J. Dairy Sci. 89:1740–1752

Optimization of Dairy Cattle Breeding Programs for Different Environments with Genotype by Environment Interaction

H. A. Mulder,*[1] R. F. Veerkamp,† B. J. Ducro,* J. A. M. van Arendonk,* and P. Bijma*
*Animal Breeding and Genetics Group, Wageningen University, PO Box 338, 6700 AH Wageningen, The Netherlands
†Animal Sciences Group, Division Animal Resources Development, PO Box 65, 8200 AB Lelystad, The Netherlands

ABSTRACT

Dairy cattle breeding organizations tend to sell semen to breeders operating in different environments and genotype × environment interaction may play a role. The objective of this study was to investigate optimization of dairy cattle breeding programs for 2 environments with genotype × environment interaction. Breeding strategies differed in 1) including 1 or 2 environments in the breeding goal, 2) running either 1 or 2 breeding programs, and 3) progeny testing bulls in 1 or 2 environments. Breeding strategies were evaluated on average genetic gain of both environments, which was predicted by using a pseudo-BLUP selection index model.

When both environments were equally important and the genetic correlation was higher than 0.61, the highest average genetic gain was achieved with a single breeding program with progeny-testing all bulls in both environments. When the genetic correlation was lower than 0.61, it was optimal to have 2 environment-specific breeding programs progeny-testing an equal number of bulls in their own environment only. Breeding strategies differed by 2 to 12% in average genetic gain, when the genetic correlation ranged between 0.50 and 1.00. Ranking of breeding strategies, based on the highest average genetic gain, was relatively insensitive to heritability, number of progeny per bull, and the relative importance of both environments, but was very sensitive to selection intensity. With more intense selection, running 2 environment-specific breeding programs was optimal for genetic correlations up to 0.70–0.80, but this strategy was less appropriate for situations where 1 of the 2 environments had a relative importance less than 10 to 20%. Results of this study can be used as guidelines to optimize breeding programs when breeding dairy cattle for different parts of the world.
Key words: genetic gain, dairy cattle, breeding program, genotype × environment interaction

INTRODUCTION

Dairy cattle breeding is increasingly becoming an international business. Due to mergers, acquisitions, partnerships, or alliances, breeding organizations are continually selling a greater proportion of semen of proven bulls to different regions of the world. Consequently, phenotypes of daughters of these bulls are recorded in different environments. Genotype × environment interaction (**G × E**) may play a role, indicated by genetic correlations lower than unity between countries. Genetic correlations are mostly between 0.85 and 1.00 for milk production traits between environments in North America and Western Europe (Weigel et al., 2001; Kearney et al., 2004; Mulder et al., 2004), but are lower between milk production traits in North America or Western Europe and New Zealand, Australia, South America or Africa (Costa et al., 2000; Ojango and Pollott, 2002; Zwald et al., 2003). Furthermore, genetic correlations are lower for functional traits than for milk production traits. For example, the average genetic correlation for longevity in different countries is 0.59 (Mark, 2004). Due to an increasing emphasis on functional traits in breeding goals, the correlation between total merit indices in different countries has decreased (Van der Beek, 2003). Note that genetic correlations between countries are less than unity not only because of G × E, but also because of differences in trait definition or statistical methods used in breeding value estimation (Mark, 2004).

Knowing that genetic correlations between environments are less than unity, breeding organizations face the problem of how to optimize the breeding program when breeding for multiple environments. James (1961) proposed 3 strategies to breed for 2 environments: 1) selection and testing in 1 environment, 2) separate selection and testing in both environments, and 3) testing progeny in both environments and applying index selection to improve performance in both environments simultaneously. Considering only sire selection, he concluded that testing progeny in both environments and applying index selection was superior to separate selection and testing in both environments or selection and testing in 1 environment,

Received September 19, 2005.
Accepted December 12, 2005.
[1]Corresponding author: herman.mulder@wur.nl

when the genetic correlation was larger than 0.70. Vargas and van Arendonk (2004) compared genetic gain of a local progeny-testing scheme in Costa Rica with genetic gain of semen importation from the United States, and concluded that semen importation was justified (from a Costa Rican point of view) when the genetic correlation was higher than 0.75. From the perspective of 2 breeding programs in 2 environments, Smith and Banos (1991) and Mulder and Bijma (2006) investigated benefits of cooperation by selection of animals across environments. Both studies concluded that there was no extra genetic gain due to selection across environments when the genetic correlation was lower than 0.80 to 0.90.

So far, only James (1961) studied genetic gain in 2 environments comparing different breeding strategies. James (1961), however, did not investigate sensitivity of breeding strategies to heritability, selection intensity, and number of progeny per bull. Furthermore, Smith and Banos (1991) and Mulder and Bijma (2006) investigated only optimization within one of the strategies as proposed by James (1961). Due to internationalization of dairy cattle breeding organizations, there is a need for a more complete evaluation of different breeding strategies, including a sensitivity analysis, to optimize dairy cattle breeding programs when the objective is to improve performance in different environments in the presence of G × E.

The objective of this study was to investigate optimization of dairy cattle breeding programs for multiple environments in the presence of G × E. The optimal breeding strategy was determined given the relative importance of environments and the genetic correlation between environments. Furthermore, sensitivity of ranking of breeding strategies was investigated with respect to selection intensity, heritability, and number of progeny per bull.

MATERIALS AND METHODS

Breeding Objective

In this study, we considered a situation with a single dairy cattle breeding organization having 2 environments in its overall objective. For simplicity, genetic improvement was focused on higher milk yield in both environments. The aim of the breeding organization was to maximize genetic gain in the overall objective (ΔG) weighing genetic gain in each environment (ΔG_i) by the relative importance of that environment (w_i):

$$\Delta G = w_1 \Delta G_1 + w_2 \Delta G_2 \quad [1]$$

where $w_1 + w_2 = 1$. The relative importance of each environment can be a reflection of, for example, semen sales, cow population size, or economic value of milk yield.

Breeding Strategies

In a situation with progeny testing of bulls, the breeding organization would have different options to maximize genetic gain in the overall objective. In this study, we considered 1) including 1 or 2 environments in the breeding goal, 2) progeny testing part of the test-bulls in environment 1 and another part in environment 2, or 3) progeny testing all test-bulls either in a single or in both environments. Splitting up the population of test-bulls with testing part of the bulls in environment 1 and another part in environment 2 was considered as making 2 breeding programs. Hence, the term "breeding program(s)" was used to refer to the number of groups of test-bulls. Both breeding programs could have either the same breeding goal or different breeding goals. The breeding goal was defined as $H = \mathbf{v'a}$, where $\mathbf{v}$ was a vector with economic values of environment 1 and 2, and $\mathbf{a}$ was a vector with true breeding values for milk yield in environment 1 and 2. Note that the breeding goal of a breeding program was not necessarily equal to the overall objective (equation [1]).

Based on the given options, the 4 most different strategies were chosen and simulated in this study: One environment breeding program with progeny testing bulls in 1 environment (**OE-1**), One joint breeding program with progeny testing bulls in 2 environments (**OJ-2**), 2 environment-specific breeding programs each with progeny testing bulls in 1 environment (**TE-1**), and 2 breeding programs with a joint breeding goal each with progeny testing bulls in 1 environment (**TJ-1**). Strategies are described below and summarized in Table 1.

OE-1. Strategy OE-1 consisted of 1 breeding program with progeny testing all bulls in environment 1. The breeding goal was to improve milk yield in environment 1; a zero economic value was given to milk yield in environment 2.

OJ-2. Strategy OJ-2 consisted of 1 breeding program with progeny testing all bulls in both environments. The breeding goal was to improve milk yield in both environments simultaneously. The economic values in the breeding goal were equal to the relative importances of both environments in the overall objective. The number of progeny per bull in each environment was equal to the relative importance of each environment multiplied by the total number of progeny per bull, which was nearly equal to the optimal distribution of progeny to maximize genetic gain in the overall objective (results not shown).