Impact of trait genetic gains on methane emissions from NZ beef and dairy farms

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Abstract

The objective of this study was to provide estimates of the impact of trait genetic gains on methane emissions from NZ dairy and beef farms. The effect of each trait on gross emissions (GE) and emissions intensity (EI) was modelled by estimating effects of trait changes on per-animal feed consumption and the associated methane production, per-animal production and numbers of animals in the system. In dairy, the annual gross emissions per breeding cow associated with genetic change were estimated to increase for all traits except Residual Survival and Fertility. Conversely, emission intensity values were estimated to decrease for Milk Fat, Milk Protein, Milk Solids, Residual Survival, Fertility and Body-condition Score (BCS) as genetic merit improves. In beef production, increases in genetic merit for cow mature weight, cow BCS, cow calving ease and heifer pregnancy were estimated to increase the annual gross emissions per breeding cow. Conversely, an increase in merit associated with stayability and gestation length reduced annual gross emissions per breeding cow. The effect of increasing carcase weight on gross emissions depended on whether the faster growth performance was used to slaughter the animal earlier, or to take the animal through to heavier finishing weights.

Keywords: methane; emissions intensity; gross emissions; dairy; beef

Introduction

Climate change is a pressing global crisis that is already having an impact both in New Zealand (NZ) and internationally. Although New Zealand accounts for a fraction of the world's greenhouse gas emissions, on a per-capita basis it has an over-sized carbon footprint, emitting 18 tonnes of greenhouse gasses per person, per year (OECD 2016). The high per-capita footprint is largely from agricultural sources, which make up close to half of the country's gross emissions (Ministry for the Environment 2019). Within agriculture, dairy cattle are responsible for 47% of emissions, while beef cattle are responsible for 17% (Ministry for the Environment 2019). Methane is generated through ruminant digestion, and the amount of emissions are largely a function of total feed consumed (Fennessy et al. 2019).

Research has demonstrated that genetic gains in livestock production efficiency traits can drive improvements in GHG emissions when expressed on a per-animal or intensity basis (i.e., CO_2 equivalent emissions per unit of product, (Pickering et al. 2015; Quinton et al. 2018; Zhang et al. 2019). Understanding how performance traits that impact on feed intake estimates for dairy and beef cattle will affect our national GHG inventory may help refine the national inventory calculations, and how they should be modified over time to account for genetic and other management changes.

The objective of this study was to provide estimates of the impact of changes in trait-performance values on enteric methane emissions from NZ beef and dairy farms.

Materials and methods

For this study we assumed that the amount of enteric methane emitted by an animal is proportional to the energy consumed by that animal in its feed (Fennessy et al. 2019). Therefore, the methods used here investigate the relationship between genetic gain in each trait and the associated changes in feed-energy requirements. The methane emissions can then be estimated, as carbon dioxide equivalents, (CO_2-eq) as a direct conversion from feed-intake energy, assuming that 21.6 grams of methane is eructated per kg of DM consumed, and that the global warming potential for methane is 25 (1 kg methane = 25 kg CO_2-eq) resulting in a conversion factor of 0.540 kg CO_2-eq/kg DM, as used in the NZ national livestock GHG inventory (Ministry for the Environment 2019).

We are presenting two different measurement definitions to describe the impact of genetic-trait changes on enteric methane emissions as follows:

Gross methane emissions. The gross enteric methane emissions (GME) as CO_2-eq emitted by a breeding cow in a year prior to genetic change (E) was estimated as a product of the number of animals, feed intake, and the conversion coefficient described above.

Methane intensity on an animal-product basis. The emission intensity (EI) was calculated as a ratio of E to total number of product outputs per cow.

The changes in gross emissions and intensity due to genetic improvement were calculated following the methodology set out by Zhang et al. (2019), Amer et al. (2018) and Quinton et al. (2017).

Dairy

The parameters used to estimate gross emissions are summarised in Table 1. For every lactating cow, emissions were aggregated for the cow herself, and the replacements required to maintain the milking herd (Zhang et al. 2019). The feed requirements for each class of animal were calculated using equations developed by Quinton et al. (2018). Briefly, these describe the nutrient requirements of a cow or replacement heifer based on live weight (maintenance), milk production, liveweight gain, mobilisation of body reserves, and stage of gestation. For each of these traits, additional energy may be required to enable a one-unit increase in the trait. For example, the amount of energy required to produce an additional one litre of milk per cow was calculated as the equivalence of the energy required to produce an additional 1 kg of lactose multiplied by the lactose composition of one litre of milk (4.9%).

To calculate emission intensities, total emissions per cow were expressed as a ratio of the total number of product output equivalents per cow. Milk protein was used as the animal product standard with other products converted to protein equivalents using a revenue ratio as described by Zhang et al. (2019). The breeding cow was assumed to be the only stock class that produces milk and meat, with all other products generated through the sale of surplus calves and replacement heifers excluded from the intensity calculations.

To align with the national inventory methodology, gross methane emissions and emissions-intensity values have been calculated using the conversion factor of 0.540 kg CO_2-eq/kg DM instead of 0.583 kg CO_2-eq/kg DM that was used by Zhang et al. (2019). This has caused a slight decrease in both the gross and intensity methane estimates compared to those presented by Zhang et al. (2019).

Beef

The parameters used to estimate gross methane emissions and meat output per breeding cow in a New Zealand beef system are summarised in Table 2. The average number of slaughtered offspring (0.62/cow per year), was based on 0.8 calves/breeding cow/year, of which all males and close to half of females are slaughtered. The average number of replacements reared was 0.18 replacements per breeding cow per year. Average gross methane emissions were calculated from feed intake. Average feed intake for slaughtered offspring was 4,223 kg DM/animal, based on 65% steers each fed 4,291 kg DM to 20 months of age, plus 35% heifers each fed 4,097 kg DM to 26 months of age. Average intake per breeding cow was 4,479 kg DM/year, with each replacement heifer consuming 4,096 kg DM/year. Applying the conversion of 0.540 kg CO_2-eq/kg DM, then emissions per offspring were 2,280 kg CO_2-eq per slaughtered offspring, per replacement is 2,212 kg CO_2-eq per replacement and per cow is 1,462 kg CO_2-eq per breeding cow per year. Therefore, average total system-wide gross emissions (based on 0.62 offspring slaughtered, and 0.18 replacements) were 3,276 kg CO_2-eq per breeding cow per year.

Average product output per slaughtered offspring was calculated from an average carcase weight of 287 kg, assuming 0.686 kg meat/kg carcase; therefore producing 197 kg meat/offspring. Average product output per breeding cow was calculated from average cull cow carcase weight of 270 kg, assuming 0.6 kg meat/kg carcase and that 18% of cows are culled per year resulting in 29.2 kg meat per breeding cow per year. Applying the above values, total system-wide meat product per average breeding female was 152 kg meat/breeding cow/year and average system-wide emissions intensity of 27.8 kg CO_2-eq/kg meat per breeding cow per year.

Table 1 Key assumptions used in the calculations of methane emissions intensity weightings for the New Zealand dairy industry (Zhang et al. 2019).

Variable	Unit	Value
Energy/kg of DM	MJ of ME	11.26
Average cow annual milk yield	kg	3,897
Average cow live weight	kg	450
Milk components		
Protein	%	3.91
Fat	%	4.85
Lactose	%	4.90
Solid	%	8.68
Herd replacement rate	%	22
Cows wintered off platform	%	35.8
Cows wintered on platform	%	64.2

Table 2 Key assumptions in the calculation of methane intensity weightings for the New Zealand beef industry.

Variable	Unit	Value
Energy/kg of DM	MJ of ME	10.05
Pregnancy rate	%	85
Pre-wean survival	%	95
Replacement rate	%	18
Proportion daughters retained	%	45
Proportion of slaughters which are female	%	35
Proportion of slaughters which are male	%	65
Average cow live weight	kg	550
Average weaning weight	kg	243
Dressing proportion (prime)	%	56
Dressing proportion (cow)	%	49

Results

Dairy

The emission values for each of the traits within the national breeding objective are presented in Table 3. When genetic merit increases by one unit, the annual gross emissions per breeding cow associated with genetic change were estimated to increase for all traits except Residual Survival and Fertility. Conversely, emission intensity values were estimated to decrease for Milk Fat, Milk Protein, Milk Solids, Residual Survival, Fertility and Body Condition Score (BCS) as genetic merit improves. Live-weight and Milk Volume emissions-intensity values were estimated to be positive but on a much smaller scale compared to other traits. High somatic cell scores (SCS) result in discarded milk, with no effect on methane, so SCS had a small unfavourable emissions-intensity value.

From the milk component figures presented by Zhang et al. (2019), we calculated that to increase total milk solids by one kilogram requires 6.52 kg of dry matter, which equates to an increase of 3.52 kg CO_2-eq emission/breeding cow/year.

Table 3 Trait-specific estimated effects of a one-unit trait change in gross methane emissions (kg CO_2-eq emission/breeding cow/year, GE) and emission intensity (kg CO_2-eq emission/kg milk protein-eq, EI) for NZ dairy cows.

Trait	Unit	GE	EI
Milk fat	kg	3.31	-0.015
Milk protein	kg	2.03	-0.015
Milk volume	L	0.07	0.0003
Milk solids	kg	3.52	-0.013
Liveweight	kg	2.22	0.005
Residual survival	day	-0.22	-0.0006
Somatic cell score	score	0	0.03
Fertility	%	-5.81	-0.03
Body-condition score	score	20.4	-0.24

A negative emissions-intensity value for any trait indicates that the increase in gross emissions associated with that trait is proportionally smaller than the increase in output of animal product.

Beef

The gross emission (GE) and emissions-intensity (EI) values for a range of traits used in the NZ beef industry are presented in Table 4. A one-unit increase in genetic value for cow mature weight, cow BCS, cow-calving ease and heifer pregnancy was estimated to increase the annual gross emissions per breeding cow. Conversely, an increase in merit associated with stayability and gestation length reduced annual gross emissions per breeding cow. The level of gross emissions associated with changes in genetic merit for carcase weight and weaning weight depended on whether the faster growth performance was used to slaughter the animal earlier (by 1.8 days per kg of carcase weight), and therefore, save feed and the corresponding emissions, or if the animal is taken through to a heavier slaughter weight, which increases the level of feed needed.

Increasing the carcase weight of offspring and increasing cow mature weight by a one-unit trait change were predicted to increase system CO_2-eq/kg meat per breeding cow per year. This was also the case for heifer pregnancy and cow BCS. Conversely, increasing carcase weight for early slaughter animals, decreasing gestation length and increasing stayability and calving ease had negative relationships with system-emissions intensity, meaning that increasing values for these traits were predicted to reduce system kg CO_2-eq/kg meat per breeding cow per year.

Table 4 Trait-specific estimated effects of a one-unit trait change in gross methane emissions (kg CO_2-eq emission/breeding cow/year, GE) and emission intensity (kg CO_2-eq emission/kg meat produced/year, EI) for NZ beef cattle.

Trait	GE	EI
Carcase weight		
Early slaughter steers	-4.21	-0.010
Heavier slaughter steers	8.49	0.003
Early slaughter heifers	-3.04	-0.007
Heavier slaughter heifers	9.28	0.004
Cow mature weight		
Maintenance energy	1.99	0.003
Replacement growth	6.92	0.0004
Weaning weight		
Slaughtered (Maternal)	4.18	0.009
Stores (Mat. & Term.)	-1.09	-0.002
Heifer pregnancy	84.06	0.005
Gestation length	-3.98	-0.005
Cow BCS	14.47	0.018
Stayability	-9.81	-0.026
Calving ease		
Maternal bull - direct	4.01	-0.002
Mat bull - descendants of daughters	3.62	-0.0006
Terminal bull	3.62	-0.002

Discussion

In 2019, the Climate Change Response (Zero Carbon) Amendment Act set into law a new domestic target of 24 to 47 per cent below 2017 biogenic methane emissions by 2050, including 10 per cent below 2017 biogenic methane emissions by 2030. These targets focus solely on reducing gross emissions, however, emissions intensity is a more informative measurement of the effect of genetic improvement of dairy and beef cattle compared with gross emissions, as it considers both improved feed utilisation of individual animals and improved total system efficiency. In contrast, focusing on a reduction in gross emissions can encourage decreasing per-animal production outputs and, consequently, decrease efficiency of production, which is highly counterintuitive (Quinton et al. 2018; Fennessy et al. 2019). The development of emissions-mitigation strategies that do not negatively affect productivity is recognised as a major challenge for ruminant nutritionists and geneticists (Cottle et al. 2011). New selection criteria will be required to reduce both gross emissions and emissions intensity. Herd et al. (2014) suggested that methane emissions could be presented as methane yield (methane production per unit of feed intake), or residual methane (observed methane production less the expected methane production at that level of feed intake). There still will be a trade-off with the inclusion of these criteria, however, as selection effort targeted at this new methane-per-unit feed criterion will draw selection emphasis and effort away from existing traits, which will reduce ongoing profitability gains from genetic improvement, in the absence of a market mechanism to incentivise reductions in emissions. New data and recording systems that facilitate accurate predictions in changes in animal feed consumption at animal and herd level, will be required so that gains from this new trait can be captured in the inventory, and to incentivise farmers to adopt breeding and other practices that reduce farm emissions.

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References

Amer PR, Hely FS, Quinton CD, Cromie AR 2018. A methodology framework for weighting genetic traits that impact greenhouse gas emission intensities in selection indexes. Animal 12(1): 5-11. doi.org/10.1017/S1751731117001549.

Cottle DJ, Nolan JV, Wiedemann SG 2011. Ruminant enteric methane mitigation: A review. Animal Production Science 51(6): 491-514. doi.org/10.1071/AN10163.

Fennessy PF, Byrne TJ, Proctor LE, Amer PR 2019. The potential impact of breeding strategies to reduce methane output from beef cattle. Animal Production Science 59(9): 1598. doi.org/10.1071/AN18186.

Herd RM, Arthur PF, Donoghue KA, Bird SH, Bird-Gardiner T, Hegarty RS 2014. Measures of methane production and their phenotypic relationships with dry matter intake, growth, and body composition traits in beef cattle. Journal of Animal Science 92(11): 5267-5274. doi.org/10.2527/jas.2014-8273.

Ministry for the Environment 2019. New Zealand's Greenhouse Gas Inventory 1990-2017.

OECD 2016. OECD Environment Statistics: Greenhouse gas emissions by source 2016.

Pickering NK, Oddy VH, Basarab J, Cammack K, Hayes B, Hegarty RS, Lassen J, McEwan JC, Miller S, Pinares-Patino CS, De Haas Y 2015. Animal board invited review: Genetic possibilities to reduce enteric methane emissions from ruminants. Animal 9(9): 1431-1440. doi.org/10.1017/S1751731115000968.

Quinton CD, Hely FS, Amer PR, Byrne TJ, Cromie AR 2018. Prediction of effects of beef selection indexes on greenhouse gas emissions. Animal 12(5): 889-897. doi.org/10.1017/S1751731117002373.

Zhang X, Amer PR, Jenkins GM, Sise JA, Santos B, Quinton CD 2019. Prediction of effects of dairy selection indexes on methane emissions. Journal of Dairy Science 102(12): 11153-11168. doi.org/10.3168/jds.2019-16943.