BREEDING FOR REDUCED ENVIRONMENTAL FOOTPRINT IN BEEF CATTLE

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Introduction

There is considerable commentary in recent years on "sustainable intensification". The world human population is expanding and becoming more affluent and thus the demand for animal-derived protein (i.e., milk and meat) is increasing. Global production of meat from livestock is expected to double over the fifty years from 1999/2001 (229 million tonnes) to 2050 (465 million tonnes; Steinfeld et al., 2006). This therefore implies that, all else being equal, the environmental footprint per unit meat produced will need to be halved if the total environmental footprint of livestock production is not to increase. Most commentary on livestock environmental footprint, however, tends to focus on greenhouse gas emissions. O'Mara (2011) stated that animal agriculture is responsible for 8.0 to 10.8% of global greenhouse gas emissions. If, however, complete lifecycle analysis (i.e., accounting for the production of inputs to animal agriculture as well as change in land use such as deforestation) is undertaken this figure can be up to 18%. Cattle are the largest contributors to global greenhouse gas emissions (O'Mara, 2011).

Livestock production systems are, nonetheless, also implicated for pollution of freshwater supplies (e.g., nitrogen and phosphorus) as well as depleting water reserves. Livestock is implicated for 32-33% of Nitrogen and Phosphorus contamination of freshwater supplies (Steinfeld et al., 2006). Moreover, 64% of the world's population is expected to reside within water-stressed areas by the year 2025 (Steinfeld et al., 2006). Livestock production accounts for 8% of the water used by the human population (Steinfeld et al., 2006). Thus water use efficiency in animal production, as well as pollutant potential of water supplies, is also a crucial characteristic of animals for environmental footprint.

Much research is focusing particularly on differences among individuals in greenhouse gas emissions. Here I discuss other, often easier and more holistic approaches to potentially reduce the environmental footprint of modern day cattle production systems while simultaneously improving profitability. This article should be viewed more for provoking discussion than a definitive solution to how best to reduce the environmental footprint of modern-day production systems.

Animal breeding programs may be summarized graphically as in Figure 1.

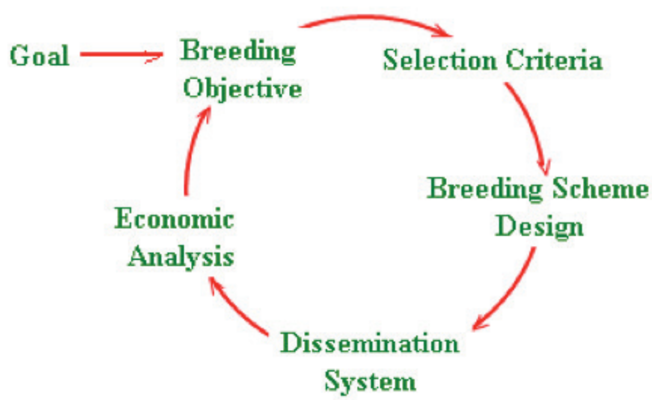

Figure 1. Schematic of an animal breeding program.

Goal

The goal of most cattle production systems in the developed world is profit. Profit is dictated by revenue and cost of production. Some traits however currently have no monetary value in most countries but are deemed to have "public good" attributes. Moreover, animal breeding strives to identify and select germplasm that will be most profitable in several years. Thus, although some attributes may have little (e.g., water) or no (e.g., greenhouse gases) current monetary value in most countries, the same may not be true in the future when the (grand-)progeny of the animals selected today will be producing. A good example is the evolution of the milk payment system in Ireland. The Irish national dairy cow breeding objective, the EBI, launched in 2001 penalized higher producing animals with lower milk composition. This was during a time when Irish producers were paid on a differential milk pricing system with no penalty for milk volume. The EBI was criticized at the time for not accurately reflecting the prevailing market signals. In 2006/2007 however, the milk payment system in Ireland changed to be strongly reflective of the relative economic weights in the EBI; thus the EBI had been identifying the most suitable germplasm for this payment system for the previous 5-6 years. Irish beef breeding programs will soon include EPDs for carcass cuts with the anticipation that the carcass payment system will change in the near future to better reflect carcass quality. Moreover, research is also underway on the inclusion of meat quality traits in the Irish national beef index, again in anticipation of financial incentives for superior meat quality in the future; the precedence already exists through incentives for meat from Angus cattle.

Therefore goals of breeding programs should be expanded to not only include profit but to do so in an "environmentally and socially responsible and sustainable manner". Although difficult, cognizance must be given to the likely policy enforced in several years.

Breeding objective

The breeding objective lists traits and their respective relative weightings to best describe the goal of the breeding program. Such traits should include revenue generating traits (e.g., carcass yield and value) as well as cost of production traits (e.g., feed intake, health and survival and in the case of maternal breeding objectives reproduction and longevity). Ideally such objectives should also include direct environmental characteristics like daily (or lifetime) methane emissions, nitrogen (and other minerals) excretion, as well as water intake. It is vitally important at this stage that cognizance is not given to whether or not these traits can be (easily) measured. Such details will be resolved in the later steps of the breeding program. If the genetic variation present in a trait cannot be adequately captured then, if not deemed sufficiently important, it can be discarded in the iterative process of the breeding program (Figure 1).

The relative weighting on each trait in the breeding goal can be derived using several approaches including economic values (i.e., from bioeconomic models or profit functions), choice experiments or willingness to pay experiments (e.g., 1,000 minds) or desired gains approaches. The contribution however of increased animal performance to reduced environmental footprint of the entire production system must be recognized. Goddard et al. (2011) defined herd feed conversion efficiency (FCE) for a beef herd as:

$$\text{Herd FCE} = \frac{W_{Off}\,(wean - loss)}{DMI_{Cow} + wean \cdot DMI_{Off}}$$

where Woff is the slaughter weight of the offspring, wean is the weaning rate, loss is the cow loss rate, DMIcow is the total feed intake of the cow, and DMIoff is the total feed intake of the offspring. This clearly shows that factors other than feed intake or direct environmental measures such as fertility (i.e., weaning rate) and cow loss rate can also affect herd efficiency and thus environmental footprint. Of key importance here is that DMI reflects total DMI and not daily DMI. Average daily DMI is almost always used in the definition of feed efficiency traits like residual feed intake (RFI; Berry and Crowley, 2013). Berry and Crowley (2012) however clearly demonstrated that animals superior for RFI, although eating less per day, may require a longer period of time to reach a target weight and thus eat more during this finishing period compared to animals ranked on their proposed index trait which included growth rate. A similar conclusion was reached in poultry (Willems et al., 2013). Although the direct translation to reduced environmental footprint is not clear, it is logical to assume that animals with lower total feed intake are also likely to have a reduced environmental footprint. This is because feed intake and daily methane emissions are positively correlated (Fitzsimons et al., 2013) and there is an expectation therefore also that lower feed intake (achieved through genetic gain without compromising performance), on average, results in less water intake, as well as less feces and uterine produced..

The dual objective of reducing feed intake per-day and number of days on feed (i.e., growth rate) is what is being achieved in holistic breeding objectives; this therefore is expected to reduce the environmental footprint of the growing cattle sector but cognizance must of course be taken of the cattle production system in its entirety (i.e., cow-calf production system). Table 1 describes the national breeding objectives for beef cattle in Ireland; the genetic evaluations are undertaken across breed and there is a single national breeding objective which operates across all breeds. The breeding objectives have a positive weight on carcass weight (i.e., reducing age at slaughter for a fixed carcass weight) and a negative economic weight on feed intake. The expected responses to selection based on the terminal index are in Figure 1. Gains in carcass weight (i.e. earlier age at slaughter for the same carcass weight) are expected despite an expected reduction in daily feed intake. This therefore is a double-whammy of reduced feed intake per day and reduced number of days of feeding. This is clearly exemplified by the mean performance of slaughtered animal divergent for the Irish terminal index (Table 2; Connelly et al., 2014); genetic merit for each animal was based on a genetic evaluation that did not include the animal's own performance record. The genetically elite animals were slaughtered 54 days younger despite their carcasses weighing 17% more than the lowest genetic merit group. Moreover, the EBVs for daily feed intake of the highest and lowest genetic merit group were -0.08 kg/day and 0.48 kg/day, respectively. These characteristics combined suggest that not only do the genetically elite animals eat food (and therefore require less associated labour and capital costs) for 54 days less but they are also eating potentially more than half a kg less per day less than their genetically inferior counterparts. These characteristics are likely to result in a lower environmental footprint of these genetically elite animals; it is important to remember that this is being achieved without any direct inclusion of an environmental trait in the breeding goal. Further reductions in environmental footprint are no doubt possible with the direct inclusion of environmental trait in the breeding objective but such inclusions will likely come at a cost and it is currently not clear what marginal gains could actually be achieved by such endeavors.

Improving cow fertility and longevity can reduce the environmental load of the entire beef production system as described in the equation above. Garnsworthy (2004) documented, using modelling, that if dairy cow fertility in the UK national herd could be restored to 1995 level from 2003 levels then herd methane emissions could be reduced by 10 to 11% while ammonia emissions could be reduced by 9% under a milk quota environment; the respective reductions were 21 to 24% and 17% if ideal fertility levels were achieved. A reduction of 4 to 5% in herd methane emissions was expected in the UK if fertility levels were restored to 1995 levels from 2003 levels where no milk quota existed (Garnsworthy, 2004). These improvements were due primarily to a reduced number of non-producing replacement animals and to a lesser extent greater milk yield (i.e., in beef would result in greater calf growth rate) when fertility was improved. No cognizance was taken here of the impact of replacement rate on genetic gain.

Animals	Trait	Maternal	Terminal
	Direct calving difficulty	-2.4	-20.5
All progeny	Direct gestation length	-0.4	-3.7
	Direct perinatal mortality	-0.4	-3.7
	Docility	0.3	2.4
Slaughtered progeny	Feed intake	-2.2	-18.8
	Carcass weight	3.5	35.8
	Carcass conformation	1.1	9.5
	Carcass fat	-0.6	-5.6
	Age at first calving	-5	
	Maternal calving difficulty	-4.5	
	Maternal weaning weight	12.4	
Replacement progeny	Calving interval	-7	
	Cow survival	5	
	Heifer feed intake	-7.7	
	Cow feed intake	-7.4	
	Cow docility	2.9	
	Cull cow weight	5.5	
	Direct calving difficulty	-8.8	
Slaughtered progeny from female replacement descendants	Direct gestation length	-1.6	
	Direct perinatal mortality	-1.6	
	Docility	1	
	Feed intake	-5.7	
	Carcass weight	8.7	
	Carcass conformation	2.7	
	Carcass fat	-1.6	

Table 1. Relative emphasis on traits in the Irish national beef maternal and terminal breeding objectives

Many studies focus on methane intensity as a breeding goal trait. Methane intensity may be described as the total (daily) methane output per unit feed intake. Heritable genetic variation in methane intensity has been reported (Donoghue et al., 2013) but Berry (2012) cautioned strongly on the interpretation of such heritability estimates as it is unclear what proportion of the heritability originates from the numerator or denominator of the intensity equation. Berry (2012) used a dataset of 2,605 growing beef bulls, described in detail by Crowley et al. (2010), to justify his concerns.

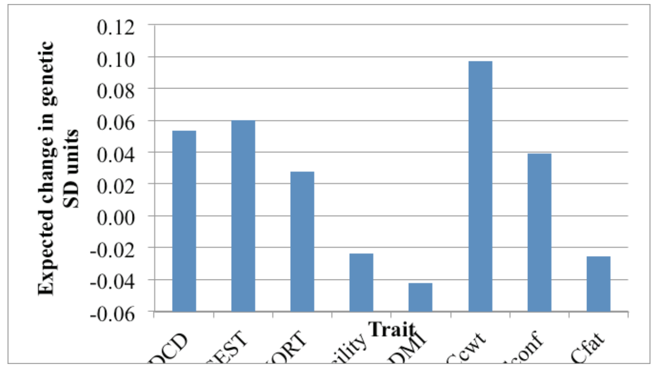

Figure 1. Expected annual gain in genetic standard deviation units (assuming an annualized genetic gain of 0.15 standard deviation units) for direct calving difficulty (DCD), gestation length (GEST), perinatal mortality (MORT), docility, dry matter intake (DMI) carcass weight (Ccwt), carcass conformation (Cconf) and carcass fat (Cfat), assuming 100 progeny records for the calving traits and docility, 6 progeny records for feed intake and 85 progeny records for the three carcass traits.

Daily methane emissions per animal were sampled from a normal probability distribution with a mean of 300 g/day and a standard deviation of 40 g/day. Methane intensity was defined as daily methane emissions divided by actual recorded daily feed intake available on those animals. As expected the heritability of the simulated daily methane emissions was zero; the heritability of feed intake was 0.49 (Crowley et al., 2010). The heritability of methane intensity was 0.19 (0.05). Berry (2012) proposed that to measure the potential of genetic selection to alter methane emissions without compromising performance, a statistical approach analogous to that used to define residual feed intake (Koch et al., 1963), should be used. This trait may be termed residual methane production (RMP) and could be defined as the residuals from a model regressing individual animal daily methane emission on energy sinks like growth rate and metabolic live-weight. Feed intake may also be included as covariate in the statistical model. If this approach was used in the example above, then the heritability of the residual methane trait was, as expected, zero. It is the genetic variation in this RMP trait that is of crucial importance as this depicts the scope for genetic improvement while still continuing to produce meat for the growing human demand. The heritability of this statistic merely describes how much one would have to invest to generate accurate genetic evaluations for this trait for individual animals. A similar approach should be undertaken for other environment traits like water use efficiency and nitrogen use efficiency.

Selection criterion

Traits and their respective weights in the selection criterion are chosen to maximize the correlation between the overall criterion and the overall breeding objective. Many are investing in high-tech facilities for the accurate measurement of feed intake (and efficiency) as well and environmental traits (and other non-environmental traits). To my knowledge

a detailed peer-reviewed cost-benefit of such endeavors, taking cognizance of selection index theory, has not be undertaken. One must remember that current carcass trait genetic evaluations (if the country actually has one!) are not perfect. Most countries use imprecise approaches to predict actual carcass value through themeasurement of carcass conformation which does not directly take cognizance of individual meat cut yields, let alone meat quality. Therefore, why such an emphasis on attempting to generate extremely accurate measures for other traits? I am not saying it is incorrect, but at least the true cost-benefit should be elucidated and a discussion should be had. Such an exercise must take cognizance of the ability to predict some of these traits, with reasonable accuracy, using selection index theory. Therefore, of real importance is what "residual" variation in the trait of interest remains that is not already captured by other easy to record traits. Ber- could explain 72% of the genetic variation in daily feed intake in growing cattle from live-weight, growth rate and ultrasound fat measures all of which are relatively easily measurable. The proportion of genetic variation increased to 90% when a subjective measure of muscularity was also included in the selection index; this is because RFI and muscularity are genetically correlated (Berry and Crowley, 2013). There is no denying that variation in RFI exists, my question is how much is there that cannot be captured through other means. It is very likely that a larger proportion of the variation total animal intake can be captured with easy to record traits since total feed intake will also be determined by days on feed. Moreover, animals not at the feed bunk are simply not eating. RFID is now routinely used in many feedlots, and if not is relatively inexpensive. Although differences in bite rate and bite size among animals exists (Chen et al., 2014), total time spent feeding (from using sensors at the feed face and transponders on animals) must explain additional genetic variation in RFI. (Robinson and Oddy, 2004; Chen et al., 2014). The difference between metabolizable energy intake and net energy intake is heat increment. Promising research from Guelph (Montanholi et al., 2009) suggests that measurement of animal heat produced from simple infra-red cameras can be used to predict RFI. Some will say that 70% prediction accuracy is too low; however the genetic correlation between carcass conformation and total meat yield (adjusted to a common carcass weight) is 0.55 (Pabiou et al., 2009) implying that the current carcass grading system in the EU explains only 30% of the genetic variation in carcass meat proportion! Would resources not be better spent on

Table 2. Association between terminal EBV (Index) and age at slaughter, carcass weight, conformation and fat score as well as price per kg and overall animal value; pooled standard error (SE) also included.

Index	Age (days)	Carcass weight (kg)	Conformation (scale 1 – 15)	Fat (scale 1-15)	Price per kg (€/kg)	Value (€)
Very High	726	371	8.68 (R+)	6.33 (3=)	3.85	1412
High	775	327	5.04 (O=)	6.40 (3=)	3.60	1174
Low	779	321	4.97 (O=)	6.44 (3=)	3.60	1153
Very Low	780	316	4.88 (O=)	6.33 (3=)	3.57	1123
SE	0.89	0.31	0.01	0.97	0.24	1.65

Table 2. Association between terminal EBV (Index) and age at slaughter, carcass weight, conformation and fat score as well as price per kg and overall animal value; pooled standard error (SE) also included.

improving this and selecting animals with more meat yield to feed the growing human demand?

Breeding Scheme Design

The breeding scheme design incorporates the genetic and genomic evaluations as well as the breeding scheme used to ensure long-term and sustainable genetic gain. There is an expectation among some that genomic selection will solve all issues in beef cattle breeding. On the contrary, genomic selection can actually exacerbate any issues that exist in a breeding program. For example, genomic selection is expected to increase genetic gain approximately 50% implying that the rate of genetic deterioration in a given (non-monitored) trait will also likely increase by 50%. Moreover, although genomics can be used to reduce the accumulation of inbreeding, in most instances in dairying, inbreeding is increasing as breeding companies battle to increase the rate of short term genetic gain. The greater use of young bulls may minimize the ability, or increase the difficulty, to purge out unfavourable characteristics. Furthermore, inaccurate, imprecise or non-pertinent genetic evaluations will not be solved with genomic selection. The input variables for genomic selection are either (a derivative) of EPDs from the genetic evaluation systems (i.e., two step) or the direct phenotypes themselves with the genetic relevant evaluation model (i.e., one-step). Therefore, implementation of genomic selection will be most optimal once the fundamentals of a successful animal breeding program are in place.

There have been long discussions on how best to incorporate feed efficiency in a breeding program (Berry and Crowley, 2013) and to-date no consensus exists. Table 3 (Berry and Pryce, 2014) outlines the advantages of disadvantages of including a residual feed intake or dry matter intake itself in the breeding objective. The same discussions are likely to prevail for environmental footprint traits especially if residual-based traits are derived. In other words should residual methane production, total daily methane production, or methane intensity be included in the breeding objective or as a stand-alone trait. The disadvantages of selection on ratio traits (i.e., methane intensity) like feed conversion efficiency has been discussed at length (Berry and Crowley, 2013) suggesting that methane intensity (or any other environment trait like water intake per unit average daily gain or per unit feed intake) may be not production, total water intake) in the breeding objective but the adjusted trait (either as EPDs or categorized as high, average, or low depending on the accuracy of the EPDs) as a stand-alone trait. By categorizing traits (or the stand alone trait as a monetary value like feed cost saved) issues with which sign is desirable (i.e., apparently negative RFI) is removed. One could simply change the sign but this will cause confusion if (international) scientists are discussing with producers since they will subconsciously say that genitive RFI is better. By categorizing, issue with fluctuation EPDs because of low reliability will be minimized. A similar categorization of traits is undertaken in Ireland for beef cattle where animals are grouped into 5 categories (termed stars in Ireland) where the top category (i.e., 5-star) are animals in the top 20% for genetic merit for that trait. Although knowledge if the animal resides in 1% percentile or the 19% is useful, getting producers to use and engage with animal breeding may actually be more beneficial.

Dissemination

Arguably the link in a successful animal breeding program that is most often ignored is dissemination. There is not much point having the best genetic evaluation system and breeding program in the world if nobody understands it or is willing to use the elite germplasm. Animal breeders find it difficult to understand why the best germplasm is not used; even if individual bull reliability is low, on average, if producers use the elite bulls the entire population will make gains. However, individual producers are more concerned with theperformance of their own animals and herd rather than the national population. It is still remarkable how many producers globally do not believe genetic evaluations. One has to question the investment in genomics to produce more accurate EPDs when the EPDs are sometimes not even used in the first place. Of course genomics will increase the accuracy of these genetic evaluations but resources must be put into explaining and demonstrating the impact of genetic differences on phenotypic performance. Dairy cattle breeders did an excellent job in convincing (mostly) non-geneticists that breeding can actually improve reproductive performance. This was achieved (eventually!) through demonstration, not structured demonstration, but because of widespread use of elite genetics in dairying the results across so many herds were impossible to ignore. Nonetheless, controlled experiments, although costly,

DMI in the breeding goal	
For	**Against**
Easy to explain and understand	Cannot easily identify efficient animals
	May be mis-understood (positive EBV may be efficient)
Economic value is relatively easy to calculate	
Amenable to customised indexes	Correlated with performance
Economic value on other components reflect reality in the market place (e.g., fat:protein price ratio)	Independent culling levels may be harmful to overall gain
	Misinterpreted that negative EBV might imply poorer performing animals
Good predictors available	
Higher "reliability" through selection index theory	
May be less susceptible to genotype by environment interactions (GxE)	

RFI in the breeding goal	
For	**Against**
Economic value is relatively easy to calculate	Difficult to explain technically
Can "easily" slot in to current breeding goals	Low reliability (currently)
(Theoretically) uncorrelated with performance	Possibly more susceptible to GxE
Relatively simple message (if not caught up in details)	Selection index within a selection index
Could materialize in faster genetic gain for efficiency	Sensible to select on something we do not understand? (Never stopped us before!)
	Mixed messages from "pro" and "against" camps
	RFI in lactating animals (as currently defined) is not ideal
	EBVs may change as the RFI model changes
	Possibly correlated with fertility (so is DMI!)

Table 3. Reasons in favor and against including DMI or RFI in a breeding goal

(Buckley et al., 2014) and beef (Prendiville et al., 2014). Controlled experiments on feed efficiency and the mean methane emissions per stratum also exist (Nkrumah et al., 2006).

Structured demonstration herds or research herds can also be informative for breeding to reduce environmental footprint. Because the routine capture of data on most direct environmental traits for genetic evaluations can be expensive, it may not make economic sense to collect such information. Estimating the impact of current breeding strategies on genetic change in environmental traits can be achieved using selection index theory. However, procuring sufficient data to estimate precise genetic parameters can also be costly. Evaluating in a controlled environment, the detailed environmental footprint of animals selected to be genetically divergent for a given selection strategy can be very useful in elucidating the impact of current breeding strategies on expected genetic trends in environmental footprint. Moreover the ideal reference population for accurate genomic evaluations should be genomically and phenotypically diverse (as well as related to the candidate population of animals). Animals divergent for the breeding strategy employed can therefore be very useful for the development of genomic predictions. This is especially true for difficult to measure traits such as direct environmental traits.

Economic analysis

Animal breeders (either academic or seedstock producers) must not be afraid to discontinue certain paths if it is not economically advantageous or if more economic gain can be realized with a different strategy. Such economic analyses however must include long-term impact, discounted to current day equivalents. Economic analyses of breeding programs can be undertaken at the producer level, the breeding company level, or at the national/global level. Moreover, as previously alluded to, the economic cost of most environmental traits can be difficult to quantify unless there is some financial incentive (e.g., carbon trading) or penalty (e.g., nitrates directive) for same. Many of the benefits of reduced environmental footprint of cattle production systems will be realized at the national or even global level. Research in this area is on-going (Wall et al., 2010)

Conclusions

Environmental footprint of modern-day production systems will undoubtedly become more important in the near future as global food production increase and the ramifications of such are contemplated. Many approaches exist to possibly reduce the environmental footprint of animal production systems. Animal breeding has the advantage of being cumulative and permanent; the main disadvantage of the long generation interval in breeding is being ameliorated with the advent of genomic selection. Nonetheless, the alternative strategies in the animal breeder's toolbox to achieve the objective of reduced environmental footprint of animal production without compromising animal performance must be thoroughly investigated taking cognizance of the cost of each strategy.

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