Traditional genetic selection for fertility: Indicator traits and potential antagonisms

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Introduction

It should be common knowledge that fertility is the most economically relevant suite of traits in beef cattle production, followed in order by growth and carcass merit. The relative importance of fertility compared to other trait complexes is roughly double for non-integrated firms, which the overwhelming majority of commercial cow-calf producers would be classified as.

To further illustrate the importance of fertility, a pragmatic view efficiency in beef cattle expressed in linear form as proposed by Dickerson (1970) is detailed below.

[Dam Weight × Lean Value of Dam + No. Progeny × Progeny Weight × Lean Value of Progeny]

– [Dam Feed × Value of Feed for Dam + No. Progeny × Progeny Feed × Value of Feed for Progeny]

The income component is comprised of output from harvesting the dam (or fraction of the dam accounting for death loss) and from harvesting progeny (again, accounting for death loss). The feed cost component accounts for the input of feed energy. The number of progeny per dam is in both components and, thus, increasing number of progeny will increase efficiency. *By simply increasing number of progeny per dam through either selection, heterosis from crossing, or better management, we will increase efficiency of production* (Nielsen et al., 2013).

Although for the commercial cattle producer improvements in fertility can be achieved in one generation via crossbreeding, there is still merit in improving the additive genetic component of fertility via within breed (or line) selection. Unfortunately, the number of EPD that currently exists for female fertility traits is limited, particular compared to the number of EPD for growth and carcass merit.

Genetic parameters

Heritability estimates of several reproductive phenotypes are listed in table 1 as reported in a review paper by Cammack et al. (2009). Many of these phenotypes can be classified as lowly heritable. However, in some cases studies have reported much larger heritability estimates than the perceived bound of 0.10 generally associated with female fertility traits. Particularly for threshold characters, the incidence rate (or success rate) can greatly influence the estimates of heritability. As the incidence rate approaches 50%, heritability estimates will likely become larger than cases where the incidence rate is more extreme.

Table 1. Summary of heritability estimates (h^2) for commonly used reproductive traits in beef cattle[1].

Trait	h^2	No. of references
Age at first calving	<0.10	2
	0.20-0.30	3
Age at puberty	<0.10	1
	0.10-0.20	3
	0.40-0.50	4
	>0.60	3
Calving date	<0.10	4
	0.20-0.30	3
	0.40-0.50	1
Calving rate	<0.10	1
	0.10-0.20	1
Calving success	<0.05	1
	0.05-0.10	1
Calving to first insemination	<0.10	2
Days to calving	<0.10	2
First-service conception rate	<0.10	1
	0.20-0.30	1
Heifer pregnancy	<0.20	1
	0.20-0.30	1
Number of calves	<0.10	2
	0.10-0.20	2
	0.30-0.40	1
Pregnancy rate	<0.10	4
	0.10-0.20	4
	0.20-0.30	4
Probability of pregnancy	<0.10	1
	0.10-0.20	1
	0.20-0.30	3
	0.50-0.60	1
Scrotal Circumference	0.20-0.40	3
	0.40-0.50	8
	0.50-0.80	3

[1]Adapted from Cammack et al., 2009.

Current national cattle evaluations

Table 2 details a listing of reproductive traits that are included in beef cattle genetic evaluations in several countries.

Table 2. Example of countries with reproduction traits as part of beef genetic evaluation systems[1].

Trait	Country[2]
Scrotal circumference	AU, NZ, SA, NA, AR, UK, IR, BR, FR, US, CA, ME
Days to calving	AU, NZ, SA, NA
Heifer pregnancy	US, VE, BR
Heifer calving success	FR
Age at 1st calving	IR, UK, BR
Calving interval	IR, DE, UK
Stayability/productive life	US, CA, VE, UK, FR, BR

[1] Adapated from Johnston (2014).
[2] AU = Australia; NZ = New Zealand, BR = Brazil; VE = Venezuela; UK = United Kingdom; IR = Ireland; SA = South Africa; FR = France; US = United States; CA= Canada; DE = Denmark; AR = Argentina; NA = Nambia; ME = Mexico.

Breeding program design

If constructed correctly, multiple-trait index tools can account for antagonisms that may exist between fertility and other economically relevant traits.

A breeding program must first start by defining a breeding objective. A breeding objective represents each animal's genetic value for economic merit. To define a breeding objective requires identifying which traits should be included and their marginal economic values. If done properly, comparison of animals then reflects differences in genetic potential for profit (Tang et al., 2011).

Hazel (1943) first introduced the selection index equations to calculate index coefficients (b) for each of the selection criteria:

$$b = P^{-1}Gv$$

where **P** is a *n* x *n* matrix of the phenotypic (co)variances among the *n* traits measured and available as selection criteria, **G** is a *n* x *m* matrix of the genetic (co)variances among the *n* selection criteria and *m* objective traits, and **v** is an *m* x 1 vector of economic values for all objective traits.

An example would be defining an objective that centers on selling all offspring as terminal towards a specified grid (e.g. CAB). This clearly defines the traits of economic importance (growth, lean yield, marbling, and feed intake, for example). In the absence of EPD for these traits, indicator traits would be used. The lack of clearly defined breeding objectives represents an initial stumbling block towards improved system efficiency. Another stumbling block is practicing selection based on index values derived with a specified breeding objective in mind that does not match the breeding objective of the user (bull buyer). An example of this would be selecting bulls based on a terminal index (e.g. Angus $B or Simmental TI) but marketing all male claves at weaning and retaining replacement heifers. In this example, the breeding objective of the bull buyer does not align with the selection criterion used to select bulls.

Using specialized sire and dam lines is not a new concept in beef cattle and in fact was fairly prominent in the 1970s. When Continental breeds first made an appearance in the US some four decades ago, these high growth and high yielding cattle were bred to British breed cows that were much more conservative in size and generally tended to have more fat (internally and externally). Challenges that arose included increased calving difficulty and the ability to source replacements in what was essentially a terminal based system. However, breeds have changed since then and data recoding schemes have improved to allow for additional EPD of economic relevance.

The goals of a terminal-based system revolve around the following traits: Early growth rate, calving ease direct (trait of the calf), calf survival, disease susceptibility, feed intake, meat quality, carcass composition, and male fertility. In contrast, the suite of traits of economic importance to a maternal-based system include: female fertility, maternal calving ease, longevity, moderate size, adaptation to production environment, disease susceptibility, milk production (optimal levels), maternal instinct, and temperament (optimal?). The only trait in common between the two is disease susceptibility, and many of the traits between the two are antagonistic. For instance, the genetic correlation between calving ease direct and calving ease maternal is -0.30. The genetic correlation between hot carcass weight and mature cow size is 0.8. If both systems, maternal and terminal, use the same bull battery (duel purpose) there is substantial opportunity cost given the differences in economically relevant traits between the two and the antagonisms that exists between the two. Although all the traits in the two systems above could be merged into one single breeding objective and thus one index, a fewer number of traits under selection allows for faster progress. The pork and poultry industries have this figured out. So why the disparity in the way the beef industry approaches breeding as opposed to other industries?

Small cowherds produce the majority of calves in the US and this seems unlikely to change. The majority of these herds retain replacement heifers. The problem with this scenario is the lack of efficiency. In smaller herds there are generally not enough replacement heifers each year to make it practical to manage them as a separate group. It also seems a waste of time to wake up during the night to attend a very small group of heifers as they calve for the first time. A more profitable, and maybe more enjoyable, system for small herds would be to purchase bred females (ideally bred for their second calf or even older). In this scenario females would be selected for maternal traits and terminal sires would be used. All offspring would be sold for harvest. This would represent a decrease in labor and an increase in profitability. This system, and the benefits of it, could also be realized by large producers as well. Admittedly the cultural change is a large paradigm shift for the beef industry and unfortunately the cow/calf industry (commercial and seedstock) is not noted for making rapid progress relative to adopting new ideas (e.g. development of selection index theory is 1943 and adoption in beef in the early 2000s).

An opportunity exists for larger commercial and seedstock ranches to produce replacement females for smaller to medium sized commercial herds. The use of sexed semen could prove beneficial. Bull claves in a maternal system, or heifer claves in a terminal system, create a source of inefficiency (although not as large as the use of all-purpose herds). Being able to alter the frequency of the undesired sex would be beneficial. An example of this comes from the dairy industry where replacement heifers are generated using sexed semen. This has actually produced more replacement dairy heifers than needed. Given the excess of dairy females, older, lower producing cows are mated to beef bulls (generally Angus or Limousin) for the production of terminal offspring. This has greatly improved system efficiency. It is interesting that one of the largest impacts to the fed beef sector has come from advances in dairy cattle. Newer technologies are also available, although it is unclear if they will be marketable, in which gene editing is used to create the desired sex.

A path forward

The use of "traditional" genetic selection tools and methods in the U.S. beef cattle industry to improve reproductive success is poor, at best. The development and use of proper crossbreeding systems is far from pervasive, the recording of reproductive phenotypes could generally be considered sparse, and the utilization of economic selection indices seems to meet with skepticism due, in part, to confusion surrounding how they are developed. Although the above statements may be controversial to some, I cannot think of three action items that would lead to more progress in reproductive performance than the three listed below:

1. The commercial cow-calf industry needs to utilize composite or F_1 females. The majority of commercial producers should breed these to an unrelated terminal sire breed. Larger commercial producers may take advantage of scale and serve as a multiplier, focusing on the production of commercial replacement females.
2. The genetic evaluation of fertility/reproduction needs to advance past the current metrics evaluated in NCE. A tangible place to start would be to use a bivariate model jointly evaluating heifer pregnancy (early fertility) and days to calving (sustained reproduction). These traits are very tractable and the joint evaluation of a threshold character and a continuous trait has the added advantage of alleviating Extreme Category Problems (ECP) sometimes associated with binary traits.
3. The effective use of economic selection indices in the development of maternal and terminal selection lines.

The three action point above are not "sexy", but will have far greater impact per units of investment than advancement genomic selection tools given the current state of phenotypic data collection and breeding program design in the U.S. beef industry. This is not to say that genomic cannot, and will not, play an important role but the utility of genomics will be marginalized relative to this trait complex until the lower handing fruit detailed above is fully exploited.

References

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