unit of product by 0.185 kg CO_2-e/kg carcass weight, or a 0.59% reduction in lamb carcass weight emissions per annum. Selection of sheep ignoring profit and solely targeting reduced GHG emissions per kilogram of lamb carcass weight could lead to emission reductions of 0.242 kg CO_2-e/kg lamb carcass weight, equivalent to a 0.77% reduction in total emissions per annum. However, doing this would come at a cost of 26.6 cents per breeding ewe reduction of 23.7% per annum in annual genetic progress. An alternative index that provides a balance between reducing GHG emissions and improving farm profits was estimated to produce an annual 0.193 kg CO_2-e/kg carcass weight or a reduction of 0.62% reduction in emissions per annum in GHG emissions with minimal sacrifice in genetic improvement of farm profitability.

Keywords: greenhouse gases; sheep; genetic selection.

INTRODUCTION

In the past, genetic improvement goals in New Zealand have generally focussed on improving traits which add to farm profit. As a consequence, the productivity of the New Zealand sheep industry has increased significantly. For example, the number of lambs born (NLB) breeding value (BV) increased 5 percentage points between 2000 and 2006 in performance recorded sheep participating in the Sheep Improvement Limited - Advanced Central Evaluation (SIL-ACE) national genetic evaluation analysis. In the same analysis, the average lamb carcass weight BV increased by 0.9 kg (Young & Amer, 2009).

With agriculture potentially becoming part of the emissions trading scheme in New Zealand, farmers may in the future be incentivised to apply technology that reduces greenhouse gas (GHG) emissions while still improving farm profitability. A more likely short term driver would be a desire by meat companies and farmers to show international consumers evidence of active efforts to reduce on-farm emissions associated with high value sheep meat products (Sise *et al.*, 2011). The use of a genetic selection tool may be one such technology to achieve this. This paper examines the GHG implications of genetic trends made in the past, particularly in regard to the change in fertility of ewes and growth of lambs. The potential for improving GHG emission efficiency in the future through the use of new selection index tools is also discussed.

METHODOLOGY

Calculating GHG emissions

GHG emissions derived from sheep energy requirements were used as the basis for predicting the GHG implications of genetic changes. This study limited consideration of GHG emissions to methane (CH_4) and nitrous oxide (N_2O) when calculating the costs of GHG emissions; as these contribute to the majority of on-farm emissions in lamb production (S.F. Ledgard, Personal communication).

Emission factors were required to predict the weight (g) of CH_4 and N_2O produced per kilogram of dry matter (DM) consumed. The values of emissions per kg DM and further methodology for calculating the GHG emissions are detailed in Ludemann *et al.* (2011).

Historic genetic progress

Six scenarios were used to simulate GHG emission changes associated with the genetic progress that occurred between 2000 and 2006 including:

- BASE scenario: Baseline against which other scenarios were compared, where no genetic improvement is assumed to have occurred.
- EMKILL scenario: Genetic merit for carcass weight of maternally sired lambs increased 0.9 kg between 2000 and 2006 with the associated genetic change in ewe mature weight of an increase of 3.11 kg ewe mature weight per 1 kg increase in lamb carcass weight (CWT). The gain in genetic merit for CWT was assumed to be exploited by commercial farmers selling the lamb at the same carcass weight (17 kg) but at an earlier age (169 days instead of 180 days).
- HMKILL scenario: Similar genetic merit changes as the EMKILL scenario, except the higher genetic merit for carcass weight was assumed to be exploited by commercial farmers selling lambs with heavier carcass weights (17.9 kg) at the same age (180 days).
- ETKILL scenario: A 0.9 kg increase in genetic merit for carcass weight of lambs due to better terminal sires without any associated genetic change to ewe mature weights. The gain in genetic merit for carcass weight was assumed to be exploited by commercial farmers selling lambs at the same carcass weight (17 kg) but at an earlier age (169 days instead of 180 days).
- INDKILL scenario: Weighted scenarios of EMKILL, HMKILL and ETKILL together according to the proportion of each scenario estimated to occur in the industry. This included 63% of lambs being maternally sired and slaughtered at a younger age (EMKILL), 27% of lambs being maternally sired and sold at a heavier carcass weight (HMKILL), and 10% of lambs being terminally sired and sold at an earlier age (ETKILL).
- INLB scenario: Increase NLB by 5 percentage points, with associated birth rank and survival changes in ewe litters.

Table 1 provides a detailed list of production and performance parameters applied in each of the six scenarios analysed. Utilising gains in lamb growth by selling lambs earlier rather than at a heavier carcass weight typified many New Zealand sheep farms over the period from 2000 to 2006. This is highlighted by the relatively small (1.5% pa) increase in industry average carcass weights over that period (Ministry of Agriculture and Forestry, 2009b). By contrast, in the period from 1990 to 2000, average carcass weight increased by 2.1% pa from 13.71 kg to 16.56 kg. Price signals from meat processors, which stipulate the optimum lamb carcass weight range, would have contributed to the period of lower gains in actual carcass weight between 2000 and 2006. Consequently, a 0.9 kg increase in genetic merit for carcass weight was simulated by increasing live weight gain to such an extent that lambs obtained the 17 kg carcass weight earlier in the EMKILL and ETKILL scenarios. This reduced the time to slaughter by 11 days based on an average post wean growth rate of 185 grams of live weight per day and a 45% killing out percentage.

A 3.11 kg increase in ewe mature weight per 1 kg increase in lamb CWT was calculated using genetic regression theory and genetic parameters used within Sheep Improvement Ltd's (SIL) national genetic evaluation system for New Zealand. The 3.11 kg value was multiplied by the 0.9 kg increase in genetic merit for carcass weight to equal the 2.8 kg increase in ewe mature weight in scenarios EMKILL and HMKILL.

The reason for the 63%, 27% and 10% weighting for scenarios EMKILL, HMKILL and ETKILL, respectively, in scenario INDKILL was firstly to align to the value of 10% lambs being from terminal sire matings assumed by P.R. Amer (Unpublished data) in the 2002 review of the SIL

TABLE 1: Variable performance and production values for the six scenarios analysed for greenhouse gas emission emissions implications. BASE = No genetic improvement; EMKILL = Earlier kill of lambs in a maternal breed; HMKILL = Heavier kill of lambs in a maternal breed; ETKILL = Earlier kill of lambs in a terminal sire breed; INDKILL = Estimated industry weighting of 63% EMKILL, 27% HMKILL, 10% ETKILL; INLB = Increase number lambs born by 5%; ELW = Ewe live weight; NLB = Number of lambs born per ewe lambing; LCW = Carcass weight of lamb; LCW = Sold, lamb carcass weight sold per breeding ewe; FP = Finishing period (days from birth to slaughter); PWLWGERpl = Post-wean liveweight gain of ewe replacement lambs; ERpl = Days to maturity from slaughter weight.

Parameter	Units	Scenario					
		BASE	EMKILL	HMKILL	ETKILL	INDKILL	INLB
ELW	kg	60	62.8	62.8	60	62.5	60
NLB	%	1.35	1.35	1.35	1.35	1.35	1.40
LCW	kg	17.0	17.0	17.9	17.0	17.24	17.0
LCW sold	kg	15.97	15.97	16.80	15.97	16.20	16.70
FP	days	180	169	180	169	172	180
PWLWGERpl	kg/day	0.160	0.185	0.185	0.185	0.185	0.160
ERpl	days	80	69	80	69	72	80

selection index. The remaining 90% of lambs are assumed to be maternally sired. The proportion of maternal sired lambs sold earlier at the 17 kg carcass weight (EMKILL) was based on the increase in average carcass weight for the 2000 to 2006 period. If 100% of lambs captured the genetic benefit of the increase in carcass weight BV, the average New Zealand carcass weight should have increased by 0.9 kg. According to the Ministry of Agriculture and Forestry (2009b), average lamb carcass weight increased only 0.24 kg. This amounted to 27% of the genetic potential for carcass weight gain over that period. It is therefore likely that the remaining farms slaughtered the faster growth rate lambs earlier.

Potential future progress

Current sheep selection indexes in New Zealand have economic weights assigned to each trait based on how a unit change in the trait impacts on farm profitability. Progress made in each trait is dependent on the relative weightings. A change in relative weights can affect the speed and direction of future genetic progress. The speed and progress toward improving GHG emission efficiency for instance could be altered by including the cost of GHG emissions in the trait relative weightings. To do this, the implications of a unit change in each trait on GHG emissions had to be determined. The same emission factors used for calculating the GHG implications of historic genetic progress were used for estimating the GHG implications of changes in traits.

TABLE 2: Objective trait names, description, response units, and economic weights used in the modelling of responses to selection. DPO = Dual purpose overall index; DPE = Dual purpose environment index; GHG = Greenhouse gas; CO_2-e = CO_2 equivalents; NLB = Number of lambs born; WWT = Weaning weight; CWT = Carcass weight; HFW = Hogget fleece weight; LFW = Lamb fleece weight; EFW = Ewe fleece weight; FEC1&2 = Faecal egg count; AFEC = Adult faecal egg count; SUR = Lamb survival; Leanyield = Carcass lean meat; EweWT = Ewe mature live weight; WWTmat = Maternal weaning weight; Longevity = Ewe longevity.

Parameter	Response unit	DPO (cents/breeding ewe)	DPE (cents/breeding ewe at \$25/t CO_2-e)	GHG intensity (kg CO_2-e /breeding ewe adjusted for production)	GHG gross (kg CO_2-e /breeding ewe unadjusted for production)
NLB	lambs	1,946	2,352	162.5	-180
WWT	kg	151	160	3.37	3.37
CWT		331	353	9.0	1.06
HFW		113	113	0.0	0.0
LFW		423	423	0.0	0.0
EFW		327	327	0.0	0.0
FEC1	eggs/gram	-4.35	-4.41	-0.022	-0.003
FEC2		-4.35	-4.41	-0.022	-0.003
AFEC		-3.28	-3.33	-0.012	-0.002
SUR	lambs	8,758	10,556	719.3	-249.6
Leanyield	kg	465	465	0.0	0.0
EweWT		-147	-160	-5.38	-5.38
WWTmat		133	139	2.70	2.7
Longevity	% of one year-olds	-15,244	-15,923	-271.5	-358.23

Two methodologies for reporting GHG emissions and the trait weights were investigated including a "Gross" and an "Intensity" method. The GHG Gross weights 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 described by Ludemann *et al.* (2011).

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 described by P.R. Amer (Unpublished data).

An economic index (Dual Purpose overall (DPO)), with economic weightings updated to reflect price projections from 2010, is presented in Table 2, along with three additional indexes developed in this study, that incorporate GHG emissions. These selection index weightings were updated from the values presented by Ludemann *et al.* (2011) following feedback from SIL (M.J. Young, Personal communication). There was minimal impact of the changes in weightings on farm profit and GHG intensity genetic progress with less than 0.4% and 3% changes in absolute values respectively. The updated DPO index presented in this paper is anticipated to be implemented for national sheep genetic improvement in New Zealand in the near future.

The GHG Gross index used gross weights, the GHG Intensity index used intensity weights and the Dual Purpose Environment (DPE) index included a combination of the DPO and GHG emission weights. The GHG emission components to the DPE weights were converted to monetary values using an acceptable carbon price. A carbon price of \$25/t CO_2-e was chosen following consultation with the sheep industry.

Table 2 provides an illustration of the variation in relative weightings between traits and between indexes. The DPE weight for NLB (2,352 cents) for example is 406 cents higher than the DPO weight (1,946 cents). Adding the GHG cost of a unit change in NLB, in monetary terms, increased the carbon cost component of the trait weight. The DPE index had greater weighting on the NLB trait relative to the DPO index because NLB reduces GHG intensity in units of kg CO_2-e/kg lamb product per annum, to a greater extent than other traits in the index.

Genetic trends were predicted by modelling the trait responses to selection using each of the contrasting index formulations. The models predicted the annual rates of genetic progress per breeding ewe, for each of the sets of trait weights in each index, as described by P.R. Amer (Unpublished data).

RESULTS

Historic genetic trend

Emissions of 500.1 kg CO_2-e/ breeding ewe per annum or 31.31 kg CO_2-e/kg lamb CWT per anum were calculated for the BASE scenario as shown in Table 3. The EMKILL scenario, with a shorter finishing period to slaughter than the base scenario for maternal sired lambs was estimated to increase emissions per unit of lamb product relative to the BASE by 0.26% pa. The HMKILL scenario simulated maternally sired lambs which grew to a 0.9 kg heavier carcass weight in the same finishing period as the BASE scenario. This resulted in a 0.24% greater annual reduction in emissions relative to the BASE scenario. A greater quantity of lamb carcass to dilute the greater GHG emissions per breeding ewe was the reason for this improvement in GHG efficiency.

The scenario which used genetic improvements in carcass weight by selling terminally sired lambs 11 days earlier at the 17 kg CWT (ETKILL) showed a 0.029 kg CO_2-e/kg lamb CWT per annum or 0.09% per annum, decrease in emission intensity relative to the BASE scenario.

TABLE 3: Annual greenhouse gas emission implications for sheep under six scenarios which simulate genetic changes that occurred between 2000 and 2006.
BASE = No genetic improvement; EMKILL = Earlier kill of lambs in a maternal breed; HMKILL = Heavier kill of lambs in a maternal breed; ETKILL = Earlier kill of lambs in a terminal sire breed; INDKILL = Estimated industry weighting of 63% EMKILL, 27% HMKILL, 10% ETKILL; INLB = Increase number lambs born by 5%; CO_2-e = CO_2 equivalents.

Parameter	Units	Scenario					
		BASE	EMKILL	HMKILL	ETKILL	INDKILL	INLB
Total emissions	kg CO_2-e/breeding ewe	500.1	509.1	517.7	496.9	510.2	506.1
Total emissions	kg CO_2-e/kg lamb carcass sold	31.31	31.88	30.79	31.11	31.51	30.32
Annualised emissions changes	kg CO_2-e/kg lamb carcass sold	0	0.081	-0.075	-0.029	0.028	-0.14
GHG changes relative to BASE	% genetic progress in kg CO_2-e per kg carcass weight	0	0.26	-0.24	-0.09	0.09	-0.45

A likely overall GHG efficiency effect of the change in carcass weight BV using a weighted average of scenarios of EMKILL, HMKILL and ETKILL in the INDKILL scenario was a 0.028 kg CO_2-e/kg CWT per annum or 0.09% per annum, increase in emission intensity.

The 5 percentage point increase in NLB in the INLB scenario, contributed the greatest reduction in emissions per unit of product with 0.14 kg CO_2-e/kg lamb CWT per annum or 0.45% per annum greater annual reductions relative to the BASE scenario.

Potential future genetic trend

Table 4 shows the overall GHG emissions and farm profit progress levels predicted with a range of selection indexes. Selection using the DPO index was predicted to reduce GHG emissions per unit of lamb carcass weight by 0.59% per annum. Using the DPE index there was a 0.62% per annum reduction. The GHG Intensity index had the greatest potential for reducing GHG emissions per unit of product by 0.77% per annum. However, the GHG Intensity index had 26.4 and 26.6 cents/breeding ewe per annum lower genetic progress for farm profit compared to the DPE and DPO indexes respectively. The Gross index which targeted reduced emissions per ewe was predicted to cause a 27.6 cents/breeding ewe per annum reduction in farm profit progress, while increasing GHG emissions per kg of lamb CWT by 0.55% per annum. However, total emissions per breeding ewe were predicted to reduce by 3.50 kg CO_2-e per annum.

DISCUSSION

This study provides evidence that past selection decisions by sheep farmers have reduced GHG emissions per unit of product, despite the fact they were designed to increase farm profits at the fastest possible rate. These reductions have primarily resulted from improvements made in prolificacy as expressed in NLB, in dual purpose sheep, and through growth rate as reflected in carcass weight, in terminally sired lambs.

However, antagonism can exist in some trait changes. This antagonism for instance leads to overall increases in GHG emissions per kg of lamb produced for maternally sired lambs if killed at an earlier age (EMKILL scenario) because of better growth, due to an associated increase in ewe mature weight. Ewes with heavier mature weights in general require greater maintenance energy requirements. This in turn leads to the ewes producing more GHG emissions.

The overall effect of increasing carcass weight in the past (INDKILL scenario) was a 0.09% per annum increase in GHG emissions per kg of product. However, increasing the proportion of terminally sired lambs could have helped improve the GHG efficiency (ETKILL scenario). Terminally sired lambs do not have the correlated affect of increasing ewe mature weight that occurs in a maternal sire system. Capturing the benefit of faster growth rates in lambs through heavier carcass weights (HMKILL scenario) over the same finishing period rather than finishing lambs earlier at a 17 kg CWT, would further dilute the GHG emissions, improving GHG efficiency. However, these recommendations may not be feasible in every farm situation. This is especially so for farms that may run into drought risk later on in the finishing period and would prefer to slaughter lambs earlier. In addition, the ability to increase the proportion of terminally sired lambs could be limited by flock prolificacy.

The GHG Gross index made progress in reducing GHG emissions per ewe (3.50 kg CO_2-e/breeding ewe per annum) but actually increased GHG emissions per kg of lamb product (+0.55 kg CO_2-e/kg lamb per annum). Selecting for lower emissions per breeding ewe would both decrease the productivity of the New Zealand sheep industry, and also result in more lambs being produced in other countries where emissions per unit of product are likely higher (Saunders & Barber, 2008).

Greater improvement in GHG efficiency could be made in the future if the relative weightings in the selection index were altered. Three indexes were proven to provide improvements in GHG intensity in units of emissions per kg of product per annum, including the proposed DPO index, as well as the DPE and Intensity indexes. Farmers who use the DPO index in the future will not only capture gains

TABLE 4: Annual greenhouse gas (GHG) emission and genetic progress in farm profit predicted for a range of index weights. DPO = Dual purpose overall index; DPE = Dual purpose environment index; CWT = Carcass weight.

Index methodology	DPO	DPE	Intensity	Gross
Genetic progress made in farm profit (cents/breeding ewe)	112.2	112.0	85.6	-27.6
Genetic progress made in GHG emission efficiency (kg CO_2-e/kg lamb CWT)	-0.185	-0.193	-0.242	+0.171
% reduction in GHG emissions relative to average total lamb emissions[1]	-0.59	-0.62	-0.77	+0.55
Genetic progress made in GHG emissions (kg CO_2-e/breeding ewe)	+0.96	+1.12	+2.50	-3.50

[1] Based on 31.31 kg CO_2-e/kg lamb CWT (P.R. Amer, Unpublished data).

in farm profitability but also gains in GHG efficiency. If greater gains in improving GHG efficiency are desired then the Intensity and DPE indexes would help achieve this. The DPE index captures a significant proportion (80%) of the GHG benefits of the Intensity index, with a relatively minor impact of less than a 1% reduction on the rate of genetic progress for farm profitability. As such, it is likely to have appeal to progressive sheep farmers supplying meat companies targeting premium markets with environmentally conscious consumers. With an efficient emissions trading scheme incorporating a farmer point of obligation, this may become the economic optimum index. In the meantime, it is only slightly sub-optimal from the perspective of improving profit. Further acceleration of the rate of improvement in GHG emissions efficiency could result from better selection criteria developed for GHG efficiency improving traits, and new genomic technologies hold significant promise in this regard (P.R. Amer, Unpublished data).

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Modelling farm management scenarios that illustrate opportunities farmers have to reduce greenhouse gas emissions while maintaining profitability

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ASBTRACT

Farmer focus groups have been involved in a range of learning exercises and farm system modelling exercises to determine the effect that alternative farm management scenarios would have on greenhouse gas (GHG) emission profiles on-farm. Annual GHG emissions from the current livestock farming policies for the sheep and beef property were estimated to be 4.91 tonnes of carbon dioxide equivalents per hectare (t CO_2-e/ha) or 14.3 kg CO_2-e per kg of meat and fibre produced. All of the alternative farm management options had a small impact on total GHG emissions, ranging from a reduction of 0.67 t CO_2-e/ha to an increase in 0.42 t CO_2-e/ha (-13% and + 8% of the whole farm emissions per hectare, respectively). Most exposed the business to greater risk due to market and climate variability. The Canterbury dairy farm annual GHG emissions from the current farm were estimated to be 13.1 t CO_2-e/ha or 9.9 kg CO_2-e per kg of milk solids. Across the mitigation scenarios investigated total GHG emissions were up to 14% lower than the baseline farm while emissions intensity ranged from 33% higher to 9% lower than the baseline farm. Opportunities which decreased emissions intensity and increased profit were identified; these require consideration of multiple risks around climate and market variability.

Keywords: greenhouse gas; farm management; sheep; dairy.

INTRODUCTION

New Zealand farmers remain uncertain about the importance of climate change and greenhouse gas (GHG) emissions to their businesses (T.G. Parminter, Personal communication). Despite this uncertainty, managing and growing their farm businesses will increasingly involve balancing the demands of export markets, regional and national regulators, and non-agricultural New Zealand stakeholders. Agriculture is included in the New Zealand emissions trading scheme (NZETS) and from 2,015 farmers will potentially be levied for a portion of their farm emissions. This levy would be deducted by the processor, who is the current point of obligation. The levy would be based on the quantity of meat and milk processed.

To help farmers develop a greater understanding of GHG emissions on-farm, several farmer focus groups have been involved in a range of learning exercises and farm system modelling exercises to determine the effect that alternative farm management scenarios would have on GHG