Dairy cows of high genetic merit for yields of milk, fat, and protein

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Summary

Extensive emphasis on milk and milk fat yields with no diversion for beef performance has increased the yield efficiency of North American dairy cattle. Heavy demand for North American genetics followed national strain comparison trials in Poland, and U.S. and Canadian dairy cattle and germplasm still are an important source of genetics for many countries. Genetic improvement has accelerated in many countries because of the implementation of sampling programs for young bulls and improved evaluation procedures. Rapid access to information and more frequent calculation of genetic information also are having a positive impact on genetic improvement. Traits other than yield should be considered in a breeding program, but those traits must have a reasonable opportunity for improvement and sufficient economic worth. Because of ever increasing efficiency, the world's milk supply comes from fewer cows each year. However, no decline in the rate of genetic improvement is apparent under current genetic practices; estimates of heritability are increasing, and a decline in yield efficiency is unlikely in the near future. As management improves, especially for subtropical conditions, many of the selection principles used in temperate climates will be adopted for more adverse environmental conditions.

Introduction

Milk often is referred to as nature's most nearly perfect food. Although critics have challenged this statement, milk has always been exonerated because it has a remarkable combination of nutrients that are required in the diet. Many different species serve to provide milk for local needs, but none have become as proficient as the dairy cow in providing large volumes to meet the needs of society. Because of her remarkable productivity, the dairy cow has been called the foster mother of the human race.

The capability of dairy cattle to produce large volumes of milk and components appears to have been evolving for centuries. Some cows had lactation yields a century ago that still compare favorably with yields of cows today. Animal breeding became accepted as a specialized science only about 50 years ago, and another decade was needed before selection programs began to have much impact on animal productivity.

Today genetic programs have become highly dependent on understanding gene action and statistical implications, and genetic evaluations have become so well accepted that individual animals of outstanding genetic merit sometimes become a parent to progeny in many countries.

Individual bulls have been documented to have as many as a million daughters and granddaughters across countries. This concentration of genes has increased the percentage of inbreeding globally and has raised concern that genetic diversity that may be needed in the future could be lost.

Should countries continue their same approaches for improving their dairy genetics? If the current rate of improvement for efficiency is high, is not more of the same better? Or have critical concerns in the current approach not been considered?

Selection for high yielding dairy cows

While North American dairy genetic programs promoted selection for milk and fat yields with some emphasis on conformation traits prior to 1980, many western European countries focused on multiple-purpose cattle because beef was produced from the same herds (Cunningham, 1983). Often they assembled young bulls in special test stations and evaluated them for growth, feed efficiency, and beef traits prior to initiating a progeny test for yield traits. The North American approach turned out to be more successful as indicated by the later elimination of the emphasis on beef traits in most other countries. Surprisingly, beef performance traits of Holsteins were often as desirable as those of Friesians from most other countries (Stolzman et al., 1988), even though beef traits had not been emphasized for Holsteins.

The high efficiency of North American Holstein strains became more widely known by 1980 when results were becoming available from the Food and Agricultural Organization's national strain comparison trial in Poland (Stolzman et al., 1981). In that trial (Jasiorowski et al., 1988), 10 leading dairy countries contributed semen that was used with Polish Friesian cows. The resulting offspring were managed as contemporaries on large state-owned farms. Offspring from U.S., Israeli, and Canadian bulls ranked first, second, and third for milk yield (Stolzman et al., 1981). Jasiorowski et al. (1988) cited 18 other research trials that compared daughters sired by bulls from two or more countries, and all trials confirmed the high milk yield of North American Holsteins. With so many confirming studies, the slow international acceptance of this knowledge was surprising and perhaps resulted because the individual studies were reported in different languages and usually within the country where the research was done. Perhaps the results also were not publicized extensively because they were an embarrassment to the breeding establishments within some of the countries.

Today the driving force in recognition and promotion of the best genetics is the genetic evaluations produced by the International Bull Evaluation Service (INTERBULL, http://www-interbull.slu.se). This international organization provides information with which to rank bulls across countries by combining the genetic information provided by individual participating countries and promotes the development and standardization of international genetic evaluations for cattle. The organization was formed because breeders wanted to make comparisons between a domestically marketed bull and a bull available through imported semen. In the past, making those comparisons was difficult because of the many differences in genetic evaluation methods and scales for reporting results. Now calculation of international rankings is possible because the bulls are related across countries and the export of semen assures that many individual bulls have milking daughters in several countries. Semen exports from the United States and Canada are responsible for providing the most ties across countries, but recent exports from France, Germany, and The Netherlands, including some to the United States and Canada, will further improve the accuracy of comparisons. In 1996, 39% of the U.S. dairy semen sold in 1996 was exported (National Association of Animal Breeders, 1997). Currently INTERBULL evaluates bulls from 20 countries and 6 breeds for 3 yield traits: milk, fat, and protein. Those evaluations are distributed widely and are the reason that comments about the best genetics today often refer to individual bulls rather than to countries.

Migration of genes

The rankings from the Polish studies of the 10 countries for milk and fat yields no longer indicate the genetic merit of cattle from those countries. During the last 25 years, movement to replace genes in Friesian populations with those from the North American Holsteins has been rapid (Cunningham, 1983). Table 1 shows the origin of the sires of artificial-insemination (AI) bulls with August 1997 INTERBULL evaluations for seven leading dairy countries for bull birth years of 1980, 1985, and 1990. The table shows that genetic replacement occurred in different European countries at different times. In 1980, 100% of Italian bulls and 93% of German AI bulls were sired by North American Holsteins; however, only 40% of British bulls were sired by North American Holsteins, and only 3% were sired by U.S. bulls. By 1990, 94 to 100% of the sires of the AI bulls from the five European countries shown were North American Holsteins, and 85 to 98% were sired by U.S. bulls. In contrast, the sires of U.S. AI bulls were 98% homebred and 2% Canadian for all 3 years.

Table 1. Origin of sires of Holstein AI bulls with August 1997 INTERBULL evaluations by birth year of bull

	Canadian sires (%)			U.S. sires (%)		
Bull's country of birth	1980	1985	1990	1980	1985	1990
Canada	37	36	27	63	64	73
France	10	13	2	68	84	98
Germany	9	15	12	84	81	86
Italy	14	9	10	86	91	87
The Netherlands	4	6	1	65	90	96
United Kingdom	37	29	9	3	50	85
United States	2	2	2	98	98	98

Selection for milk volume versus components

Because genetic selection is a long-term endeavor, consistency in the selection goal is desirable for maximizing efficiency. Milk pricing and selection goals should be coordinated. Dairy producers should not be expected to produce a product for which they will not be compensated.

In the United States, methods for pricing milk have undergone substantial changes over the last 15 years. Increasing attention has been given to the value of milk components because 60% of the milk marketed in the United States in 1996 was used for manufactured products (http://usda.mannlib.cornell.edu/reports/nassr/dairy/pmp-bbm/milk_production_disposition_ and_income_05.15.97). Multiple component pricing (assigning a value to one or more components in addition to fat) has been implemented in several forms, frequently as premiums or differentials for either protein or solids-not-fat. Sometimes payment for those extra components has been tied to milk quality requirements (somatic cell count or standard plate count), primarily because of the influence of milk quality on cheese yields. Several U.S. Federal Orders now include separate payments for fat, protein, and remaining solids. A price for protein that is two or three times that for fat is common, particularly if cheese is being produced.

With the changes in pricing, U.S. dairy producers are changing their selection goals. Cows with high genetic merit for component percentages are migrating to marketing areas that pay high prices for components. Regardless of country, dairy products should be produced for the economics of the market (domestic or international), and dairy animals should be bred to produce for that market.

Opportunity to intensify selection for high yield

Robertson and Rendel (1950) showed three ways to increase genetic improvement: 1) increase selection intensity, 2) improve genetic evaluation methodology, and 3) reduce generation interval.

Increasing selection intensity. Rapid improvement in the genetic merit of U.S. dairy cattle for milk and component yields (ftp://aipl.arsusda.gov/pub/trend) has been attained partly because AI organizations have increased the number of Holstein bulls that are sampled each year: 857 in 1980, 1,257 in 1985, and 1,526 in 1995 (C. G. Sattler, National Association of Animal Breeders, 1997, personal communication). Growth in sampling programs has provided an opportunity for more intense selection, thus enabling AI organizations to market bulls that have outstanding genetic merit. With these increases in numbers of bulls tested in the United States, increases in the rate of genetic improvement are expected. At the same time, many countries have moved rapidly toward implementation or expansion of sampling programs that were successful in North America for young sires. Table 2 shows the number of young dairy bulls sampled in 1977 and 1997 by 10 leading dairy nations. The number of young sires sampled through AI programs in those countries has increased from about 2,500 to 4,500 over the last two decades.

Table 2. Number of Holstein and Friesian bulls sampled by AI organizations in 1977 and 1997 for 10 leading dairy countries

Country	Bulls sampled 1977[1]	1997[2]
Australia	61	225
Canada	119	400
Denmark	174	200
France	371	600
Germany	. . .[3]	800
Italy	110	350
New Zealand	87	125
The Netherlands	. . .[3]	380
United Kingdom	156	120
United States	687	1,300
All countries	~2,500	4,500

[1]Source: International Bull Evaluation Service (1988). Either birth year of 1977 or year of first evaluation of 1982 depending on how reported by the country.
[2]Source: D. Funk, ABS Global, 1997, personal communication.
[3]Not available.

Improving genetic evaluation methodology. Genetic evaluations have become more accurate as evaluation procedures became more complex. Today computers have faster processing speed and more memory, which provides an opportunity to use statistical models with adequate fixed and random effects. Genetic evaluations for U.S. dairy bulls have been calculated by the U.S. Department of Agriculture (USDA) since the 1920's, and evaluation procedures have evolved from daughter averages to daughter-dam comparisons to herd mate comparisons (Henderson et al., 1954; Plowman and McDaniel, 1968), modified contemporary comparisons (Dickinson et al., 1976; Norman, 1976) to animal model predictions (Wiggans et al., 1988). Statistical models based on test-day data have been implemented in a few countries, and many more countries have planned implementation during the next 2 years.

Reducing generation interval. Reducing the generation interval can increase the rate of genetic improvement. Average ages of sire of sire, dam of sire, sire of dam, and dam of dam at birth of progeny all influence the generation interval. The generation interval also is influenced somewhat by the time required to process information, which is a factor that USDA can partially control. The database maintained by USDA's Animal Improvement Programs Laboratory (AIPL) of more than 60 million lactation records is probably the largest dairy database in the world. Computer programs for editing those records, calculating genetic evaluations, and preparing files for industry distribution are elaborate, require substantial computer resources, and, therefore, substantial time between evaluations.

An effort was initiated at AIPL to reduce the processing time between receipt of input data and release of genetic information. In 1995, AIPL developed a plan for preparing the distribution of bull evaluations on a workstation to take advantage of its faster processing speed and greater disk capacity. The new programs reduced processing time by a week for evaluations released in February 1997. In the spring of 1996, AIPL developed a similar plan for preparing the distribution of cow evaluations on a workstation. Improvements in system design made preparation of cow files more efficient and reduced the processing time by another week.

Early in 1996, AIPL developed a web site (http://aipl.arsusda.gov) with the goal that all genetic information would be distributed electronically via the Internet. This electronic transfer system now provides access to common files for the public as well as organization-specific files with password protection. Preparation of genetic evaluation files for distribution via the Internet was quicker than the previous approach of preparing more than 100 files on a variety of magnetic media. Initial evaluation receipt by cooperators through the Internet was optional, and cost savings to AIPL were small without widespread acceptance. Adoption of electronic receipt of evaluations was encouraged by making information released in February 1997 available in electronic form earlier than if overnight delivery was used. In May 1997, genetic evaluations were only available via the Internet.

The result of these initiatives was that the time required for calculating genetic evaluations was reduced from 8 weeks in July 1996 to 4 weeks in November 1997. The capability to compute evaluations more efficiently was a key factor in AIPL's decision to calculate genetic evaluations quarterly instead of semiannually. Increasing the number of annual evaluations from two to four reduced the average delay to receive a genetic evaluation by 6 weeks.

The effort required at AIPL to provide genetic evaluations quarterly is about the same as that needed previously for semiannual evaluations, primarily because of the improved computer plan and distribution protocol implemented at the same time. One advantage of quarterly release is that the workload is spread more evenly throughout the year. A disadvantage is that time between evaluations required to implement revisions needed by the industry is reduced.

The resources required to promote and to market bulls by the AI organizations is greater with quarterly release of evaluations. As a result, U.S. AI organizations disagree among themselves as to whether two or four official evaluations annually is preferable. However, accessibility to genetic information earlier and more frequently should increase the demand for domestic semen and improve a country's international competitive position.

Impact on genetic improvement. Earlier access to genetic evaluations, regardless of whether it is from reduced processing time or from more frequent delivery, allows the industry to select semen, embryos, and animals with higher genetic merit, thus increasing genetic improvement. A reduction in processing time benefits all users. Because the current annual genetic gain in the United States is estimated to be 120 kg of milk, each week of reduced processing time should increase genetic gain by 2.3 kg. Likewise, the 4-week reduction in processing time achieved by AIPL should increase genetic gain for milk yield by 9.2 kg per successful breeding. The quarterly release of evaluations will deliver information approximately 6 weeks earlier than did semiannual release. Using the same logic, this should result in increased genetic gain for milk yield approaching 13.8 kg. Together these initiatives can deliver 23 kg of milk per successful breeding, a substantial benefit to breeders. Genetic gains are permanent and cumulative, and gains in efficiency are expected to result in some combination of increased producer profits or reduced consumer food costs.

If genetic evaluations were calculated monthly instead of quarterly, the delay in receiving genetic information would be reduced by another month. If evaluations were calculated daily (continuous evaluation), the delay would be reduced by an additional 2 weeks. The elimination of the current 6-week delay could increase genetic gain another 13.8 kg, but the resources needed to calculate genetic evaluations daily would be prohibitive and not cost effective at present.

Selection for more than high yield

Breeders sometimes suggest that if intense selection pressure is directed toward milk yield, the cow population may deteriorate in other traits that are needed to allow cows to stay in the herd as long as other cows that result from a more balanced breeding program. Research (Van Vleck, 1964; White and Nichols, 1965; Miller et al., 1967; VanRaden and Wiggans, 1995) almost always contradicts this misconception, because those groups of animals with the highest first lactation yield are also the groups with the highest average herd life. This finding was reinforced in the Polish field trial, as the rankings of the 10 countries for lifetime milk and fat yields or herd life were nearly the same as the rankings for first lactation yields (Zarnecki et al., 1997). Some reports show a slight deterioration in mastitis resistance (Schutz, 1994) and reproductive efficiency (Eicker et al., 1996) with selection for higher yield.

Dairy producers want animals that have the capability to stay in the herd as long as producers choose to keep them. Herd life is a useful trait that encompasses all fitness and health traits, even those that are otherwise difficult to define and measure. There is less need to be concerned about reducing genetic herd life, as more countries are including it in their national genetic evaluation program. Of the 20 countries that participate in INTERBULL evaluations, 6 countries provide some kind of an evaluation for herd life, longevity, or stability (International Bull Evaluation Service, 1996). The United States initiated an evaluation for productive life (VanRaden and Wiggans, 1995) in 1994. An economic index called net merit dollars (VanRaden and Wiggans, 1995) was introduced at the same time so that the new traits of productive life and somatic cell score (Schutz, 1995) would be emphasized appropriately.

An examination of the genetic evaluation information and selection indexes for many countries shows that dozens of traits are being considered. Table 3 shows the traits that are included in the selection programs of several countries that participate in INTERBULL. The current selection emphasis that is being directed toward some traits is far more than justifiable based on the heritability and economic worth of the traits. In many cases, breeders would make greater genetic progress for traits of economic importance if they ignored the secondary traits. Even in the United States, some dairy producers put far more emphasis on some body conformation traits than is justifiable. Studies (Foster et al., 1989; Short and Lawlor, 1992; Norman et al., 1996) generally show that many of the udder traits are related to lifetime profitability, but the body traits are not.

Table 3. Traits included in total merit indexes for 10 countries participating in INTERBULL

Country	Yield	Conformation[1]	Mastitis resistance[2]	Herd life	Fertility	Dystocia[3]	Workability[4]	Beef
Canada	X	X	X	X				
Denmark	X	X	X		X	X	X	X
Finland	X	X	X		X			
France	X	X					X	
Italy	X	X						
Spain	X	X						
Sweden	X		X		X	X	X	X
The Netherlands	X	X	X				X	
United Kingdom	X	X						
United States	X	X	X	X				

[1]Conformation includes any information on conformation (type).
[2]Mastitis includes somatic cell score, mastitis index, etc.
[3]Dystocia includes stillbirth information.
[4]Workability is temperament and milking speed.

Increasing efficiency

Producing more milk from fewer cows equals increased efficiency. Table 4 shows that the 25 million milking cows in the United States in 1945 had decreased to 9.5 million in 1995. In 1997, 9.2 million cows produced more total milk by over 30% than did the 1945 population (http://mann77.mannlib.cornell.edu/reports/nassr/dairy/pmp-bb/1977/milk_production_12.15.97) while eating less grain and forage and producing fewer total byproducts of manure and methane. World cow numbers (Table 5) have declined as well, which indicates that the blame that dairy cows receive for contributing to increasing problems with global warming is unwarranted.

Table 4. Numbers of dairy cows in the United States and average annual milk yield

Year	Cows (millions)	Yield (kg)	Year	Cows (millions)	Yield (kg)
1940	23.7	2,097	1970	12.0	4,423
1945	25.0	2,171	1975	11.1	4,699
1950	21.9	2,410	1980	10.8	5,394
1955	21.0	2,650	1985	11.0	5,908
1960	17.5	3,188	1990	10.0	6,705
1965	15.0	3,767	1995	9.5	7,462

Table 5. Millions of dairy cows by country

Region	Country	1970	1980	1990	1997
North America	Canada	2.4	1.8	1.4	1.3
	Mexico	9.3	2.7	2.1	2.0
	United States	12.0	10.8	10.0	9.2
South America	Argentina	3.4	2.8	2.2	2.4
	Brazil	. . .	13.6	29.8	29.4
	Chile	.6	.7	. . .	. . .
	Peru	. . .	1.5	1.2	. . .
	Venezuela	. . .	1.2	1.3	1.2
Western Europe	Austria	1.2	1.1	1.0	.7
	Belgium-Luxembourg	1.1	1.4	.9	.7
	Denmark	1.2	1.2	.9	.8
	Finland	.9	.7	.5	. . .
	France	7.3	7.5	5.4	4.6
	Germany	. . .	. . .	. . .	5.2
	Greece	. . .	.4	.2	.2
	Ireland	1.6	1.8	1.6	1.5
	Italy	3.6	3.1	2.9	2.1
	Portugal	. . .	.4	.4	.4
	Spain	1.8	1.9	1.8	1.3
	Sweden	.7	.7	.6	.5
	Switzerland	.9	.9	.8	.7
	The Netherlands	1.4	2.3	1.9	1.4
	United Kingdom	3.3	3.8	3.3	3.0
Eastern Europe and Russia	Poland	5.8	5.8	4.8	3.6
	Romania	1.1	1.6	2.0	1.0
	Russia	. . .	. . .	20.8	16.1
	Ukraine	. . .	. . .	8.5	7.0
Asia	China	. . .	.6	1.3	4.5
	India	. . .	87.1	94.7	102.8
	Japan	1.8	1.0	1.1	1.0
Oceania	Australia	3.5	2.4	2.2	2.0
	New Zealand	2.3	2.0	2.3	3.3

Some producers contend that management systems that provide cows with moderate to high levels of grain, which frequently is done in North America and western Europe, is not an environment conducive to maximum efficiency. Those same people might insist that producing milk from lush forage, such as pasture, can supply milk at lower production costs. However, methane byproducts per unit of milk output from a pasture management system are much greater. Regardless of the management system chosen, the efficiency of individual animals must increase to remain competitive, and, therefore, the yield required will continue to come from fewer cows.

Increasing heritability

Heritability estimates that were being used for Holstein evaluation in 1996 by 19 of the countries that participate in INTERBULL (http://www-interbull.slu.se/lastev/lastev1.html) are in Table 6. Estimates range from .21 to .35 and average .29. Many of the heritabilities are higher than those reported in 1988 (International Bull Evaluation Service, 1988). Results of Van Tassell et al. (1997) showed that the heritability of first-lactation milk from 1980 to 1989 was higher than that from 1970 to 1979. They stratified herds into four groups according to variation in milk yield. Heritability estimates in the herds with highest variation, which are the better managed and higher production herds, were higher than those from the two groups with lower variation. One reason that heritability is increasing is because herd management is improving or becoming more uniform. The trend toward better management will continue, because only the more efficient dairy producers can compete and continue their dairy operation. Pasture systems will continue to be tested, but whether the number of producers that adopt such systems will increase is difficult to predict. Regardless of management system, the number of herds is likely to continue to decrease as during the past several decades. Because heritability estimates for milk yield have been increasing for some time, they are not expected to decrease for several generations (20 years or longer). For this reason, altering current, highly successful genetic practices would be a mistake. If sustained selection concentrates desirable genes in the global population so that selection is no longer effective, then heritability estimates will show a decrease. Then alternative genetic practices would be more competitive than they are today.

Table 6. Heritability estimates used by 19 countries for calculation of national evaluations[1]

Country	1988	1996	Country	1988	1996
Australia	.25	.25	Italy	.25	.30
Austria	.23-.34	.27-.32	New Zealand	.25	.28-.35
Belgium	.25	.30	Slovenia[2]	.25	.25
Canada	.25	.33	Spain	.25	.25
Czech Republic[2]	.25	.23-.24	Sweden	.25	.25
Denmark	.27-.30	.27-.30	Switzerland	.27-.34	.21-.27
Finland	.25	.30	The Netherlands	.32	.35
France	.25	.30	United Kingdom	.30	.35
Germany[3]	.18-.25	.30-.33	United States	.20	.30
Ireland	.25	.35			

[1]Source: INTERBULL (1988; http://www-interbull.slu.se/lastev/lastev1.html).

[2]Estimate for 1988 was for Czeckoslovakia.

[3]Estimates for 1988 were reported as .18-.19 for the Federal Republic of Germany and .25 for the German Democratic Republic.

Relevance of breeding strategies to the subtropics

The focus has been on breeding strategies relevant to moderate climatic conditions. However, with the accumulation of additional knowledge, the production difficulties encountered in a subtropical climate should diminish. In the United States, the effect of calving season on milk yield over time (Norman et al., 1995) was examined. In the 1960's, cows that calved during the summer were at a substantial disadvantage compared with those that calved during other seasons, especially in southern states where summer temperatures had a substantial impact. During each of the next four decades, the handicap for summer calving became smaller primarily because of improved management. The dairy producer learned how to manage cows better in stressful environments. Dairy producers in subtropical climates should experience the same phenomenon. As their herd management improves, their breeding strategies will become more like those used in moderate climates.

Conclusions

Extensive emphasis on milk and milk fat yields with no diversion for beef performance has increased the yield efficiency of North American dairy cattle. This efficiency was documented in several European studies that compared local Friesian strains with Holsteins. Heavy demand for North American genetics followed, and the U.S. and Canadian dairy populations are still an important source of genetics for many other countries as indicated by the origin of sires of bulls used in leading dairy countries. Genetic improvement has accelerated in many countries because of the implementation of sampling programs for young bulls and improved evaluation procedures; the number of young sires has nearly doubled in the last 20 years. Rapid access to information and more frequent calculation of genetic information also have a positive impact on genetic improvement. Traits other than yield should be considered in a breeding program, but those traits must have a reasonable opportunity for improvement and sufficient economic worth (for example, longer productive life or trouble-free health) to be included in selection decisions. Because of ever increasing efficiency, the world's milk supply comes from fewer cows each year. However, no decline in the rate of genetic improvement is apparent under current genetic practices; estimates of heritability are increasing, and a decline in yield efficiency is unlikely in the near future. Numerous opportunities exist for improving milk recording and initiating genetic improvement programs in countries that currently have limited selection and breeding activities. As management improves, especially for subtropical conditions, many of the selection principles used in temperate climates will be adopted for more adverse environmental conditions.

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