Effects of genetic gains in the Irish beef maternal replacement index on greenhouse gas emissions

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Abstract

There is evidence globally that genetic gains in cattle production efficiency traits can also drive improvements in greenhouse gas (GHG) emissions intensity (i.e. methane or CO_2 equivalent emissions per unit of product). In this study, we predicted improvements in GHG emissions intensity expected from genetic progress in the Irish Cattle Breeding Federation (ICBF) Beef Maternal Replacement Index due to the proposed Beef Data and Genomics Programme (BDGP) and associated breeding strategies.

Effects of each trait in the Maternal Replacement Index on gross GHG emissions (kg CO_2e/cow/year/trait unit) and GHG emissions intensity (kg CO_2e/kg meat/cow/year/trait unit) were modelled for age- and weight-constant slaughter systems. Carcass Weight and Feed Intake of the calf, along with Calving Interval, Age at First Calving, and Live Weight of the cow influenced gross CO_2 emissions though individual feed consumption. GHG intensity was further influenced by Weight, Conformation and Fat of the calf carcass which affected kg meat produced per calf and per cow, as well as Survival and Calving Interval which affected system-wide numbers of animals.

Genetic trends in index traits were used to predict GHG reductions that could be achieved through effective deployment of beef breeding programs. Genetic gain in the Replacement Index was predicted to reduce GHG intensity on a system-wide basis. Summed over changes in all index traits, GHG intensity was estimated to be reduced by 0.009 kg CO_2e/kg meat/year/€ index value. By combining the Replacement Index with an Emissions Intensity Index created from the trait effects, GHG emissions could be reduced by a further 16% with a trade-off of only 4% decrease in Replacement Index € progress.

Proposed breeding strategies integrated with the BDGP national initiative were predicted to improve long-term industry profitability and GHG emissions intensities. In a conservative scenario incorporating genomic selection on the Replacement index, an average trend of 5€/year improvement in index value and corresponding reductions of 229 kt CO_2e after 5 years, and 1952 kt CO_2e after 20 years were predicted. An optimal scenario of maximum use of elite Replacement bulls by AI in pedigree herds that sell large numbers of bulls for natural mating and with genomic selection led to faster genetic progress of 9.5€/year in index value and reductions of 350 kt CO_2e after 5 years, and 3335 kt CO_2e after 20 years.

Keywords: beef, greenhouse gas, selection, economic index, breeding program

Introduction

There is evidence globally that genetic gains in cattle production efficiency traits can also drive improvements in greenhouse gas (GHG) emissions intensity (i.e. CH_4 or CO_2 equivalent emissions per unit of product) (Pickering *et al*., 2015). Generally, increasing growth rate and numbers of animals in a system will increase overall feed intake and resultant gross GHG. However, genetic and management improvements also increase system-wide production efficiency, so that proportionally more product is made per unit feed input. This comes from more efficient feed conversion into product on an individual animal basis, plus improved reproductive and survival rates that improve system-wide output of each breeding animal.

The objective of this study was to use international "best-practice" methodology to predict improvements in GHG emissions intensity expected from genetic progress in the Irish Cattle Breeding Federation (ICBF) Beef Indexes and Beef Data and Genomics Programme (BDGP) breeding strategies.

Methods

The ICBF beef Maternal Replacement Index consists of calf traits Calving Difficulty, Gestation Length, Mortality, Carcass Weight, Carcass Conformation, Carcass Fat, Feed Intake, and Docility; plus cow traits Cow Survival, Calving Interval, Age at First Calving, Maternal Weaning Weight, Maternal Calving Difficulty, Cow Live Weight, Heifer Live Weight, Cull Cow Carcass Weight, and Docility.

Effects of trait changes on gross GHG emissions

Effects of each trait on gross GHG emissions (kg CO_2e/breeding cow/year) were quantified based on how changes in these traits directly affect feed intake, assuming 0.583 kg CO_2e/kg DM feed intake (Fennessy *et al*., 2015). Gross GHG effects (kg change in CO_2e / unit change in trait) were estimated for calf Feed Intake, based on the above relationship between feed and CO_2e; Calving Interval, based on change in number of calves produced per year and additional cow feed required to produce those calves; Age at First Calving, based on additional feed required for maintenance of a mature cow for each day of delay until first calving; and Cow Live Weight and Heifer Live Weight, based on additional feed requirements of larger animals. Other traits in the index were assumed to have no influence on gross GHG.

Effects of trait changes on GHG emissions intensity

Effects of each trait on GHG emissions intensity (kg CO_2e/kg meat /cow/year) were quantified from the effects of trait changes on system-wide emissions intensity ($EI = \sum e / \sum y$). The sum of all gross GHG emissions produced per breeding cow per year ($\sum e$) was estimated from number of slaughtered offspring, kg CO_2e per slaughtered offspring, number of replacement heifers reared, kg CO_2e per replacement, and kg CO_2e per breeding cow; all as functions of genetic traits g. The sum of all meat produced ($\sum y$) per breeding cow per year was estimated from number of slaughtered offspring, kg meat per slaughtered offspring, and kg meat per cull cow; all as functions of g.

System-wide change in EI per unit change in each index trait g (dEI/dg) was calculated as the first partial derivative of EI with respect to g. Offspring meat output was influenced by calf traits Carcass Weight, Carcass Conformation, and Carcass Fat. Cull cow meat output was influenced by Cow Carcass Weight. Number of replacement heifers required was influenced by Cow Survival. Number of offspring per breeding cow was influenced by calf Mortality and cow

Calving Interval. Other index traits were assumed to have no effect on EI. Annual change in EI (kg CO_2e/kg meat/cow/year/trait unit) were calculated by multiplying by the trait number of discounted genetic expressions per year (Amer *et al.*, 2001).

Effects of index selection and BDGP breeding strategies

For each trait, the total yearly change in GHG intensity due to genetic gain in Maternal Replacement Index value was calculated from annual change in EI multiplied by the change in each trait achieved from index selection (trait unit/€ Maternal Replacement Index value), as calculated by regression of ICBF bulls' proofs for each index trait on their total index value. The sum of values for all traits was the total change in GHG emission intensity due to genetic gain in index value (kg CO_2e/kg meat/cow/year/€ Replacement Index value).

Trait yearly effects on GHG intensity were also applied as index weights to form an EI Index, so that by multiplying individual bulls' EBVs were by these weights, a total EI Index value for each animal may be calculated. A Combined Replacement + EI Index was also explored with a range of relative contributions of Replacement vs. EI calculating index values for groups of evaluated Irish bulls, and predicting effects on genetic and economic change.

Industry-wide effects of BDGP breeding schemes on GHG emissions intensity were evaluated by predicting change in Replacement Index and EI Index over 20 years, applying selection with the Replacement Index, or with a Combined Replacement + EI Index. Scenarios included increased usage of elite AI sires, and genomics to improve accuracy.

Results and Discussion

Effects of Replacement Index on gross GHG and emissions intensity

Effects of index traits on gross GHG and annual emissions intensity for an age-constant slaughter endpoint system are shown in Table 1. Calf Feed Intake, and cow Calving Interval, Age at First Calving, and Live Weights influenced gross emissions though individual feed consumption. On an age-constant slaughter basis, calf Carcass Weight gross GHG was assumed to be zero because Feed Intake is a separate index trait, so the estimate was defined as effect of weight change at a fixed age independent of feed intake. However, on a weight-constant system with variable number of days fed, faster growth reduced number of feeding days and resultant gross GHG emission.

Trait effects on GHG intensity were influenced by gross GHG effect described above, plus effects on kg meat produced per animal and system-wide number of animals. Carcass Weights, Conformation and Fat which affected kg meat produced. Number of offspring per breeding cow was influenced by calf Mortality and cow Calving Interval, and number of replacements heifers required in the system was influenced by Cow Survival. Therefore, the typical beef desired trait goals of increased survival, growth to slaughter, carcass muscling (conformation), and decreased feed inputs, carcass fat, calving interval, and age at maturity were all predicted to reduce system-wide GHG intensity.

Based on current genetic trends in index traits, genetic gain in the Replacement Index was predicted to reduce GHG intensity on a system-wide basis. Combining effects from responses in all traits in the Maternal Replacement Index, total GHG intensity was estimated to be reduced by 0.009 kg CO_2e/kg meat/year/€ index value in both age- and weight-constant slaughter systems (Table 1).

Table 1. Effects of Replacement Index traits on gross GHG emissions and system GHG emissions intensity for an age-constant slaughter system, and predicted trait-wise responses in GHG emission intensity due to genetic gain in the Replacement Index.

Part	Trait (unit)	Effect on Gross GHG (kg CO_2e / trait unit)	Effect on GHG intensity (kg CO_2e/kg meat /trait unit/year)	Response in GHG intensity (kg CO_2e/kg meat /trait unit/year/€ index)
Calf	Mortality (%)	0	0.14524	-0.0003297
	Carcass Weight (kg)[1]	0	-0.02498	0.0005131
	Carcass Conformation (score)	0	-0.14829	0.0002507
	Carcass Fat (score)	0	0.10857	0.0001455
	Feed Intake (kg DM)	0.583	0.00107	0.0000005
Cow	Cow Survival (%)	0	-0.20715	-0.0039989
	Calving Interval (d)	-1.232	0.06428	-0.0018198
	Age at First Calving (d)	3.167	0.01106	-0.0005025
	Cow Live Weight (kg)	1.864	0.02336	-0.0026804
	Heifer Live Weight (kg)	5.483	0.00383	-0.0004393
	Cull Cow Carcass Weight (kg)	0	-0.00001	0.0000004
				Total = -0.0088604

[1] For weight-constant slaughter system, gross GHG = -8.844 kg CO_2e/kg, GHG intensity = -0.01629 kg CO_2e/kg meat/kg/year, response = 0.0003347 kg CO_2e/kg meat/kg/year/€ index.

Industry-wide effects of index selection and BDGP breeding strategies

In addition to quantifying average GHG intensity reduction via selection, trait effects on GHG intensity (Table 1) can be applied as index weights to form an EI Index. This is a potential method to evaluate individual bulls for their genetic potential to reduce EI, where low or negative EI index values are preferred. However, this EI Index is not integrated with production economics and is therefore impractical for long-term genetic improvement. Compared with the Replacement Index, this EI Index put greater emphasis on improving Cow Survival and reducing Cow Weight, and less emphasis on milk production (Maternal Weaning Weight). Therefore, some trade-off between economic gain and EI reduction exists.

A Combined Replacement + EI Index can balance economic and GHG reduction goals. By shifting the relative emphasis from Replacement toward EI, marked improvement in EI progress could be obtained with little loss in € progress. An optimal Combined Replacement + EI Index was predicted to reduce GHG emissions by a further 16% compared with Replacement only, with a trade-off of only 4% decrease in Replacement Index € progress.

Proposed breeding strategies integrated with the BDGP national initiative were predicted to improve long-term industry profitability and GHG emissions intensities. In a conservative scenario incorporating genomic selection on the Replacement index, an average trend of 5€/year improvement in index value and corresponding reductions of 229 kt CO_2e after 5 years, and 1952 kt CO_2e after 20 years were predicted. An optimal scenario of maximum use of elite Replacement Index bulls by AI in pedigree herds that sell large numbers of bulls for natural mating and with genomic selection led to faster genetic progress of 9.5€/year in index value and reductions of 350 kt CO_2e after 5 years, and 3335 kt CO_2e after 20 years.

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