Broadening breeding goals in a changing world

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Introduction

Improving the quality of breeding stock is one of the most cost effective ways of improving the long-term profitability of livestock enterprises. Improving long-term profitability has been one of the driving goals of livestock genetic improvement across species and around the world. In many parts of the world, farmers have to undertake an optimisation to maximise production whilst minimising costs of production. In modern dairy cows, reduced profitability is increasingly becoming associated with health and fertility costs of maintaining the dairy herd where as in the past many countries focused breeding goals on increasing production output on improving profitability. However, more recently there has been a move away from on-farm profitability as the only focus of breeding goals to include sustainability and societal considerations (Liinamo and Neeteson-van Nieuwenhoven, 2002). Amer (2006) described some of the methodologies that could be used to incorporate some broader sustainability and social considerations in breeding goals. Some of these wider objectives may move away from breeding goals that improve animals for on-farm performance only but also consider the wider society and/or policy environment.

In today's world, livestock production systems have a dual role, not only in food production, but also in the provision of public good objectives including biodiversity and landscape value. However, agriculture also generates external costs or negative public goods; for example, diffuse pollution to air and water. Mitigating greenhouse gas (GHG) emissions from livestock is increasingly recognised as a necessary part of the meeting world wide climate change obligations. For example, under The UK Low Carbon Transition Plan, the UK Government plans to cut farming and waste emissions by 6% of 2008 by 2022 as part of the more long-term targets set out in the UK Climate Change Act 2008 for reducing national emissions by 80% of 1990 levels by 2050. There are many possible technical mitigation options for livestock systems, of which genetic improvement is one. This paper will outline methods by which GHG emissions reduction could be considered in breeding goals. The potential conflict with other requirements from livestock systems in a changing world will also be explored.

Considering greenhouse gas emissions in breeding goals

Methods. This paper will use UK dairy cattle breeding goals as an example. However, methods described here in have also been applied to a range of UK beef and sheep breeding

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goals. The study of Stott *et al.* (2005) described how relative economic values (REVs) are calculated for traits included in the UK dairy profit index (£PLI) using dynamic programming tools to model a whole farm system. The REV for each trait is calculated by examining the consequence of a unit change in a trait of interest on net farm revenue, while keeping all other traits in the index fixed.

Wall *et al.* (2010a) described how whole farm model of greenhouse gas (GHG) emissions could be developed to help investigate the potential to use genetic selection as a tool to reduce ruminant GHG. This study utilised IPCC (2006) Tier II/III methodology were used as the basis for developing the GHG models. The GHG benefit/cost of trait changes was estimated by first posing a 'base scenario'. The 'base scenario' had typical production and performance values for that farm type as described by Stott *et al.* (2005). Once the base system for each scenario was set the individual traits were altered, one by one, holding other traits constant. The impact of changing the biological traits on GHG emissions from the animals (e.g., CH_4 from enteric fermentation, N2O from animals grazing) and from the management of the manure were calculated. Traits (e.g., milk yield and cow fertility) were altered separately and the total farm GHG were estimated to compare to the 'base scenario'.

Where appropriate changes in ruminant feed requirements were calculated based on the genetic response seen in a trait. The feed requirements had a carbon benefit/cost attached to them depending on whether the trait lead to lower or higher energy requirements for the whole farm system respectively. The reasoning for this was if a trait change lead to a higher total energy requirement, the farmer would have to buy in supplementary feed or produce more feed at a GHG cost. Alternatively, a reduction in feed requirement could enable a farmer to cut back on GHG associated with producing or buying feed (i.e., putting on less fertiliser or buying less concentrates). The carbon cost of the feed was based on data from the Cranfield LCA model.

Impact of trait improvements on GHG emissions from dairy systems. The 'base' dairy system defined by Stott *et al.* (2005) was estimated to produce approximately 1150 t CO_2 e per annum. The largest proportion of GHG emissions can be attributed to the milking herd, making up approximately 50% of the total emissions (including N_2O and CH_4 from enteric fermentation and manure management).13% of the emissions are due to following herd. Over 37% of the emissions can be attributed to the GHG emissions associated with the production of diet for all categories of animals throughout the year.

Table 1. Impact on GHG emissions for changes in production traits in dairy cattle

Trait	Change in system CO_2e/cow/unit change in trait	Change in system CO_2e /kg milk/unit change in trait)
Milk yield (kg)	0.681	0.079
Milk fat (kg)	-6.166	-0.719
Lifespan (lactations)	68.91	7.96
Conception rate	3.382	0.615

Table 1 show the environmental impact (in terms of decrease/increase of GHG emissions) of changing selected traits in a dairy herd. The range of traits that this could be examined in the dairy herd was limited due to trait definition within the dairy herd. For example, the trait "lifespan" incorporates culling for all non-production traits, including health and fertility. This means that the benefit/disbenefit of improving health and fertility in the dairy herd on overall GHG emissions due to reduction in culling rate is encapsulated in lifespan.

Overall, improving milk yield in the dairy herd has a favourable impact on GHG emissions as fewer cows and followers are required to meet the same production level. The average lifespan in the base dairy scenario was 3.5 lactations. Improving this by one lactation (4.5 lactations) had large and favourable impact on GHG emissions from the dairy herd, reducing them by 69 kg of CO_2e per milking cow.

Impact of incorporating GHG emissions in dairy breeding goals. Until recently, the consequences of selection on various indices have been examined in terms of their biological (e.g., changes in traits) and economic perspective. In the past selection indices have focussed on production traits. However, the genetic correlation estimates between production, health and fertility are predominantly unfavourable and therefore selection indices (and breeding goals) have been updated to include a range of both production and functional (fertility, health, survival traits).

Selection index theory (Hazel, 1943) was used to examine the consequences of selection on current and alternative future breeding goals. Models of selection in dairy were developed to explore the expected responses in the component traits, both those in the breeding goal and index as well as a range of correlated traits, as well as the overall economic and environmental performance of alternative selection indices. The overall breeding goal for the current selection index in dairy cattle, £PLI, is profit, milk, fat and protein kgs, lifespan, mastitis, lameness and fertility as goal traits. This was used as the base index to compare the impact of different breeding goals to.

Expected responses to selection of alternative breeding goals, with differing weights were examined by building a dairy selection index framework. Phenotypic and genetic parameters between the traits in the breeding goal, selection index and correlated traits of interest were collated from previous studies (Stott *et al.*, 2005; Wall *et al.*, 2003). Responses to selection on the index were calculated (Hazel, 1943). Annual returns were calculated based on a 0.22 standard deviations change in the aggregate index (Robertson and Rendel, 1950). This value approximates selection response in 'typical' four pathway dairy cattle breeding schemes. Generation intervals were assumed to be 6.5 years for sires and 5 years for dams. Following a progeny test scheme example bulls were expected to have, on average, 75 daughters across all traits.

The change in overall GHG emissions related to a change in an individual trait (Table 1) can be used to calculate a new set of weights for dairy breeding goals. These environmental weights are expressed in 2 forms, in terms of CO_2 e per dairy (milking) cow and per kg of milk. Taking account of societal views in an economic framework of a selection index can be difficult as they are a combination of market and non-market attributes (Neilsen *et al.,* 2005). Non-market goods are those that typically cannot be transacted in conventional markets but whose provision increases social welfare. Many non-market goods have public good characteristics, meaning that the public sector (i.e. government) often has to intervene to address the so-called market failure in their adequate provision. That is, while some attributes provide a public good, there is by definition no corresponding monetary return from their provision.

The impact of a unit change in a trait on GHG emissions can be used as stand-alone selection index weightings ("relative environmental values") to create an environmental selection index. However, as with all indices using weightings other than those based on expected market values, such indices may produce suboptimal profitability for producers. From a public perspective (e.g. government) the economic appraisal of GHG emissions is complex, and mitigation options must compare the costs associated with that option with the benefits in terms of emissions damage avoided. The latter is approximated by the shadow price of carbon (SPC), which is derived from the best estimate of the present value of damages associated with a tonne of GHG emission in carbon dioxide equivalents (CO_2 e, Price et al, 2007). The value of the SPC is the focal point of much research in the economics of climate change around the world. It could also conceivably become the basis of a publicly-backed breeding initiative aimed at GHG mitigation from livestock. This SPC is useful because it provides a benchmark against which to judge the cost efficiency of mitigation options as well as providing a monetary value for GHG emissions.

An alternative set of selection index weights were derived for dairy systems by combining the current set of economic index weights with the environmental weights using an economic cost of carbon such as the SPC. The hybrid index weights (Eco+ CO_2£) was a combination of the carbon cost in £ of CO_2e for each unit trait change expressed per breeding cow (GHG1) added to the economic weight. For the purposes of this paper 1 price of carbon was considered, namely the 2020 SPC of £32.90/t CO_2e.

Impact of selecting on breeding goals to reduce GHG emissions. The expected annual response in milk yield/cow increased when selection index weights were increase from current economic weights to environmental weights (79kg vs. 116 kg, Table 2). However, the negative weighting on milk fat in the environmental index resulted in a lower rate of improvement in milk solids when selecting on an index with environmental index (3.94 kg/cow/annum improvement in milk fat with current index vs. 2.58 kg with environmental index). Generally the environmental index weights resulted in a poorer response across functional traits compared to current economic index weights. For example, the expected annual response in lifespan with the current index is 0.055 lactation/cow and this response falls to 0.014 lactations with an environmental index. Also, the expected response in condition score, was predicted to get worse when selecting on an environmental index compared to the current index. The expected responses in traits between the two environmental index weights (GHG1 and GHG2) were negligible.

All of the indices studied resulted in a positive economic response per cow/annum ranging from £3.21 with an environmental index to £7.11 with the current index (Table 3). All of the indices studied also resulted in a favourable response in overall GHG emissions ranging from a reduction of 33.5 kg CO2e/cow/annum with the current index to 64.07 kg CO2e/cow/annum with the environmental index. This equates to a doubling of the expected response in the reduction of GHG emissions from a dairy system when the selection index is altered from the current index to an environmental index. The environmental index is predicted to have a cumulative reduction on GHG emissions of dairy systems by 1% per cow per annum.

Table 2. Index and correlated trait responses for dairy cattle when seven different breeding objectives were selected

	Breeding objectives and trait responses (in trait units pa.)			
	Current	GHG1	GHG2	Eco+ CO_2£
Milk (kg)	79.29	116.05	116.06	98.36
Fat (kg)	3.94	2.58	2.58	4.05
Protein (kg)	2.96	2.70	2.70	3.23
Lifespan (lactations)	0.055	0.014	0.014	0.050
Mastitis (cases)	0.0015	0.0039	0.0039	0.0023
Lameness (cases)	0.0006	0.0001	0.0001	0.0006
Calving interval (days)	0.37	0.79	0.79	0.46
Non-return rate (0/1)	-0.0027	-0.0047	-0.0047	-0.0032
Condition score *	-0.021	-0.033	-0.033	-0.027

* Condition score, 1 = thin, 9 = fat

Table 3. Summary of dairy annual selection response outcomes over the alternative breeding objectives

		Overall responses per annum			
Selection index weights used	Units	Current	GHG1	GHG2	Eco+ CO_2£
Current index	£/cow	£7.11	£3.21	£3.21	£6.92
GHG reduction per cow	kg CO_2e/cow	-33.50	-64.07	-64.08	-45.43
GHG reduction per kg product	g CO_2e/ kg product	-14.15	-28.79	-28.79	-19.64
UK SPC 2020 (£32.90/t CO_2e)	£/cow	£7.99	£4.91	£4.91	£8.13

Conflicting pressures in breeding goals

Conflicting outcomes of environmental breeding goals. Nielsen *et al.* (2005) reviewed methods that could be used to include environmental and welfare considerations in breeding goals. Restricted or desired gains approaches derive index weights that restrict unwanted changed or achieve the desired response in traits of interest. Table 4 shows that how restricted index methodology could be used to help quantify the potential trade-off between selection on an index based on profit (current index), environment (GHG1) and livestock welfare (restricted). The latter of these indices was based on responses from an index that would halt the decline in the health and fertility traits as seen with the current index. All three indices were predicted to result in a overall favourable economic response, with the current index resulting in the highest overall economic response per cow (£7.11), the welfare index the second highest (£6.80) and the environmental index the lowest (£3.21). All 3 indices were also predicted to have a favourable outcome on predicted GHG emissions with the environmental index the highest (-64.1 kg CO_2e/cow), the current index the second highest (-33.5 kg CO_2e/cow) and the welfare index the lowest (-20.5 kg CO_2e/cow). In terms of health and welfare of the cows (as defined by improving longevity, health and fertility traits) the welfare index was predicted to have the highest welfare benefit of all three, the current index the second highest (e.g., increase in the cases of mastitis by 0.0015 case/cow/year) and the environmental the lowest (e.g., increase in the cases of mastitis by 0.0039 case/cow/year).

Table 4. Summary of dairy annual selection response outcomes based on current index, environmental index containing all GHG emissions (GHG1) and a restricted index where expected responses health and fertility traits are held at zero.

	Breeding objectives and trait responses (in trait units per cow per annum)		
	Current	GHG1	Restricted
Milk (kg)	79.29	116.05	51.25
Fat (kg)	3.94	2.58	3.08
Protein (kg)	2.96	2.70	2.35
Lifespan (lactations)	0.055	0.014	0.067
Mastitis (cases)	0.0015	0.0039	0.00
Lameness (cases)	0.0006	0.0001	0.00
Calving interval (days)	0.37	0.79	0.00
Non-return rate (0/1)	-0.0027	-0.0047	0.00
Economic response £/cow	£7.11	£3.21	£6.80
Environmental response kg CO_2e/cow	-33.50	-64.07	-20.52

Results such as those in Table 4 can help inform producers, retailers and/or policy makers on the trade-offs within the livestock system that may occur in a number of key outputs such as sustainability, animal welfare and environmental impact. This may help to put a value on the premium that would need to flow to producers to achieve a number of goals from their farming system. For example, if a dairy producer were to focus on producing high welfare milk and would choose bulls based on such an index than this would cost £0.31/cow/year and result in a slower reduction in GHG emissions 13 kg CO_2e/cow/year compared to current index. It should be noted that these costs would cumulate year on year and would be worth £0.72/cow and 26 kg CO_2e/cow/year in two years relative to progress with the current index. These differences in economic and environmental margins would potentially need to be accounted for in the overall price that a producer is paid for milk.

Future proofing breeding goals. Changing breeding goals to respond to one particular pressure, such as reduced GHG emissions, may have unfavourable longer term impacts. This has been shown previously with the unfavourable impact on fitness traits when breeding goals have focussed on production only. It has already been shown that shifting focus to reduce GHG emissions only would have predicted infavourable impact on health and fertility traits in dairy cattle (Table 4). Choosing an appropriate balance between the economic (i.e., on-farm profit), government policy (e.g., GHG reductions) and societial (e.g., animal welfare) outcomes of alternative breeding goals is complex and would require broad stakeholder prioritisation, utilisation methods such as those in Amer *et al.* (2006).

Conflicting with climate change. Wall *et al.* (2010b) described the biological and economic impact of a changing UK climate on dairy cow production on survival, modelling the impact of heat stress on dairy cows, showing that the warming climate in the UK will result in reduced milk yield as well as increased mortaility due to heat stress. Bohmanova *et al.* (2008) showed a genotype * environment interaction on the impacts of heat stress. Breeding goals that focus on production traits tend to reduce the heat tolerence of a species and therefore increase their susceptability to heat stress. Breeding goals to reduce GHG emissions are likely to focus on prodcution efficiency traits and therefore select animals that may be more susceptable to future warming climates. Therefore, breeding goals that aim to reduce GHG emissions today or in the near future, should consider the future production system, including climatic conditions, to ensure complementary of the breeding goals.

Conflicting with land use policy. One of the other limitations to ruminant predication systems in the future may well be that some of the high quality pasture land in the UK that has traditionally supported ruminant production systems, particularly dairy, would be suitable for producing crops for human food and bio-fuels and therefore challenge this type of ruminant system. However, these future land-use challenges do not necessarily preclude ruminant production. In fact, ruminant animals provide a route to producing food for humans from land not suitable for crop production. Also under climate change scenarios there is potential for currently non-prime agricultural land to have increased production potential and therefore increase not only crop yields on prime categories of land but also increase area of, and grass growth potential on, those less than prime categories. Matching alternative future land use scenarios to breeding objectives could help ruminant producers to adapt to the potential challenges from alternating land use strategies. To optimise breeding goals to fit with land use strategies it may be necessary to develop a breeding goal that works across species, balancing the goals all livestock species to the potential mapped land uses, rather than considering individually within species.

Conclusion

This paper has shown that current UK dairy selection objectives have favourable economic and environmental benefits. Altering selection objectives to target environmental goals only can further enhance the reduction in GHG emissions at a relatively small economic cost. The quantified economic losses for altering the focus of the selection objective could be classed as the cost to farmers of achieving additional emissions reductions above and beyond their current trajectory. The environmental weights calculated place emphasis on both production efficiency and system efficiency traits. However, there tends to be a larger emphasis on the production efficiency traits in the environmental index relative to the system efficiency traits. This may conflict with some of the other issues that livestock producers face as increasing the weighting on production traits can have an unfavourable impact on fitness traits. This may be contrary to some wider societal requirements of improving health and welfare of livestock on farms. This study has described some of the trade-offs that could occur between economic, environmental and animal health and welfare outputs from livestock systems when breeding goals need to consider a multi-faceted range of outputs. Although some of the potential reduction in emissions may seem small it must be noted that genetic improvement is a cumulative benefit, with the annual reduction in emissions adding up year on year. Genetic improvement is a relatively cost-effective mechanism by which to achieve reduction in GHG emissions as there no continued input costs, above and beyond the establishment of the breeding and recording programme. Genetic improvement tools provide a useful and cost-effective mechanism for help UK livestock agriculture meet the challenges of the reducing GHG emissions.

Acknowledgements

This work has been supported from Defra and The Scottish Government. The authors would like to acknowledge the input to aspects of this work from Dominic Moran, Kairtsy Topp, Bob Rees, Mike Coffey and Tim Roughsedge (SAC); Huw Jones (Biosciences KTN); Adrian Williams (Cranfield University); and Peter Amer (AbacusBio).

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