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Breeding and management of dairy cows to increase profit and reduce greenhouse gas emissions

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Abstract

The aim of this study was to compare the effect of changing a range of biological traits on farm profit and greenhouse gas emissions (GHG; expressed as carbon dioxide equivalent, CO_2-eq.) for dairy cows in Northern Ireland, and also in the whole of the UK. An average cow was modelled for each population of animals, using average values from milk recording records. Previous work developed a dynamic model, to include nutrient partitioning to allow investigation of GHG abatement options over an animal's lifetime. A Markov chain approach was used to describe the steady-state herd structure, as well as estimate the CO_2-eq. emissions per cow and per kilogram of milk solids (MS). The effects of a single phenotypic and genetic standard deviation change in a range of production and fitness traits were assessed. For each dairy cow population, the study will identify traits that will improve production efficiency by bringing about a desirable increase in profit, and reduce average CO_2-eq. emissions per cow and per kg MS of herds. Selective breeding and appropriate management can both potentially improve health, fertility and feed utilisation of dairy systems and reduce its environmental impact.

Keywords: *dairy cow; biological variation; greenhouse gas emissions; profit.*

JEL code *Q1*

1. Introduction

Dairy production has made large advances in efficiencies over the past 60 years as a result of changes in breeding, nutrition and management. However, losses of dietary energy as well as nitrogen in manure, are significant inefficiencies and sources of pollution in the form of methane (CH_4) and nitrous oxide (N_2O) gases. Given the effect of GHG emission levels on climate change, mitigation of these gases has gained importance in recent years. Dynamic models, as used in the current study, that encompass differences in genotype, nutrition and environment and their effect on feed intake, growth and body composition, are being developed to allow farmers to evaluate their own system (economically and in terms of resource use). This allows phenotypic and genetic values to be derived, which are tailored to an individual system and allow improvements in production efficiency and environmental impact to be assessed at the herd level. This information is needed to allow improvements in production efficiency and emission intensities to be quantified by individual herds. While diet manipulation and management changes can alter the potential production of emissions, selective breeding offers a cost-effective means of abating emissions in the medium to long-term, with the effect being permanent and cumulative.

Previous work by Bell *et al.* (2013; 2015) showed that improved efficiencies of production associated with health and fertility (and overall survival), as well as feed efficiency, could reduce GHG emissions from dairy herds in the UK and Australia. The current study builds on that work, and looks to use the same model to assess the impact of changing biological traits within Northern Ireland, and compare the results to those from across the UK. The study also explores the economic, phenotypic, genetic and GHG emission responses to adjusting a wide range of production and fitness traits.

The objectives of the present study were: (1) to model the average milk-recorded dairy herd in Northern Ireland and the UK, (2) to assess the effect of a phenotypic and genetic standard deviation change in a range of production and fitness traits on profit per cow, GHG emissions per cow and per kg MS for the average dairy herd, (3) to assess the economic responses to selection and reduction in emissions per cow and per kg MS from selection on multiple production and fitness traits, and (4) compare responses to changing biological traits for the average herd in Northern Ireland and the UK.

2. Materials and Methods

2.1 Model and data

The Breeding Objectives Model was constructed in Microsoft Excel by Bell *et al.* (2013, 2015) to calculate changes in profit per cow in response to changes in biological traits. The economic model dynamically describes the lifetime of an individual animal and the dairy herd, to allow changes in GHG emissions per cow and per kg MS due to a management or genetic change to be assessed. Responses were quantified by calculating differences between the current state (baseline situation) and a positive or negative change in a biological trait (adjusted situation).

Data for average number of days for each lactation, milk production at maturity, milk composition and calving intervals were obtained for the year 2014 from the Centre for Dairy Information (CDI, 2015), which collates data from recorded dairy cows in all regions of the UK. Production data were obtained from approximately 513,000 cows in the UK and a subset of 47,000 in Northern Ireland. Data represented the average milk-recorded dairy herd (referred to as the average herd) in Northern Ireland and the UK (Table 1). Also, production data from 1,891 dairy cows at the Agri-Food and Biosciences Institute (AFBI) in Northern Ireland were obtained to assess phenotypic variation in live weight, condition score and dry matter intake. The data from the AFBI herd are included in the Centre for Dairy Information records.

The animal model is described in more detail by Bell *et al.* (2013, 2015). Briefly, it was assumed that energy requirements (of milking cows and herd replacements) for maintenance, growth, pregnancy, activity and lactation were achieved and that feed intake was always sufficient to achieve energy requirements in the baseline situation. The diet composition of a lactating cow was calculated based on the average animal using the FeedByte® rationing model version 3.78 (available at http://www.sruc.ac.uk/info/120110/dairy/354/dairy_services-key_features), which calculates a least cost ration that meets the energy, protein and mineral requirements of the animal. The ration was formulated from pasture, grass silage and dairy concentrate based on nutrient composition (Table 2) and cost (Table 3). The diet was constrained to a maximum of 50% pasture per kilogram of fresh feed. The lactating cow diet (heifer diet in parentheses) consisted of 36 (41)% pasture, 33 (41)% grass silage and 31 (17)% concentrate per kilogram DM intake per lactation for cows in Northern Ireland and 33 (39)% pasture, 33 (44)% grass silage and 34 (17)% dairy concentrate per kilogram DM intake per lactation for cows in UK. The cost of feed consumed by each age group was estimated by multiplying total DM intake by ME content and cost per unit ME of the diet (Table 3). Metabolisable energy (ME, MJ/d) required for maintenance (E_{maint}), gain or loss of body protein (E_p) and lipid (E_l), pregnancy (E_{preg}), activity (E_{act}) and lactation (E_{lact}) for the average cow are presented in Table 4. Feed intake of an animal was calculated from total ME requirement as: Feed intake (kg DM/d) = $E_{total} \times 1 / (ME – 0.616 \times (E_{CH4} \times GE) - (3.8 / 20 \times (FE \times GE)) – 29.2 \times (DCP / 6.25))$, where ME, GE, FE and E_{CH4} is the metabolisable, gross, faecal and enteric CH_4 energy (all MJ/kg DM). The values of 0.616 and 3.8 are the heat increments associated with fermentation and faeces production, and energy lost in faeces was assumed to be 20 MJ/kg faeces DM. A unit reduction in DM intake assumed that ME requirement of the animal remained constant in the baseline and adjusted situations, but ME intake and associated cost of consumed feed were lower to represent an improvement in residual feed intake. Residual feed intake represents variation in efficiency of metabolic processes, which is estimated from regression of DM intake against milk production traits, live weight, condition score and the interaction between live weight and condition score.

The animal’s live weight was assumed to be its empty body weight (550 kg of kilograms of protein, lipid, water and ash; Figure 1) plus gut fill, which gave an average live weight of a cow of 614 kg in Northern Ireland and 607 kg in the UK (Table 5). Gut fill was assumed to equate to the water held by dietary fibre content and estimated as 13.2 times the intake of neutral detergent fibre (NDF; kg/d). The body condition score of the cow was estimated from body lipid on a 1 to 9 point scale (Body condition score = ([body lipid % × 0.12 + 0.36] – 1) × 2 + 1), which gave an average body condition score of 4.4 (Table 5).

The total amount of milk produced during each lactation was estimated by multiplying the milk production at maturity, from the CDI data, by the proportion of mature productivity for each lactation. The proportion of mature productivity was calculated to be $E_{maint} - (E_p + E_l)$ / maximum of $E_{maint} - (E_p + E_l)$ across lactations. Mature productivity of milk was reached at four lactations for the average cow. Amounts of milk protein, fat and lactose produced were calculated based on milk fat and protein content (Table 1), and an assumed milk content of 5% lactose. Average yields per lactation were 8,172 litres of milk, 330 kg of fat and 262 kg of protein in Northern Ireland, and 8,561 litres of milk, 346 kg of fat and 274 kg of protein (Table 5).

All cows were assumed to be artificially inseminated. The average number of inseminations per cow was calculated as: No. of inseminations = 1 + ((calving interval (days) – (gestation length (days) + start of oestrus (days))) / 21), where the start of an oestrous cycle was assumed to be 426 days after birth of a replacement heifer and 82 days after calving for a lactating cow. Gestation length was assumed to be constant at 283 days (Table 1). This allows for a replacement to enter the herd at 730 days of age and a milking cow to have a 365 day calving interval. Calving interval was obtained from the CDI (2015). The cost of poor fertility was calculated from the cost of each insemination (labour cost per hr / 2 + semen straw cost; Table 3), the additional feed consumed by a milking cow, and the cost of a milking herd replacement per extra day required. Along with poor fertility, mastitis and lameness are considered to be two of the most costly health problems in dairy cattle and are therefore included. The percentage of cows in each lactation that had mastitis (Table 6) was calculated using a cumulative normal distribution with a mean log transformed SCC of 400,000 somatic cells/ml (de Haas *et al.*, 2004). A linear extrapolation of the data of Rutherford *et al*. (2009) provided the increase in incidence of lameness with parity (Table 6). It is reasonable to assume that the incidence levels of lameness are similar across the UK (Baird *et al.*, 2009), but the incidence of mastitis to be higher in Northern Ireland than across the UK (Table 5; Carson *et al.*, 2008). A cow with mastitis and lameness had an associated cost for treatment and loss of milk. For mastitis, 0.3 incidences were assumed to be clinical cases; for lameness, 0.25 were assumed to be clinical cases; the remainder were assumed to be subclinical cases. A case of clinical mastitis was assumed to cost £206 per incidence and subclinical £54, which is consistent with costs reported by Heikkilä *et al.* (2012). A case of clinical lameness was assumed to cost £305 per incidence and subclinical £40, which is consistent with costs reported by Willshire and Bell (2009). The costing of mastitis and lameness are described in more detail by Bell *et al.* (2015).

2.2 Herd structure

A total of 13 age groups were modelled, which included the period between birth and first calving for herd replacements, and 12 lactations. Replacement animals were assumed to calve at 2 years of age. It was assumed that all births resulted in a single live calf, and that 50% of calves were male and 50% female. The only animals to leave the system were cull cows, male calves and surplus female calves. All calves sold were assumed to leave the system immediately after birth (and contribute no GHG emissions to the system).

Herd structure was derived using a Markov chain approach for Northern Ireland and UK populations (Table 6). A Markov chain can be used to describe the herd as a vector of states (s) that cows occupy at a given point in time (Stott *et al*., 1999), which in this study was each age group. The vector of states at time t is multiplied by a matrix of transition probabilities (s × s) to give the vector of states at time t + 1. The probability of a cow progressing to the next lactation (from lactation *n* to *n* + 1 and from lactation 1 to *n*) was dependent on the chance of a cow being culled during the current lactation. If the transition matrix is constant for all stages; that is, the model is stationary, then repeated matrix multiplication will produce a fixed long-run vector (steady-state), which is independent of the initial state vector. This long-run steady-state vector provides a useful basis for comparative assessment of alternative herd structures i.e. a change in the number of cows in each age group. For simplicity individual cow values were multiplied by 100 to represent a herd of 100 cows.

2.3 Change in profit

The model included a partial budget calculation to determine the change in profit (e.g. income – variable costs = profit or loss) per cow for each age group in the herd for a change in a trait; this is referred to as the economic value of the trait. The change in income corresponds to the maximum amount of money that could be made by a change of one unit in each trait (e.g. 1 kg milk). The economic value of a trait is over a lifetime, but breeding values are expressed in lactating cows, so feed costs of growing heifers and lactating cows are shared amongst lactating cows. Variable costs and income that correspond to the traits of interest were included in the analysis in pounds sterling. The average values for milk, feed and livestock prices were obtained from Redman (2014; Table 3) and assumed to be similar across the UK.

2.4 Greenhouse gases and improved efficiencies of production

The loss of greenhouse gas emissions in the form of enteric and manure CH_4 and direct N_2O from stored manure and application of dung, urine and manure, and indirect N_2O from storage and application of manure to land (from leaching and atmospheric deposition of nitrogen from NOx and NH_3) were calculated (Table 5) and used as a measure of production efficiency (UKGGI, 2010). Emissions were expressed as CO_2-eq. emissions per cow and per kilogram of MS. Kilograms of CO_2-eq. emissions for a 100-yr time horizon were calculated using conversion factors from CH_4 to CO_2-eq of 25 and from N_2O to CO_2-eq of 298 (IPCC, 2007). Losses of CH_4 and N_2O emissions were assumed to be linearly related to all biological traits except survival (a curvilinear relationship with survival is generated by the Markov chain). IPCC (2006) Tier II methodology was used to predict manure CH_4 and N_2O emissions (from N excretion) for manure handling systems, as well as manure deposited on pasture. The N excreted by the animal was partitioned into dung (N intake – digested N intake) and urine (N intake – (N retained + N in dung)). Emission factors for manure CH_4 and N_2O are shown in Table 7. Based on UK GHG inventory values the following were fixed in the calculations: CH_4 conversion factor of 0.662 $m^3\ kg^{-1}$ CH_4 and CH_4 producing capacity of manure of 0.24 $m^3\ kg^{-1}$ volatile solids (UKGGI, 2010). Volatile solids in manure were calculated from the undigested organic matter (1 – digestible organic matter kg/kg).

The change in CO_2-eq. emissions per cow and per kg MS by a single phenotypic (a change effected by any means) and genetic (a change by selective breeding) standard deviation increase in each biological trait were assessed. The traits represent a range of production traits and fitness traits. A change in each trait was investigated while keeping all other traits constant. The traits being assessed are: milk volume (litres / lactation), fat and protein yield (both kg / lactation), live weight (kg), body condition score (1 to 9 point scale), survival (% / lactation), residual feed intake (kg / day), SCC (‘000 cells / ml), mastitis and lameness incidence (both % / lactation) and calving interval (days / lactation).

Economic values were derived by a single unit increase in each trait studied. A multi-trait selection index, as described by Pryce *et al*. (2009), was used to estimate the annual change in each trait and the economic change, with an estimate of annual change in profit per cow from selection on multiple traits. A multi-trait selection index takes into account the economic values of the traits included, their heritabilities, and genetic and phenotypic correlations between traits in order to calculate optimal index weights for each trait. Phenotypic and genetic correlations between traits were obtained from Pritchard *et al.* (2012), except for live weight, condition score (both Pryce *et al.*, 2009), and DM intake and residual feed intake (Veerkamp *et al.*, 1995; Vallimont *et al.*, 2010 and 2013).

3. Results

3.1 Change in profit

An increase in each trait by 1 phenotypic standard deviation showed that an increase in milk protein yield and an increase in survival are the most important traits in terms of increasing profit in both Northern Ireland and the UK, with a similar magnitude increase of £235 and

£238 per cow in Northern Ireland and £246 for both traits in the UK respectively, compared to the baseline situation (Figure 2). A phenotypic standard deviation reduction (rather than an increase) in milk volume and calving interval would also bring notable increases in profit in both Northern Ireland and the UK, compared to the baseline.

3.2 Efficiencies of production and greenhouse gas emissions

The largest contribution to total CO_2-eq. emissions came from enteric fermentation (58 to 60%), followed by N_2O (29%) and CH_4 from manure (11 to 13%) (Table 5).

Of the 11 traits studied, a 1 phenotypic standard deviation increase in residual feed intake produced the largest change in CO_2-eq. emissions of 14.5% (with 8.1% per genetic standard deviation change) per cow (Figure 3) and per kg MS over the lifetime of a cow (Figure 4). A 1 standard deviation increase in most traits resulted in an increase in emissions per cow and per kg MS, but an increase in survival reduced emissions per cow and per kg MS, and an increase in milk fat and protein yield reduced emissions per kg MS. Traits where a single standard deviation change (increase or reduction) would result in both a desirable increase in profit and a reduction in emissions intensity per cow and per kg MS were an increase in survival and decreases in milk volume, live weight (and body condition), residual feed intake, SCC, mastitis incidence, lameness incidence and calving interval.

In practical situations, selection is often on several traits simultaneously, rather than single-trait selection. Selection on multiple traits where each trait is weighted by its respective optimal index weight (Table 8) showed that profit is expected to increase by a similar magnitude of £31 per cow per year in Northern Ireland and across the UK, largely through increased milk fat and protein yields, and survival. Inserting the predicted annual response of each trait in Table 8 back into the animal model, showed that CO_2-eq. emissions are estimated to increase by 1.0% per cow and to decrease by 1.2% per kg MS per year in both populations, based on the estimated annual response.

4. Discussion and Conclusions

This research used national production data, experimental records and modelling to assess the effect of changing production and fitness traits on profit and greenhouse gas emissions from dairy cows across the UK and within Northern Ireland. The national data obtained from the CDI showed that the average values per cow for production and fitness traits in Northern Ireland are similar to the UK as a whole, except average milk production is lower in Northern Ireland (8,172 litres compared to 8,561 litres). The model used was developed to allow assessment of profitable lifetime dairy system abatement options and improved efficiencies by breeding, feeding and management, and potentially provide a more dynamic approach to national greenhouse gas accounting.

The main benefits of genetic selection to improve production efficiencies, compared to a management change, are the cumulative and permanent increase in productivity and gross efficiency (i.e. the ratio of yield of milk to resource input) by firstly, diluting the maintenance cost of animals in the system and secondly, less animals are required to produce the same amount of product (Capper *et al.,* 2009). Studies have found (van de Haar and St Pierre, 2006) that more energy efficient animals produce less waste in the form of CH_4 and nitrogen excretion per unit product. Based on the annual genetic response in each trait, the current study predicted a reduction in GHG emissions per unit product of 1% per year and an increase of 1.2% per cow. These are similar to responses found by other studies (Jones *et al.*, 2008; Bell *et al.*, 2015).

Of the traits investigated, increased production efficiencies associated with herd milk volume, live weight (and body condition), survival, residual feed intake, calving interval, SCC, mastitis and lameness incidence would increase profit and reduce emissions per cow and per kg MS of dairy systems across the UK. An increase in survival and reductions in residual feed intake, calving interval, SCC, mastitis and lameness incidence seem possible based on selection on multiple traits (Table 7). Given the low heritability of fitness traits such as fertility, survival, mastitis and lameness, reductions in emissions intensity of dairy systems may be harder to achieve than selection on a production trait like feed intake or residual feed intake (i.e. feed efficiency). Compared to production traits, improving the environment of cows (e.g. nutrition or management), rather than genetics, can make a significant contribution to reducing GHG emissions per cow and per kg MS with improvements in fitness traits such as survival and calving interval. Customised models, where producers evaluate their own farm circumstances, would be possible using the model in this study in the future, which would particularly improve system efficiencies, and fitness traits.

Using a multi-trait selection index with the economic values derived in this study (Table 8), the annual increase in profit from selection would average about £31 per cow for Northern Ireland and across the UK. This is higher than previously reported (£7.11, Wall *et al.*, 2010), but derives from use of much higher economic values for milk production traits due to an increase in the average price of milk from 17 pence per litre in previous calculations (Stott *et al.*, 2005) to 24 pence per litre and the use of recently published phenotypic and genetic parameters for the UK (Pritchard *et al.*, 2012).

This study evaluated production and fitness traits that are largely breeding objectives currently used in UK genetic evaluations, but with some differences in definition of traits such as survival and fertility, and with the addition of feed efficiency. Generally, the economic values calculated in this study (Table 8) were similar for the health and fertility traits (allowing for the difference in how lifespan and survival traits are derived) to those currently implemented in UK genetic evaluations (Wall *et al.* 2010a), with the exception of milk production values which were higher in this study as mentioned above. It would also seem appropriate to use the same economic values and index weights for individual traits, given the similarity in results for cows in Northern Ireland and across the UK. Higher economic values will increase the estimated annual economic response for each trait. The phenotypic variation in live weight, condition score and dry matter intake (and feed efficiency) were derived using experimental records from the last 15 years from AFBI. This may underestimate the actual phenotypic and genetic variation that exists in the national population and hence the response to selection on these efficiency traits could be greater if phenotypic records were available from commercial herds. Although assumptions are used to model a cow over its lifetime to derive economic values (along with actual national records), Pryce *et al.* (2009) showed that economic values derived using the model in this study are generally robust to these assumptions. As expected, the annual response to selection is sensitive to the price of milk, as discussed above.

Of the 11 traits studied, a single phenotypic standard deviation increase in residual feed intake produced the largest change in CO_2-eq. emissions of 14.5% (with 8.1% per genetic standard deviation change) per cow and per kg MS (Figure 3). However, the annual response to selection on feed efficiency was small (0.2%), but positive in multi-trait selection (Table 8). This is probably due to the variation being accounted for by other traits in the index. Selection on feed efficiency or even CH_4 output is not yet available in the UK, but using DNA information is especially promising for difficult or expensive to measure traits such as these (de Hass *et al.*, 2011). It may also be that feed utilisation efficiency or residual intake as proxies for enteric CH_4 would be sufficient to explain the variation that exists. However, this needs to be evaluated.

In conclusion, this study showed that increased production efficiencies associated with an increase in survival, and decreases in milk volume, live weight (and body condition), feed efficiency, SCC, mastitis incidence, lameness incidence and calving interval, would increase profit and reduce emissions per cow and per kg MS of dairy systems. The GHG emissions per cow are estimated to increase by 1% per year and reduce by 1.2% per unit product based on current breeding objectives and the inclusion of residual feed intake and live weight. Predicted increases in health and fertility (and overall survival), and residual feed intake, will increase farm annual profitability and reduce GHG emissions through improved breeding and management.

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Table 1. Production values included in the model for an average cow in Northern Ireland, with UK values in brackets where different

	Units	Average
Age at first calving	days	730
Lactations	no.	2.75 (2.68)
Growth rate	kg protein/d	0.0033
Empty body weight	kg	550
Mature milk volume *	litres/lactation	9,367 (9,806)
Milk protein *	%	3.20
Milk fat *	%	4.03
Gestation	days	283
Lactation length *	days	345 (346)

* From CDI (2015)

Table 2. Assumed nutrient composition of pasture, grass silage and dairy concentrate in Northern Ireland (UK values in parentheses) [*]

	Units	Pasture	Grass silage	Concentrate
Dry matter digestibility at maintenance (DMD_m) [†]	% of DM	76.6 (79.9)	71.6 (75.5)	91.0
Organic matter digestibility at maintenance (OMD_m) [‡]	% of OM	76.2 (78.9)	72.2 (75.4)	87.9
CP	g/kg DM	196 (214)	154 (158)	215
Digestible CP[§]	g/kg DM	163 (183)	121 (126)	190
NDF	g/kg DM	481 (442)	538 (498)	237
Ether extract	g/kg DM	42 (37)	28 (44)	25
Ash	g/kg DM	91 (80)	93 (78)	81
Sugar	g/kg DM	196 (90)	42 (20)	128
Undigested organic matter[§]		3.21 (3.75)	2.60 (3.06)	7.26
Gross energy (GE)	MJ/kg DM	18.9 (18.5)	20.0 (19.2)	18.0
Metabolisable energy (ME)	MJ/kg DM	11.5 (11.7)	11.4 (11.5)	13.0

[*] Nutrient compositions for Northern Ireland from AFBI, and UK values in parentheses from Bell *et al.* (2015).

[†] Using equation of Minson and McDonald (1987).

[‡] Estimated from Rowett Feedingstuffs Evaluation Unit Third Report data (Wainman *et al.*, 1981) as: $\% \ OMD_m = 14.36 + 1.0183 \times (ME / GE) \times 100$.

[§] Digestible CP (kg/kg DM) = CP – (((0.3 × (1 - (DMDm + 0.1))) × CP) + (0.105 × ME × 0.008) + 0.0152); Undigested organic matter = ratio of digestible to undigested organic matter of feed at maintenance intake level.

Table 3. Assumed income and costs associated with production for an average herd in Northern Ireland and the rest of the UK, obtained from Redman (2014)

		Average
Income	Units	£/unit
Milk fat*	kg	2.42
Milk protein*	kg	4.40
Bull calf	kg dead weight	1.79
Heifer calf	head	155
Culled cow	kg dead weight	0.91
Costs		
Milking herd replacement†	head	1500
Charge on volume	litres	0.027
Enterprise‡	kg milk solids	0.50
Labor§	hour	10
Semen	per straw	30
Pasture	MJ metabolisable energy	0.003
Grass silage	MJ metabolisable energy	0.009
Concentrate	MJ metabolisable energy	0.020

* Based on milk compositions for milk fat and protein in table 1 and an average price of 24 pence per litre of milk.

† Feed costs were deducted to give a non-feed cost associated with a milking herd replacement in the model

‡ Herd test, animal health, housing and dairy supplies.

§ Assumed cost of 30 minutes per artificial insemination, 50 minutes per case of severe and fatal clinical mastitis and 15 minutes for digital lameness, 12 minutes for interdigital lameness and 20 minutes per case of sole ulcer lameness.

Table 4. Percentage of total energy (% of ME) for a heifer replacement and the average lactating dairy cow in Northern Ireland (UK values in parentheses where different) for maintenance (E_{maint}), protein growth (E_p), lipid growth (E_l), pregnancy (E_{preg}), activity (E_{act}) and milk production (E_{lact}) over a lifetime

Energy requirement	Heifer	Lactating
E_{maint}	48.3	24.3 (23.6)
E_p	12.3	0.1
E_l	26.9	0.6
E_{preg}	7.7	4.0 (3.8)
E_{act}	4.8	2.4
E_{lact}	0.0	68.6 (69.5)
Total per age group (MJ)	28249	68215 (71301)

Table 5. Average values per cow for production and fitness traits, and nitrogen (N) excretion, enteric and manure methane (CH_4) and nitrous oxide (N_2O) emissions for a long-run steady state herd in Northern Ireland (UK values in parentheses where different)

Trait	Units	per cow
Milk volume	litres/lactation	8172 (8561)
Milk fat yield	kg/lactation	330 (346)
Milk protein yield	kg/lactation	262 (274)
Live weight	kg	614 (607)
Body condition score	1 to 9 scale	4.4
Survival	%/lactation	69.5 (69.8)
DM intake *	kg/d	18.2 (18.4)
Somatic cell count	‘000 cells/ml	237 (234)
Mastitis	%/lactation	28.9 (22.5)
Lameness	%/lactation	18.1 (17.9)
Calving interval	days/lactation	411 (413)
N excretion *	kg/d	0.42 (0.45)
Enteric CH_4 *†	g/d	390 (422)
Manure CH_4 *	g/d	88 (80)
Manure N_2O *	g/d	16 (17)

* Includes contribution from herd replacements.

† Enteric CH_4 emissions were estimated per kg DM intake by: CH_4 (g/kg DM intake) = 8.014 - 0.1047 × ether extract – 1.738 × (OMD_m/ [1000 – OMD_m]) - 0.0367 × sugar + 0.0419 × $DOMD_p$ (all g/kg DM) where $DOMD_p$ is estimated from the organic matter concentration of the diet (g/kg DM) multiplied by digestibility of organic matter at the production level (OMD_p) by the equation of Huhtanen *et al.* (2009) where: OMD_p (%) = 257 + 6.85 × (OMD_m) - 2.6 × DM intake (kg/day) / 10.

Table 6. Modelled average milk fat yield, milk protein yield, dry matter (DM) intake, somatic cell count (SCC), calving interval, mastitis incidence, lameness incidence, survival and long-run steady state for a 100 cow herd from the Markov chain for an average Northern Ireland herd (UK values in parentheses where different) in the baseline situation for a heifer replacement and lactations 1 to 12

Age group	Milk fat [*]	Milk protein [*]	DM intake	SCC [*]	Interval [†]	Mastitis	Lameness	Chance of being culled [*]	Steady-state herd
	kg/lactation	kg/lactation	kg/d	’000 cells/ml	days	%	%		hd/100 cows
Heifer			4.1		730				36.4 (37.3)
1	269 (280)	213 (222)	14.6 (14.7)	156 (125)	410 (409)	17.3 (12.2)	12.9	0.19 (0.15)	30.4 (30.4)
2	339 (355)	269 (282)	17.0 (17.2)	181 (147)	408 (411)	21.5 (15.8)	15.9	0.27 (0.29)	24.6 (25.6)
3	362 (379)	288 (301)	17.7 (17.9)	258 (202)	410 (413)	33.0 (24.8)	18.9	0.34 (0.35)	17.7 (18.0)
4	366 (390)	291 (309)	17.9 (18.1)	314 (257)	408 (417)	40.4 (32.9)	21.8	0.39 (0.40)	11.7 (11.5)
5	372 (394)	295 (313)	17.9 (18.1)	357 (307)	413 (420)	45.4 (39.6)	24.8	0.43 (0.44)	7.0 (6.8)
6	376 (397)	298 (315)	17.9 (18.1)	420 (362)	418 (424)	52.0 (46.1)	27.8	0.46 (0.47)	4.0 (3.7)
7	374 (396)	297 (314)	17.8 (18.1)	456 (401)	417 (425)	55.2 (50.1)	30.8	0.53 (0.50)	2.1 (1.9)
8	379 (398)	301 (316)	17.7 (18.0)	473 (428)	427 (430)	56.7 (52.7)	33.8	0.49 (0.58)	0.9 (0.9)
9	366 (389)	290 (309)	17.6 (17.8)	452 (438)	416 (425)	54.8 (53.6)	36.8	0.27 (0.51)	0.5 (0.4)
10	360 (385)	286 (305)	17.4 (17.6)	477 (455)	416 (427)	57.0 (55.1)	39.8	0.37 (0.55)	0.3 (0.1)
11	352 (381)	280 (303)	17.1 (17.3)	476 (471)	416 (434)	56.9 (56.5)	42.7	0.40 (0.62)	0.2 (0.0)
12	342 (368)	271 (293)	16.7 (16.8)	465 (397)	416 (434)	56.0 (49.7)	45.7	1	0.1 (0.0)

[*] From CDI (2015).

[†] Heifers assumed to enter the milking herd at 730 days of age, with calving intervals obtained from CDI (2015).

Table 7. Assumed percentage of manure produced by management system for a herd replacement and lactating cow for an average system, and emission factors used to calculate the greenhouse gas emissions (UKGGI, 2010)

	Manure produced (%)		Fraction of nitrogen lost	Nitrous oxide	Methane conversion factor
	Heifer	Lactating	N/N present	kg of N_2O/kg of N	%
Solid storage	3.6	12.9	0.35	0.02	1
Liquid system	38.3	9.1	0.4	0.001	39
Daily spread	13	9	0.07	0.0125	0.1
Grazing animal	45.1	69	0.2		1
Urine				0.02	
Dung				0.02	
Leaching			0.3	0.025	
Atmospheric deposition				0.01	

Table 8. The expected annual response per cow in Northern Ireland (UK values in parentheses or shown) based on the biological variation in breeding objective traits and their economic values using a multi-trait selection index[*]

Trait	Units	Phenotypic standard deviation[*]	Genetic standard deviation[*]	Economic value	Annual response[†]			
					NI	UK	NI	UK
				£	per unit	per unit	£	£
Milk volume	litres	1978 (2147)	1083 (1176)	-0.08 (-0.09)	115.45	118.29	-9.77	-10.16
Milk fat yield	kg	81 (82)	41 (42)	1.48 (1.44)	6.72	6.75	9.96	9.74
Milk protein yield	kg	60 (63)	31 (33)	3.92 (3.9)	5.12	5.28	20.10	20.62
Live weight	kg	49	33	-0.25	1.49	1.47	-0.37	-0.37
Body condition score	1 to 9 scale	0.51	0.25	-12.92 (-13.15)	-0.01	-0.01		
Survival	%	36 (37)	8.0 (8.3)	10.00 (9.43)	1.05	1.07	10.55	10.12
Dry matter intake	kg	2.16	1.34		0.10	0.09		
Residual feed intake	kg	1.61	0.88	-52.31 (-55.63)	-0.001	-0.001	0.06	0.06
Somatic cell count	'000 cells/ml	58 (57)	21.7 (21.3)	-0.34 (-0.3)	-0.83	-0.78	0.28	0.24
Mastitis	%	38	7	-1.05 (-1.09)	-0.59	-0.58	0.62	0.63
Lameness	%	37	5	-1.08 (-1.12)	-0.10	-0.11	0.11	0.12
Calving interval (fertility)	days	61	12	-2.11 (-2.13)	-0.03	-0.02	0.06	0.04
Total							31.53	31.01

[*] The phenotypic standard deviation (σp) and heritability (h^2) were used to calculate the genetic standard deviation (σa) using the formula σa = σp × h, where h is the square root of the heritability. For most traits the phenotypic standard deviation (σp) was obtained from CDI (2015) and heritability (h^2) was obtained from Pritchard *et al.* (2012), except for live weight (σp from AFBI and h^2 from Veerkamp and Brotherstone (1997)), condition score (σp from AFBI and h^2 from Veerkamp and Brotherstone (1997)), and DM intake (σp from AFBI and h^2 for DM intake from de Haas *et al.* (2012)) and residual feed intake (σp from AFBI and h^2 from Veerkamp *et al.* (1995)). The phenotypic standard deviation (σp) and heritability (h^2) for mastitis and lameness were obtained from Pritchard *et al.* (2012).

[†] It was assumed that residual feed intake was only available as a genomic breeding value, while breeding values for the other traits were available from progeny-testing, with bulls having 80 daughters for production trait estimates and 40 daughters for health and fertility traits estimates. Annual response calculated based on a 0.22 standard deviation change in the aggregate index value (Robertson and Rendel, 1950).

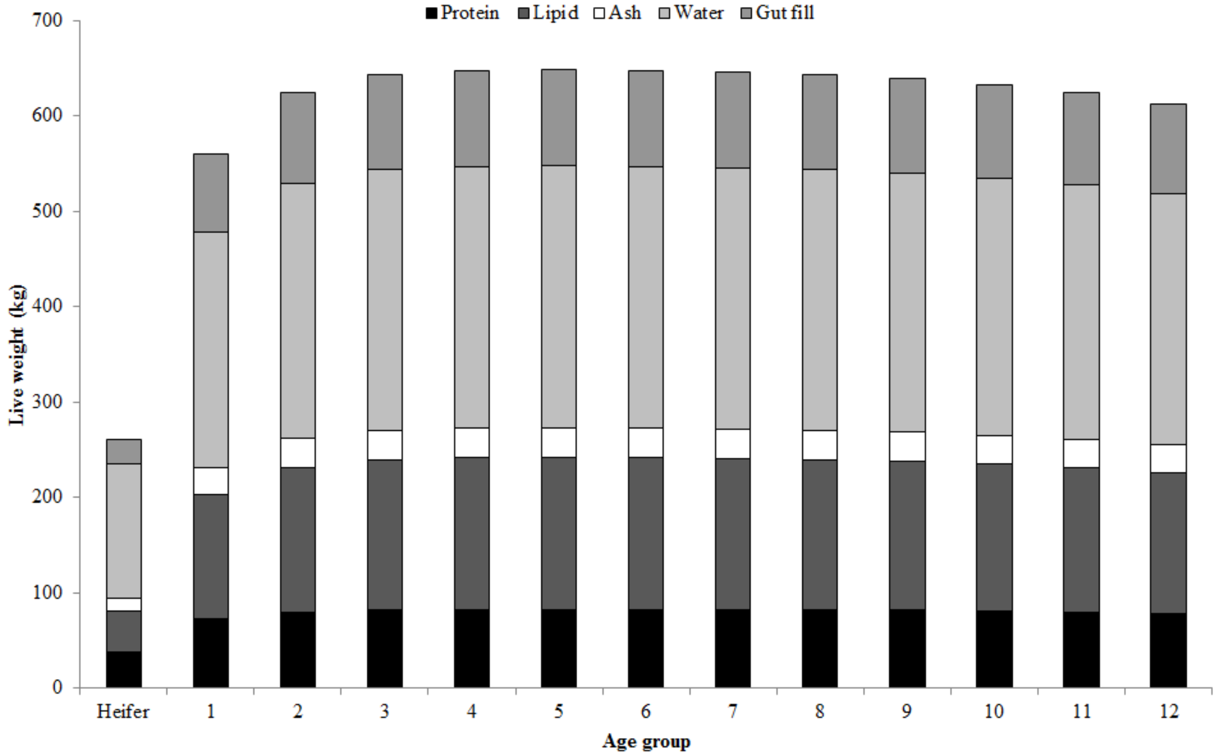

Figure 1. Average mass of protein, lipid, ash, water and gut fill in the live weight of an average heifer replacement and a dairy cow in Northern Ireland from lactations 1 to 12 with a mature empty body weight of 550 kilograms.

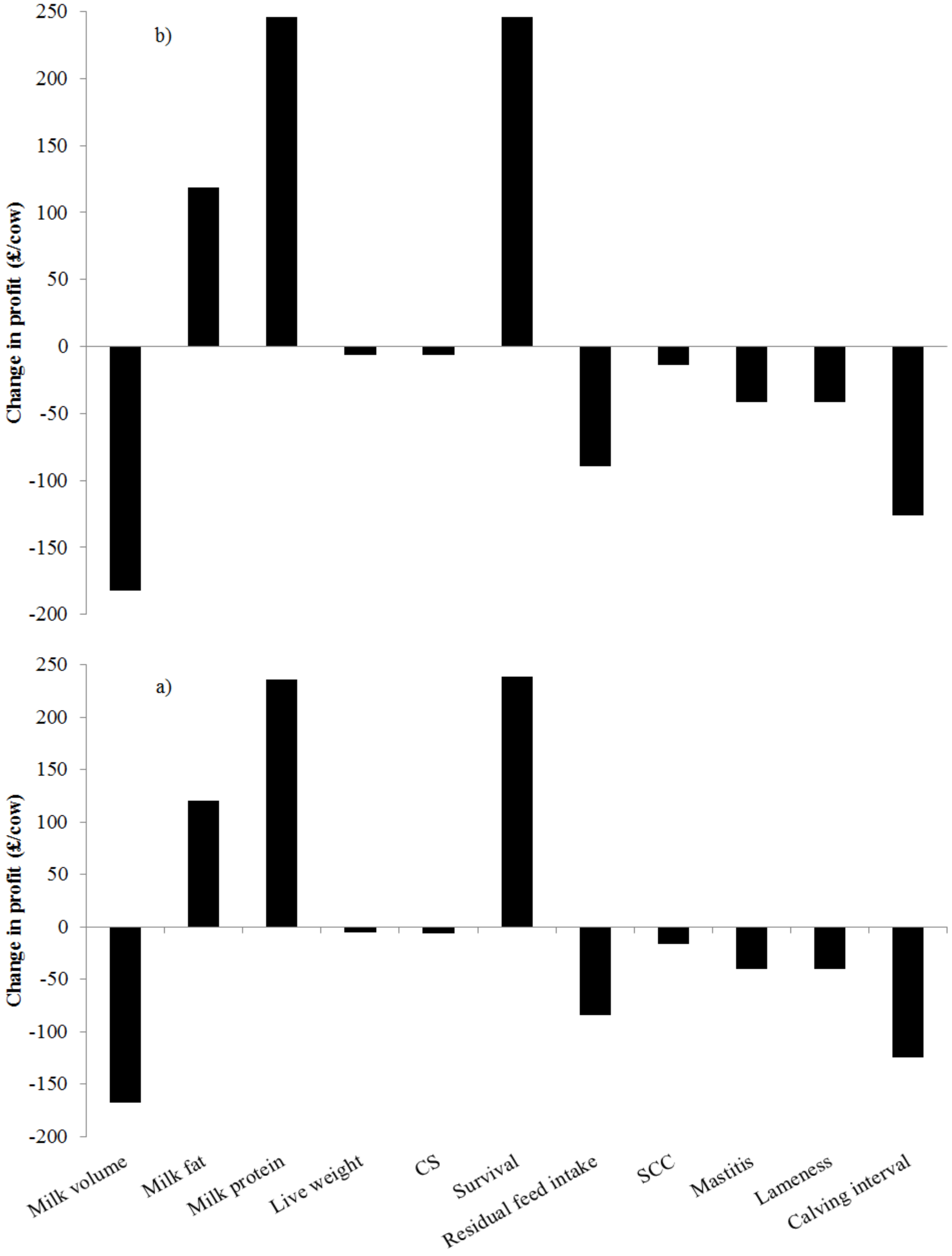

Figure 2. Change in the average herd profit per cow for a) Northern Ireland and b) UK as a result of a 1 phenotypic standard deviation (SD) increase in milk volume, milk fat yield, milk protein yield, live weight, condition score (CS), survival, residual feed intake, somatic cell count (SCC), mastitis incidence, lameness incidence and calving interval.

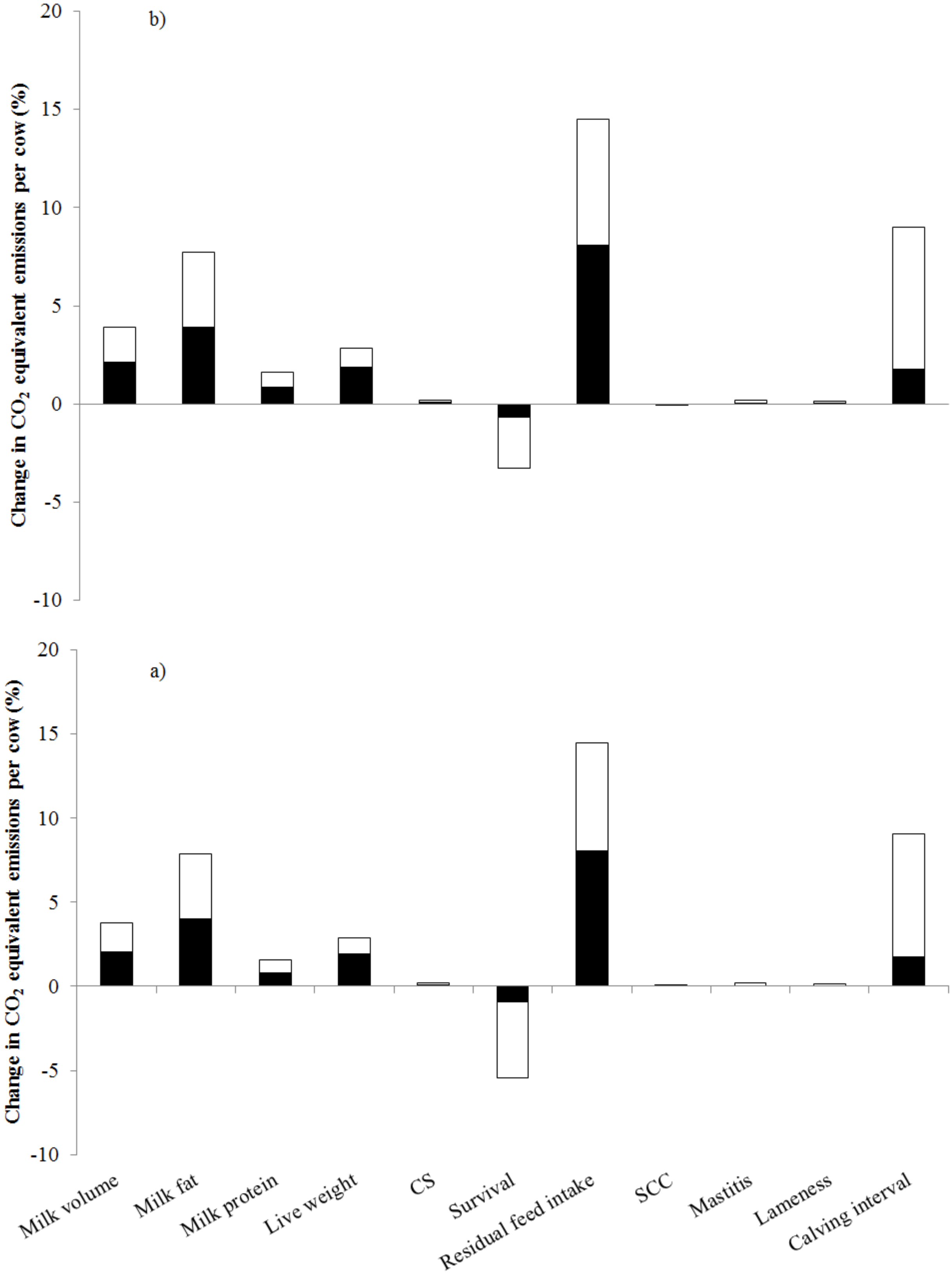

Figure 3. Change in the average herd carbon dioxide (CO_2-eq.) emissions per cow for a) Northern Ireland and b) UK as a result of a 1 phenotypic (□) and 1 genetic (■) standard deviation (SD) increase in milk volume, milk fat yield, milk protein yield, live weight, condition score (CS), survival, residual feed intake, somatic cell count (SCC), mastitis incidence, lameness incidence and calving interval.

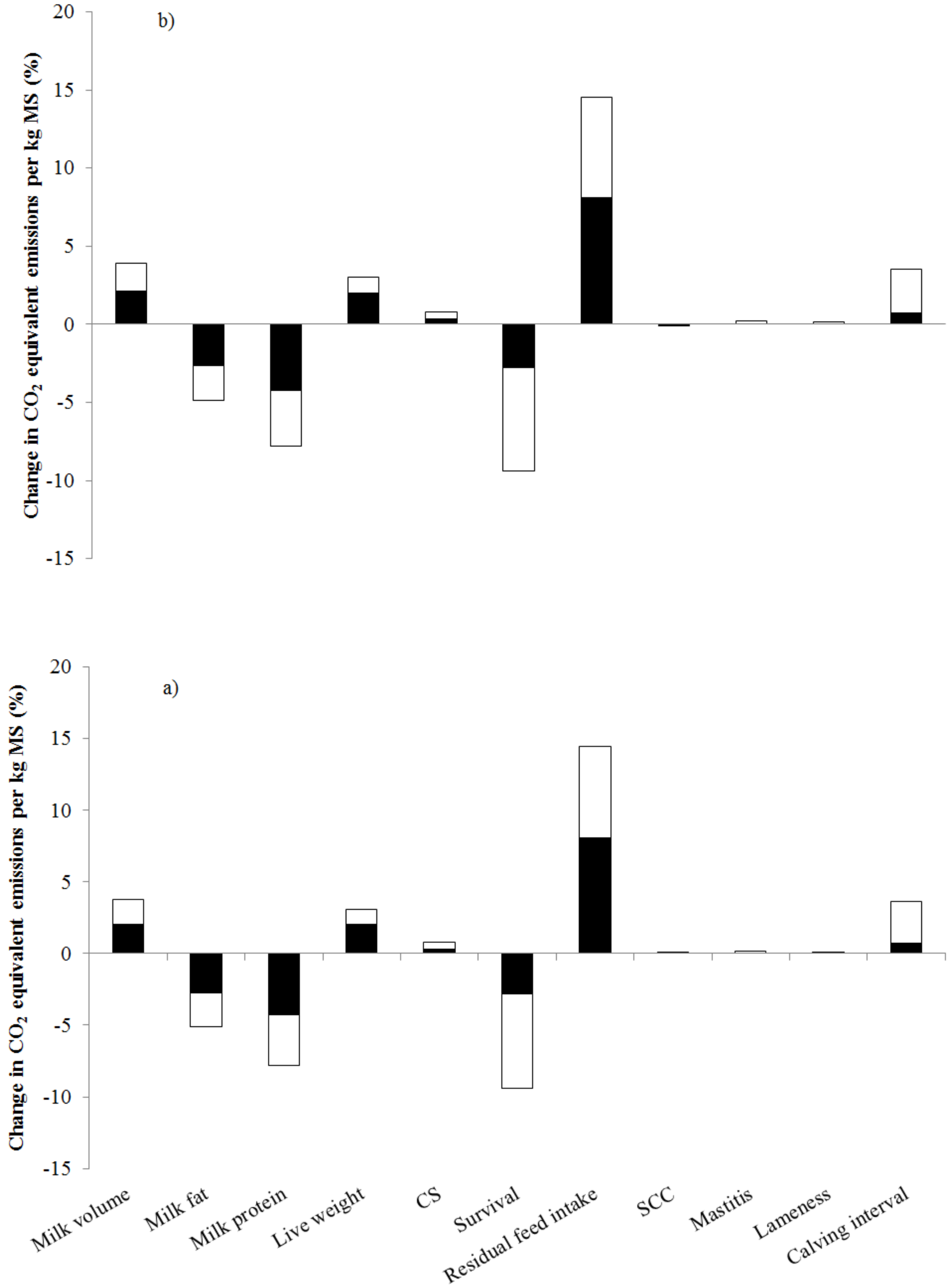

Figure 4. Change in the average herd carbon dioxide (CO_2-eq.) emissions per kilogram milk solids (MS) for a) Northern Ireland and b) UK as a result of a 1 phenotypic (□) and 1 genetic (■) standard deviation (SD) increase in milk volume, milk fat yield, milk protein yield, live weight, condition score (CS), survival, residual feed intake, somatic cell count (SCC), mastitis incidence, lameness incidence and calving interval.