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EFFECTS OF IRISH BEEF INDEXES AND BREEDING PROGRAMS ON GREENHOUSE GAS EMISSIONS

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SUMMARY

Effects of Irish beef Maternal Replacement Index and Beef Data and Genomics Program on system-wide greenhouse gas (GHG) emissions intensity were predicted. Expected index selection responses of increased offspring feed intake, decreased carcass weight and conformation, and increased carcass fat were predicted to increase system GHG intensity. These were offset by expected decreases in offspring mortality, cow and heifer live weights, calving interval, and age at first calving, and increased cow survival that were predicted to reduce system GHG intensity. Summed over responses in all traits, system GHG intensity was predicted to be reduced by 0.0088603 kg CO_2e/kg meat/breeding cow/year/€ index. Genomic selection and AI strategies were predicted to improve genetic progress and reduce total CO_2e by 5-10% after 20 years.

INTRODUCTION

Beef cattle genetic improvement programs have a key role in reducing global greenhouse gas (GHG) emissions. Genetic gains in livestock productivity and efficiency can reduce GHG emissions when expressed on a per-animal or intensity basis (i.e. emissions per unit of product) (Wall *et al.* 2010; Capper 2011; Hayes *et al.* 2013), and these changes from selection are permanent and cumulative over generations. Recognizing this, the Irish government has launched the Beef Data and Genomics Program (BDGP) as a major initiative to accelerate genetic progress for beef maternal efficiency traits and reduce GHG emissions. The potential system-wide impacts of trait genetic changes on GHG emissions therefore need to be quantified.

The objectives of this study were to quantify the effects of each trait in this index on system GHG emissions intensity, and predict the overall effects of genetic change from index selection and BDGP strategies on system GHG emissions intensity.

MATERIALS AND METHODS

The ICBF beef Maternal Replacement Index is an economic index containing offspring and cow production, carcass, reproduction and survival traits. System-wide emissions intensity (EI) per breeding cow per year was calculated as the sum of all system emissions (Σe) divided by the sum of all meat produced in the system (Σm), as follows:

$$EI = \frac{\sum e}{\sum m} = \frac{(o \times e_{offspring}) + (r \times e_{replace}) + (e_{cow})}{(o \times m_{offspring}) + (m_{cow})}$$

where o=number of slaughtered offspring per breeding cow per year, r=number of replacements reared per breeding cow per year, $e_{offspring}$=gross emissions (kg CO_2e) per slaughtered offspring over its lifetime, $e_{replace}$=gross emissions per replacement over her rearing period, e_{cow}=gross emissions per breeding cow per year, $m_{offspring}$=meat output (kg meat) per slaughtered offspring, and m_{cow}=meat output per breeding cow per year. These factors were considered as functions of the index genetic traits g.

The change in EI per change in each index trait was calculated as the partial derivative of EI with respect to each trait g (dEI/dg), as follows:

$$\frac{dEI}{dg} \approx \frac{1}{\sum m}\left\{\begin{array}{l}\left[\beta_{e.offspring}(g)\times o\right]+\left[\beta_{e.replace}(g)\times r\right]+\beta_{e.cow}(g)-\left[\beta_{m.offspring}(g)\times o\frac{\sum e}{\sum m}\right]\\ -\left[\beta_{m.cow}(g)\times\frac{1}{\sum m}\right]+\left[\beta_{r}(g)\times e_{replace}\right]+\left[\beta_{o}(g)\times\left(e_{offspring}-m_{offspring}\frac{\sum e}{\sum m}\right)\right]\end{array}\right\}$$

where for each trait, $\beta_{e.offspring}(g)$, $\beta_{e.replace}(g)$, and $\beta_{e.cow}(g)$ are traits effects on gross emissions per slaughtered offspring over its lifetime, per replacement reared from birth until it becomes a breeding cow, and per breeding cow per year, respectively; $\beta_{m.offspring}(g)$ and $\beta_{m.cow}(g)$ are trait effects on meat produced per slaughtered offspring, and per breeding cow per year, respectively; $\beta_r(g)$ and $\beta_o(g)$ are trait effects on number of replacement heifers required and number of offspring reared, per breeding cow per year, respectively; and other variables as previously defined.

For the current age-constant slaughter system, numbers of animals were o=0.6 and r=0.2. Gross emissions were calculated from feed intake, assuming feed intake of offspring, replacements, and cows of 3970.6 kg DM, 3522.4 kg DM, and 2874.6 kg DM, respectively, and conversion of 0.583 kg CO_2e/kg DM (Fennessy *et al.* 2015). Therefore, $e_{offspring}$=2314.9 kg CO_2e, $e_{replace}$=2053.6 kg CO_2e, and e_{cow}=1675.9 kg CO_2e, per breeding cow per year. Meat outputs were $m_{offspring}$=234.61 kg meat and m_{cow}=35.09 kg meat, per breeding cow per year. Therefore, Σe=3475.5 kg CO_2e, Σm=175.9 kg meat, and EI=160.5 kg CO_2e/kg meat, per breeding cow per year.

Estimated trait effects $\beta(g)$ are shown in Table 1. Effects on gross emissions were based on how trait changes affect feed intake, with conversion of 0.583 kg CO_2e/kg DM. Offspring emissions were affected by feed intake. Replacement emissions were affected by heifer live weight based on additional feed required of 9.406 kg DM/kg LW. Cow emissions were affected by cow live weight based on additional feed required of 3.197 kg DM/kg LW, and age at first calving based on additional feed required of 5.432 kg DM/d delay until calving. Meat produced was affected by carcass weight, conformation and fat (Drennan *et al.* 2009). Number of replacement heifers required was affected by cow survival. Number of offspring reared was affected by offspring mortality and calving interval. Other index traits were assumed to have no influence on equation terms.

Trait responses to index selection (trait unit/€ index value; Table 1) were predicted from linear regressions of individual bulls' ICBF proofs for each trait to their Maternal Replacement Index value. Trait-wise yearly responses in emissions intensity from index selection were calculated from trait *dEI/dg*, multiplied by the trait number of discounted genetic expressions (Table 1; Amer *et al.* 2001) and the predicted trait responses to index selection. Values were summed over all traits to obtain total response in EI per unit of index genetic gain.

RESULTS AND DISCUSSION

Effects of index traits on system emissions intensity. Offspring feed intake, mortality, carcass fat, cow and heifer live weights, calving interval, and age at first calving had numerically positive relationships with system EI, while offspring carcass weight, carcass conformation, and cow survival had negative relationships with system EI (Table 1). These values could potentially be used as weightings in an index to evaluate individual bulls for GHG emissions intensity. However, an emissions-only index would not consider trait economics. A more practical index for would combine economics of production from the Replacement Index with the GHG emissions intensity changes and consider potential trade-offs between direct farm profit improvement and GHG intensity.

Expected responses to index selection. Expected responses of increased offspring feed intake, decreased offspring carcass weight and conformation, increased carcass fat, and decreased cow carcass weight were predicted to increase system GHG intensity (Table 1). These were offset by expected decreases in offspring mortality, cow and heifer live weights, calving interval, and age at first calving, and increased cow survival that were predicted to reduce system GHG intensity (Table 1). Cow live weight, calving interval and survival had the greatest effects on system GHG intensity, while other traits had comparatively minor effects. Summed over responses in all traits, system GHG intensity was predicted to be reduced 0.0088603 kg CO_2e/kg meat/breeding cow/year/€ index.

Table 1. Maternal Replacement Index trait specific effects, effects on system emissions intensity, discounted genetic expressions (DGE) per year, and predicted trait unit and emissions intensity responses to index selection

Trait (unit)	Specific effects in model (change/trait unit)	Effect on EI (kg CO_2e/kg meat/trait unit)	DGE	Trait response (trait unit/€ index)	EI response (kg CO_2e/kg meat/€ index)
Feed intake (kg DM/d)	$\beta_{e.offspring}$(FI)=0.583 kg CO_2e	0.0020	0.54	0.0005	0.0000005
Mortality (%)	β_o(M)=-0.01 offspring	0.1320	1.10	-0.0023	-0.0003297
Carcass weight (kg)	$\beta_{m.offspring}$(CW)=0.686 kg meat	-0.0463	0.54	-0.0205	0.0005131
Carcass conformation (score)	$\beta_{m.offspring}$(CC)=4.072 kg meat	-0.2746	0.54	-0.0017	0.0002507
Carcass fat (score)	$\beta_{m.offspring}$(CF)=-2.982 kg meat	0.2011	0.54	0.0013	0.0001455
Cow live weight (kg)	$\beta_{e.cow}$(CLW)=1.864 kg CO_2e	0.0106	2.204	-0.1147	-0.0026804
Heifer live weight (kg)	$\beta_{e.replace}$(HLW)=5.484 kg CO_2e	0.0062	0.614	-0.1147	-0.0004393
Calving interval (d)	$\beta_{e.cow}$(CI)=-1.232 kg CO_2e, β_o(CI)=-0.0027 offspring	0.0292	2.204	-0.0283	-0.0018198
Age at first calving (d)	$\beta_{e.cow}$(AFC)=3.167 kg CO_2e	0.0180	0.614	-0.0454	-0.0005025
Cow survival (%)	β_r(S)=-0.008 heifers	-0.0940	2.204	0.0193	-0.0039989
Cow carcass weight (kg)	$\beta_{m.cow}$(CCW)=0.6 kg meat	-0.00002	0.288	-0.0777	0.0000004

These findings are consistent with studies that have found GHG emissions benefits arising from productivity and efficiency gains over time (Wall *et al.* 2010; Capper 2011; Hayes *et al.* 2013). Generally, increasing growth rate and numbers of animals in a system will increase overall feed intake and resultant gross GHG produced by the system. However, genetic and management improvements have also increased system-wide efficiency, meaning that more product is made per unit feed input. This comes from more efficient feed utilization on an individual animal basis, plus improved reproductive and survival rates that mean each breeding animal and associated replacements can produce more output-generating animals.

Genetic change from selection generates permanent and cumulative effects on traits, and therefore system-wide reductions in GHG achieved through selection will continue over generations. In previous studies (Hely *et al.* 2016; Hely and Amer 2016), genetic trends for the Irish BDGP were predicted for three scenarios: 1) current selection with Replacement Index; 2) genomic selection, increasing use of top progeny-tested maternal AI bulls to 30% in pedigree herds and 20% in commercial suckler herds; and 3) genomic selection with use of elite AI sires increased to 50% in pedigree herds and 30% in commercial herds (Table 2). Applying these predicted trends to the estimated reduction of 0.0088603 kg CO_2e/kg meat/breeding cow/year/€ Replacement Index, and maintaining a fixed population size of 800,000 breeding cows, annual GHG emissions can be reduced up to 9.5% which corresponds to a total reduction of 3335 kt CO_2e after 20 years (Table 2).

Therefore, Irish beef genetic improvement initiatives are predicted to have important outcomes of reducing GHG emissions.

Table 2. Predictions of genetic trends in Maternal Replacement Index from 3 scenarios, and corresponding percent annual and total GHG emissions reductions after 5 and 20 years with constant population size

Scenario	Index trend (€/y)	5y annual GHG	5y GHG (kt CO_2e)	20y annual GHG	20y GHG (kt CO_2e)
1) Current selection	+1.67	-0.4%	-34	-1.5%	-481
2) Genomic selection + increased use of elite AI sires	+5	-1.9%	-229	-5.4%	-1952
3) Genomic selection + maximum use of elite AI sires	+9	-3.1%	-350	-9.5%	-3335

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