Dairy Cattle: Breeding and Genetics

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Abstract
Five primary factors affect breeding genetically improved dairy cattle: 1) identification; 2) pedigree; 3) performance recording; 4) artificial insemination; and 5) genetic evaluation systems (traditional and genomic). Genetic progress can be measured as increased efficiency (higher performance with fewer animals). Knowledge of differences in genetic merit of dairy populations resulted in a global marketplace for germplasm and live animals, which led to calculation of international genetic evaluations. Selection indexes in which genetically evaluated traits are combined according to economic value are used by nearly all countries that calculate genetic evaluations.

INTRODUCTION

For thousands of years, the dairy cow has been a valuable producer of food for humans and animals. Animal breeding began when owners decided that mating the best with the best was a winning strategy; however, choosing which animals are best requires considerable insight. As genetic principles were discovered, animal breeding transformed into a science rather than an art. Early cattle gave only a few liters of milk per day; some herds now average 40 L/cow/day, and a few individual cows have averaged over 80 L/day for an entire year. Although much has been learned about how to feed and manage dairy cows to obtain larger quantities of milk, current yield efficiency would not have been achieved unless concurrent progress had been made in concentrating those genes that are favorable for sustained, high milk production.

GENETIC IMPROVEMENT

Five factors are primarily responsible for the exceptional genetic improvement achieved by dairy cattle: 1) permanent unique identification (ID); 2) parentage recording; 3) recording of milk yield and other traits of economic importance; 4) artificial insemination (AI); and 5) accurate genetic evaluation systems. Ironically, failure of any one factor effectively neutralizes most genetic improvement.

Identification

Systems for dairy cattle ID have evolved from being unique to the farm to being unique internationally. Although five characters or digits are sufficient to be unique within a herd, today's international dairy industry requires a 19-character ID number: 3-letter country code, 3-letter breed code, 1-letter gender code, and 12-digit animal number. Global ID has come at a price; larger ID numbers contribute to more data entry errors. Electronic ID tags and readers are becoming more common for managing feeding, milking, breeding, and health care of individual cows, with the data transferred to an on-farm computer, especially for large herds. In some countries, unique ID for each animal is mandatory.

Parentage (Pedigree)

Genetic improvement was slow before breeders began to summarize and use performance information from bulls' daughters. Proper recording of sire ID was required for this advance and has been used throughout the last century in selection decisions. Proper recording of dam ID was encouraged during that period, but its benefit to selection decisions was less during early years. As genetic principles became better understood, accurate estimates of dams' genetic merit became extremely important. Cows of high genetic merit were designated as elite and usually were mated to top sires to provide young bulls for progeny-test programs of AI organizations. In countries that require unique ID for each animal, the sire, dam, and birth date sometimes are known for nearly 100% of animals. Genetic evaluation systems today use sophisticated statistical models that can include performance information from many or all known pedigree relationships.

Performance Recording

Little genetic improvement can be achieved without objective measurement of traits targeted for improvement. Countries vary considerably in percentage of cows that are

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in milk-recording programs. In the United States, almost 50% of dairy cows are enrolled in a dairy records management program, which supplies performance records to the national database, and parentage of only about two-thirds of those cows is known.

The first traits to be evaluated in most countries were milk and butterfat yield and percentage. Since the 1970s, accurate evaluation of protein yield and percentage, conformation traits, calving traits (calving ease/dystocia, stillbirth/calf survival, calf size/birth weight, and gestation length), longevity (herdlife, productive life, stayability, survival, and risk of involuntary culling), mastitis resistance (udder health/traits, somatic cell count/score, and clinical mastitis), female fertility (heifer and cow conception rates, daughter pregnancy rate, nonreturn rate, number of inseminations, days open, calving interval, and other reproductive intervals), and workability (milking speed and temperament) have been initiated in many countries.[1]

Artificial Insemination

Because some dilution of semen can provide nearly as high a conception rate as the original collected sample, 100 progeny or more can originate from a single ejaculate. In addition, semen can be frozen and kept for decades without any serious compromise to fertility. The ability to extend and freeze semen while achieving satisfactory fertility facilitates progeny testing early in a bull's life. A progeny test involves obtaining dozens of daughters of a bull and allowing those daughters to calve and be milked so that their performance can be summarized and a determination can be made on whether the bull is transmitting favorable traits to his offspring. After distribution of semen for a progeny test, most bulls traditionally were held in waiting until the outcome of the progeny test. Progeny testing many bulls provided an opportunity to select from among them, keep only the best, and use those few bulls to produce several thousand daughters and, in some cases, millions of granddaughters. Characteristics of U.S. progeny-test programs were documented by Norman et al.[2] Percentage of dairy animals that result from AI in the United States is nearly 80%; that percentage varies considerably among countries.

Genetic Evaluation Systems

Traditional

Accurate methods for evaluating genetic merit of bulls and cows for economically important traits are needed to identify those animals that are best suited to be parents of the next generation. The degree of system sophistication needed depends partially on effectiveness of the sampling program in randomizing bull daughters across herds that represent various management levels. If randomization is equitable for all bulls, less sophisticated procedures can be used. In the United States, methodology for national evaluations has progressed from daughter–dam comparison (1936) to herdmate comparison (1960) to modified contemporary comparison (1974) and, finally, to an animal model (1989).[3] A recent development in genetic evaluation systems is the use of test-day models, which have been adopted by several countries. Because test-day models account better for environmental effects and variations in testing schemes, they can provide more accurate estimates of genetic merit than do lactation models; however, test-day models are statistically more difficult and computationally more intensive.[4] Once evaluations are released to the dairy industry, dairy farmers have an opportunity to select among the best bulls for their needs and purchase frozen semen marketed by AI organizations. Mating decisions for specific animals can be based on estimated genetic merit for individual traits or selection indexes that combine traits of economic interest.

Genomic

The most recent advance in evaluation methodology for dairy cattle is the combination of genomic information with traditional phenotypic and pedigree data to produce a genomically enhanced estimate of genetic merit. Advances in genomic technology in recent years allow genotypes for more than 40,000 single-nucleotide polymorphisms (SNP; an SNP is a DNA base pair) equally distributed across all 30 chromosomes to be used as a third source of data for genetic evaluations of dairy cattle in addition to phenotypes and pedigrees. Genotypes must be matched to phenotypes to estimate SNP effects. Genomic predictions are computed using linear and nonlinear systems of equations.[5] Linear predictions assume that all markers contribute equally to genetic variation (no major genes are present). Nonlinear predictions assume that previous distributions of effects of marker or quantitative trait loci are not normal.

Genomic data greatly increase the reliability of predicted genetic merit when added to phenotypic data for large populations. Because genomic predictions are calculated as soon as a DNA sample is available and provide an evaluation with accuracy equivalent to one based on records from early offspring, this technology is causing dramatic changes in the dairy industry that are expected to accelerate the rate of genetic improvement. Dairy breeding programs with rapid turnover of generations could result in >50% faster progress by using genomically enhanced evaluations.

Other Factors

Dairy farmers continue to make additional genetic improvement by culling within the herd. Herd replacements often allow a turnover of about 30% of milking animals per year. Some culling decisions are under the manager's voluntary control, but others may be driven by fitness traits that limit the animal's ability to remain profitable and stay in the herd. A cow must be capable of timely pregnancies so that a new lactation can begin with high yield, and she must remain free of chronic diseases and conditions such as mastitis and lameness so that lactation can be maintained.

Supplemental breeding techniques also can help to increase genetic gains. Embryo transfer has increased the number of offspring possible from individual cows and helped to assure that potential bull dams will produce a son. Nucleus herds allow direct comparison of elite females, but they have had limited use as an alternative to traditional AI progeny testing. Cloning technologies (embryo splitting, nuclear transfer, and adult cloning) also can produce some genetic gains, but their commercial use has been limited because of cost.[6] Use of sexed semen to produce offspring of a desired gender has increased, but it reduced conception rates, and higher production costs limit widespread use. Producing more females allows farmers to increase within-herd genetic gains.

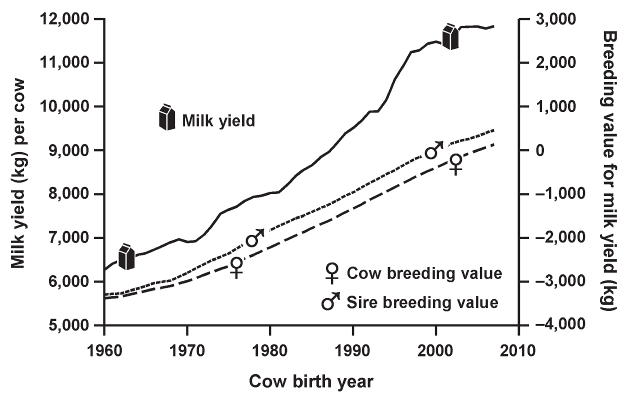

Fig. 2 Mean milk yield, genetic merit (breeding value), and sire genetic merit of U.S. Holstein cows with national genetic evaluations by birth year.
Source: Animal Improvement Programs Laboratory, Agricultural Research Service, U.S. Department of Agriculture: Beltsville, MD; http://aipl.arsusda.gov (accessed April 2009).

GENETIC PROGRESS

Practical success of genetic improvement procedures is evident in most dairy populations around the world. As cow numbers decreased, yield per cow increased (Fig. 1), in part because of improved genetic capacity for efficient dairy production, as indicated by similar trends in the genetic merit of dairy bulls and cows (Fig. 2).

Because of increased efficiency achieved through genetic programs, competition for sales of genetic material has increased. Higher productivity of North American breeds, particularly Holstein, in the 1980s[7] has led to U.S. semen exports of $100 million per year.[8] As a result, the international dairy population is much more related, and population sizes of many local breeds were reduced, in a few cases, to the point of extinction. As selection methods intensified, concern about level of inbreeding has increased, and interest in crossbreeding has grown somewhat to alleviate this concern and capture the known benefits of heterosis.

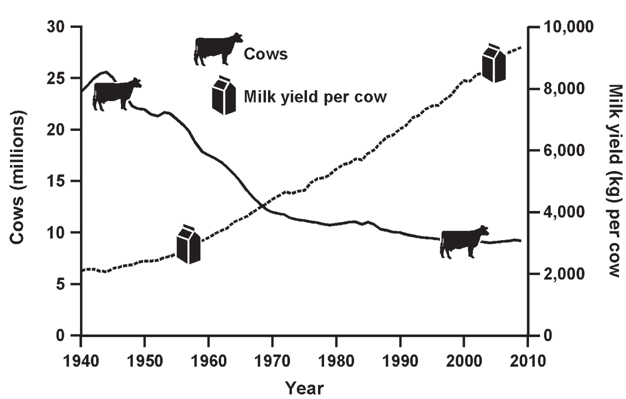

Fig. 1 Numbers of U.S. cows and mean milk yield by year.
Source: National Agricultural Statistics Service, U.S. Department of Agriculture: Washington, DC; http://www.nass.usda.gov (accessed April 2009).

INTERNATIONAL EVALUATIONS

Increasing global trade in semen, embryos, and livestock resulted in a need for accurate comparisons of animal performance both within and across countries. However, such comparisons are made difficult by different genetic evaluation methods, breeding objectives, and management environments. In 1983, the International Bull Evaluation Service (Interbull) was established as a nonprofit organization for promoting development and standardization of international genetic evaluations of cattle.[9] Currently, Interbull provides evaluations for bulls from 27 countries for production, 22 countries for conformation, 23 countries for udder health, 18 countries for longevity, 14 countries for calving, 19 countries for female fertility, and 11 countries for workability.[1]

SELECTION INDEXES

Nearly all dairy countries that calculate genetic evaluations for different traits produce an overall economic index in which traits are combined according to economic value. Past decisions on whether to allow animals to be parents have been made based on independent examination of each trait. Today's indexes for countries (Table 1) differ in the traits included and values assigned to each.[10]

Cytokine – Eggs

Table 1 Relative emphasis of traits in Holstein selection indexes around the world.

	Trait emphasis, %							
Country (index)	**Protein**	**Fat**	**Milk**	**Conformation**	**Longevity**	**Udder health**	**Fertility**	**Other health traits**
Australia (APR)	37	14	−18		8	7	5	10
Canada (LPI)	31	20		27	7	3	10	2
Czech Republic (SIH)	34	15		25	7	7	12	
France (ISU)	37	13		12	12	12	12	
Germany (RZG)	36	9		15	20	7	10	3
Hungary (HGI)	40	15		35		10		
Ireland (EBI)	25	5	−12		11		23	24
Israel (PD07)	42	15			8	13	16	7
Italy (PFT)	45	14		23	8	10		
Japan (NTP)	55	20		25				
Netherlands (NVI)	22	5	−6	22	20	6	19	
New Zealand (BW)	40	12	−14		6	7	8	−13
Scandinavia (NTM)	20	5	−5	13	4	14	13	26
South Africa (BVI)	26	26		45		3		
Spain (ICO)	35	12	12	35	3	3		
Switzerland (ISEL)	39	14		24	7	10	6	
United Kingdom (PLI)	22	12	−11	6	21	6	18	4
United States (NM)	16	19		17	22	10	11	5
United States (TPI)	26	16		26	14	5	10	3

Source: Adapted from Schneider.[10]

CONCLUSION

Animal ID that includes pedigree information, routine recording of performance traits, widespread use of AI, and development of state-of-the-art statistical models and evaluation systems have led to increasing genetic gains in traits of economic importance for dairy cattle during the past 100 years. The resulting improvement in production efficiency allows dairy products to be produced with fewer cattle, thereby reducing adverse environmental impacts and conserving natural resources. Increased genetic merit of dairy populations has resulted in a global marketplace for germplasm and live animals. Recent incorporation of genomic information promises faster progress during the next 100 years.

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