Background for Guidelines to Facilitate Enhanced Genetic Potentials for Cow Efficiency

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Introduction

Efficiency is the ability to produce an output without wasting inputs. Quantifying efficiency must relate outputs to inputs and its units are those of the inputs and outputs. Study of efficiency has been an important topic of investigation for more than a century (Mumford *et al.*, 1917) and of fundamental interest to the Beef Improvement Federation at least since its 2002 meeting when virtually the entire program focused primarily on that topic in honor of the life's work of Dr. Gordon Dickerson. The papers published therein provide useful background for today's conversation. Dickerson (1969) defined *biological* objectives, in a manner consistent with these being a measure of efficiency, as "the relative *economic* importance of the major components of performance in terms of the approximate direct effect of each on cost per unit of production. This definition seems consistent with identification of what has since come to be termed "Economically Relevant Traits" (Golden et al., 2000). Consider the mathematical definition of efficiency for animal production adapted similarly to Tess and Davis (2002) from the works of Dickerson (1970, 1976, 1982).

$$\frac{Expense}{Product} = \frac{\overbrace{R_d + I_d + F_{md} + F_{pd}}^{\text{per breeding female}} + \overbrace{N_o\left[D_o\left(I_o+F_{mo}+F_{po}\right) + S_o\right]}^{\text{per her offspring}}}{P_d V_d + N_o P_o V_o}$$

Where:

> R_d = annualized replacement cost; I_d = annual non-feed cost; F_{md} = annual maintenance feed cost; F_{pd} = annual feed cost for performance (e.g., milk production); N_o = number of offspring marketed per breeding female (may be fractional); D_o = number of days from weaning to harvest for offspring; I_o = daily non-feed cost for progeny during the postweaning period; F_{mo} = daily feed cost for maintenance of offspring; F_{po} = daily feed cost for performance of offspring; S_o = annual non-feed cost per offspring marketed; P_d = annualized product marketed from a breeding female (i.e., a cull cow); V_d = unit value of

product marketed from a breeding female; P_o = annual product marketed from offspring; and V_o = unit value of product marketed from offspring.

It is anticipated that any evaluation for efficiency would be based on a corresponding breeding objective: one to be improved following transformation to linearity (Lin 1980; Gunsett, 1984). In context of genetic evaluation a key question is: how well does the current suite of genetic predictions indicate the merit of individuals with respect to components of efficiency? It must be recognized that, with exceptions, genetic evaluation for the offspring-related components of the objective is currently substantially more accurate than it is for the breeding female-related components of the objective. One notable exception is the lack of widespread evaluation of days to finish (Brigham et al., 2006; Speidel, 2011) However, this deficiency aside, the aim of this paper is to review aspects of current genetic evaluation systems for traits of the breeding female and to stimulate progress toward more effective systems of evaluation of her genetic potential as she contributes to efficiency of the production system.

Current tools

Conceptually, the number of offspring marketed per breeding female can be divided into two components: the probability of producing an offspring from each breeding season, and longevity. When non-pregnant females are consistently culled these components are at least somewhat intertwined. This interrelationship is obvious in the genetic evaluation of "stayability" developed by Snelling *et al*. (1995) following its formal definition as the probability of surviving to a specific age, given the opportunity to reach that age (Hudson and Van Vleck, 1981). As such, the observations are binary and observed late in life (6 years of age in most current evaluations), with static contemporary groups defined at the time each female is first exposed for breeding. Inefficient use of contemporary group information and partial records are two problems that may limit current genetic evaluations for stayability. For instance, a cow sold to another breeder may result in her observation not being included in genetic evaluation due to the resulting single-animal contemporary group. These problems can be addressed by using survival analysis to account for time-dependent contemporary groups and censored records (Ducrocq and Sölkner, 1994, 1998). However, implementation of survival analysis for animal models can be challenging (Ducrocq, 2001). Due to issues of timeliness of phenotypic observations and generally low heritability, achieving a desirable level of accuracy in evaluation of individual animals prior to making a "keep or cull" decision may also be difficult.

Replacement costs are in large part functionally related to an opportunity cost for weaning weight not marketed, postweaning growth, postweaning feed intake, and pregnancy (calving) and culling rates. Weaning weight and postweaning growth are long-time standard components of genetic evaluation in beef cattle. Multi-trait genetic evaluation of postweaning growth and feed intake was more recently developed (MacNeil et al., 2011). Genetic evaluation of heifer pregnancy rate was developed more than 15 years ago (Doyle et al., 2000), but implementation has been slow due in part to the inability to record proper contemporary groups and exposure information. Heifer calving rate has been proposed as an alternative to heifer pregnancy rate in order to overcome issues with data recording (Callis, 2010; Venot et al., 2013). Impacts of pregnancy and culling rates may be understood from a stable age distribution modeled following Leslie (1945, 1948). Days to calving has also been proposed as a trait for genetic evaluation to improve fertility in beef cattle (Johnston and Bunter, 1996). However, the trait days to calving does not readily lend itself to quantifying either annualized replacement cost or number of offspring marketed.

Equations, of varying degrees of complexity, are readily available to predict feed requirements for beef females. In many cases, these equations contain cow weight and milk production as independent variables and explain upwards of 75% of the phenotypic variation in annual energy consumption (e.g., Anderson et al., 1983; Kirkpatrick et al., 1985). More complex predictions of intake are part of the National Research Council (1987) treatise on predicting feed intake. Genetic evaluation of preweaning gain or weaning weight is virtually universal and the genetic prediction of the maternal contribution to preweaning growth is widely available. The genetic correlation between milk production and maternal weaning weight may be sufficiently strong to indicate these are alternative measures of the same trait (Miller and Wilton, 1999; Meyer et al., 1994; MacNeil et al., 2006). Further, genetic evaluation for cow weight is somewhat commonplace (e.g., Northcutt and Wilson, 1993; Anonymous, 2014). To date, genetic prediction for energy intake by cows has been accomplished without reliance on direct measurement of the trait of interest (MacNeil and Mott, 2000; Evans, 2001), which is expected to be exceedingly costly and necessarily only recorded late in life. Whereas, forage consumption depends not only on characteristics of the animal, but also on characteristics of the forage (Van Soest, 1965; Allison, 1985) whether or not genetic prediction of intake is robust across environments remains a researchable question.

In summary, some components of efficiency, such as stayability and longevity, related to breeding females are measured late-in-life with evaluations that could be facilitated by early-in-life indicator traits including genotypes. Likewise, there are additional components of the objective that are exceedingly expensive to measure directly and whose evaluation would also be facilitated by highly correlated indicator traits and accurate genomic predictions. Finally, evaluation of these traits depends on them being accurately recorded and perhaps even more so on the appropriate grouping of contemporaries. This should be a goal of “whole-herd” reporting systems.

Implementation

Successful evaluation of “efficiency” requires capturing the full range of variation in its underlying components. Making data capture too onerous is likely to dissuade producers from participating in national cattle evaluation systems focused on efficiency. Thus, while whole herd reporting is essential and must include information about females that “fail” and leave the system, specific data to be captured should be carefully thought out.

More accurate description of variation in probability of producing an offspring from each breeding season and measurement of longevity could be enhanced by culling codes that are both limited in number and focused on the economically relevant traits. It is recommended that disposal date be routinely reported and coupled with coded descriptors (e.g., age, open, bred late, or unsoundness: teats, udder, feet, legs, mouth, sold for breeding use).

Survival analysis offers a number of opportunities to accommodate unique characteristics of time-to-event reproductive data from beef cattle. First, modeling non-genetic effects, particularly on traits expressed as a time-to-event (reproductive failure, culling) can be somewhat different than similar modeling for traits expressed once early-in-life. For the latter class of traits the individuals that are most directly compared make up a single static contemporary group. However, for the former class of traits the non-genetic effects change over time as do the animals that are directly compared one to another. For instance, consider a hypothetical breeding group of females exposed for breeding together in a given year. Some of them will not become pregnant thus experience reproductive failure (an event) while others will become pregnant and thus do not experience the same event. Those not becoming pregnant will be culled and replaced by heifers that calved at two years of age. This changes the competitive structure within the group of females exposed the following year. Further, as environmental conditions fluctuate over years those experiencing reproductive failure after the second year have been exposed to different effects than those exhibiting the same event after the first year. This leads to a recommendation for modeling time-dependent contemporary groups. A second complication for some traits that are expressed late-in-life is the difficulty of including contemporary animals in an evaluation as they have not yet expressed the relevant phenotype. This missing data problem is referred to as censoring. The analysis of censored data is accommodated by survival analysis (Miller et al., 1981). Survival analysis can also accommodate time-to-event data that are categorical in nature (Prentice and Gloeckler, 1978); a cow calves at 2, 3, 4, years of age, but fails to become pregnant after her third calf and hence does not calve at 5. Further, Giolo and Demétrio (2011) show the concept of frailty may provide a useful extension to survival analysis in order to account for unobserved within group heterogeneity (e.g., accounting for relationships among daughters of sires) in the context of genetic evaluation. Results from survival analysis correspond with predictions derived from matrix models of stable age distributions. This correspondence can be exploited in the development of breeding objectives.

Some components of efficiency may be geographically dependent and thus require different emphases depending on the region where the germplasm is intended for use. For example, given an EPD for heat tolerance, the economic weight placed on it is appropriately far greater in selection of cattle for use in Texas than those for use in Montana. Similar regionally specific emphases would include traits like fescue endophyte tolerance and disease resistance. This concept may even extend to dystocia as evidenced by Hereford cows of comparable genetic make-up moved from Miles City, Montana, to Brooksville, Florida, and vice versa. Ten years after this switch was made, birth weights in the Montana herd that had been moved to Florida had declined from 81 pounds to 64 pounds. Conversely, birth weights in the Florida herd that had been moved to Montana had increased from 66 pounds to 77 pounds. Other studies have yielded similar results, indicating that calves of comparable genotype will be born lighter in the south than in the north (Ritchie and Anderson, 2001).

It should be noted that any index of "cow efficiency", while generally in keeping with Dickerson's description of efficiency is incomplete, due to the omission of some traits, with respect to the efficiency of beef production. This circumstance requires the economic values be adjusted to account for the incomplete recording and limits the opportunity to break genetic antagonisms (Amer et al., 2014). Thus, there is no guarantee that improvement in cow efficiency leads to generally more efficient beef production. Efficiency cannot be quantified, and therefore useful in genetic selection, without recording the economically relevant inputs and outputs. Past experimental evaluations of cow efficiency have focused on indexes of weaning weight of the calf divided by energy consumption by its dam (Marshall et al., 1976; Davis et al., 1983) and on weaning weight of the calf divided by body weight of its dam (e.g., Kress et al., 2001; MacNeil, 2005) or weaning weight of the calf divided by Large Stock Unit (Mokolobate, 2015). In all of these cases, the denominator is considered as a proxy for energy consumption by the cow. Use of these indexes as a selection criterion to improve efficiency seems debatable; certainly they fail to account for differences in reproduction and the latter indexes may not explain much variation in energy consumed. Furthermore, selection for ratio traits places inconsistent emphasis on the component traits, resulting in variable responses to selection (MacNeil, 2007).

It is envisioned that any evaluation of efficiency would proceed from components evaluated via direct measurement and indicators to a multiple-trait index. Economic weights for such indexes could be restricted (e.g., Eisen, 1977) so as to not allow improvement in efficiency to result from increased resource utilization. Smith et al (1986) extended this principle to focus weighting selection criteria in a way that facilitates genetic change that can be achieved by a resource-constant enterprise. Estimating economic weights by procedures adapted from microeconomic production theory may also be viable in accomplishing genetic improvement in efficiency (Amer and Fox, 1992). Currently, the greatest impediment to genetic evaluation of efficiency is having data to allow evaluation of the components. Successful implementation of EPD or EBV for "efficiency" rests on the twin pillars of "whole-herd" and "complete" reporting. Compromising either pillar results in a reduced ability to evaluate and thus improve efficiency.

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