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Symposium review: Possibilities in an age of genomics: The future of selection indices[1]

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ABSTRACT

Selective breeding has been practiced since domestication, but early breeders commonly selected on appearance (e.g., coat color) rather than performance traits (e.g., milk yield). A breeding index converts information about several traits into a single number used for selection and to predict an animal's own performance. Calculation of selection indices is straightforward when phenotype and pedigree data are available. Prediction of economic values 3 to 10 yr in the future, when the offspring of matings planned using the index will be lactating, is more challenging. The first USDA selection index included only milk and fat yield, whereas the latest version of the lifetime net merit index includes 13 traits and composites (weighted averages of other additional traits). Selection indices are revised to reflect improved knowledge of biology, new sources of data, and changing economic conditions. Single-trait selection often suffers from antagonistic correlations with traits not in the selection objective. Multiple-trait selection avoids those problems at the cost of less-than-maximal progress for individual traits. How many and which traits to include is not simple to determine because traits are not independent. Many countries use indices that reflect the needs of different producers in different environments. Although the emphasis placed on trait groups differs, most indices include yield, fertility, health, and type traits. Addition of milk composition, feed intake, and other traits is possible, but they are more costly to collect and many are not yet directly rewarded in the marketplace, such as with incentives from milk processing plants. As the number of traits grows, custom selection indices can more closely match genotypes to the environments in which they will perform. Traditional selection required recording lots of cows across many farms, but genomic selection favors collecting more detailed information from cooperating farms. A similar strategy may be useful in less developed countries. Recording important new traits on a fraction of cows can quickly benefit the whole population through genomics.
Key words: breeding program, genetic improvement, selection index

INTRODUCTION

Breeding indices are important tools in modern dairy cattle breeding. They provide a way to combine information about many traits into a single number that can be used to rank animals and make breeding decisions. The need for such a tool was recognized very early in the history of modern animal breeding, when Hazel and Lush (1942) applied the method of Smith (1934) to the improvement of economically important traits of livestock. The ideal breeding objective for dairy cattle remains a popular topic and has been reviewed periodically (e.g., Hazel et al., 1994; Philipsson et al., 1994; VanRaden, 2004; Miglior et al., 2005; Shook, 2006), but there is no single selection objective that is best for all populations or all herds within a population.

Historically, selection indices in the United States were developed by the USDA and purebred dairy cattle associations, frequently with input from scientists at land-grant universities, using data available through the national milk recording system and breed type appraisal programs. Proposed indices were typically reviewed by groups of experts and information about the derivation of the indices was published in technical and trade publications, ensuring confidence in the values because of that review process. Recently, genetic evaluations for novel traits and new selection indices have been computed and distributed by companies such as CRV (Arnhem, the Netherlands), Genex (Shawano, WI), and Zoetis (Parsippany-Troy Hills, NJ). This provides farmers with new tools and may drive demand for new phenotypes, but transparent review processes may be lacking. The purpose of this paper is to present a brief overview of how selection indices are constructed, describe traits included in current indices, review desirable properties of new traits, discuss traits that may be included in selection indices in the future, and dem-

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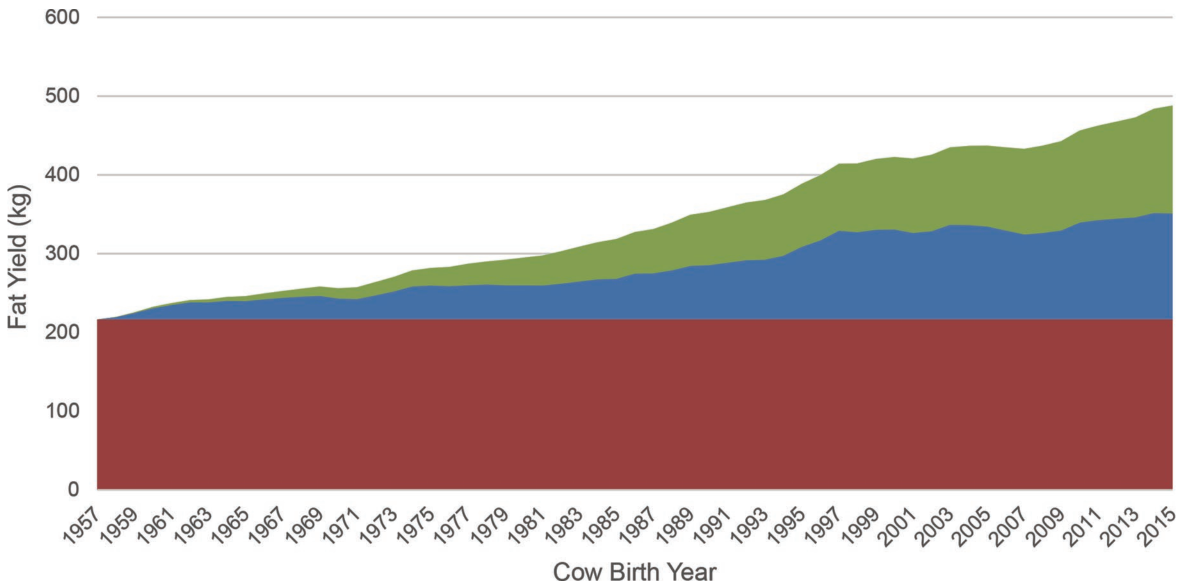

Figure 1. Changes in fat yield for US Holsteins, 1957 to 2015. The black (red) area represents average production in 1957, the light gray (blue) area shows changes due to improved feeding and management, and the dark gray (green) area shows gains from increased genetic merit. Color version available online.

onstrate that selection indices are robust to incorrect assumptions about model parameters.

SELECTION INDICES

Improving Animal Performance

Animal performance is a function of both genetic and environmental factors and interactions among the two. Predictions of genetic merit are based on a quantitative model that assumes that traits are controlled by many genes, each of which has a small effect on the phenotype (Falconer and MacKay, 1996). This model has been found to accurately describe many traits of economic importance in dairy cattle (Cole et al., 2009). Environmental influences include all sources of phenotypic variation that cannot be attributed to genetics, such as nutrition, climate, disease exposure, error in measurement, and other unknown factors. These factors vary from farm to farm and between individual animals on the same farm and may change over time (e.g., Windig et al., 2005).

Figure 1 shows the change in fat yield for US Holsteins between 1957 and 2015. Production in 1957 is used as a baseline, and gains over time were found to be evenly divided between increased genetic potential and improvements in feeding and management. Gains in genetics and management each represent 28% of 2015 production, whereas the 1957 base represents 44% of current yield. The proportion of gains from improved genetics versus improved environment differs from trait to trait and is a function of the heritability of a trait. Fat yield has a heritability of 20% (VanRaden, 2017), whereas daughter pregnancy rate has a heritability of only 4% (VanRaden et al., 2004). When the proportion of variance in a trait due to genetics is low, it is often easier to make gains by improving the environment in which the cow is performing, and gains from genetic improvement may not be visible to producers for a long time.

Construction of Selection Indices

The following discussion focuses on the simplest formulation of a selection index; greater detail, including derivations, may be found in the literature (e.g., Lin, 1978; Cameron, 1997). When using a selection index, the goal is to improve one or more traits, referred to as the selection objective, by ranking and choosing mates using a combination of one or more traits, known as the selection criterion. In modern breeding programs, the selection objective is typically a measure of lifetime profitability, whereas the selection criterion usually comprises traits that are included in national milk recording programs. In the mathematical terms of Hazel and Lush (1942), an index including m terms in the selection criterion for an animal takes the form

$$I = b_1X_1 + b_2X_2 + \ldots + b_mX_m,$$