Maximizing the Impact of Dairy and Beef Bulls Through Breeding Technology

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ABSTRACT

Both biological and monetary considerations influence adoption of new breeding technologies. Therefore, genetic, reproductive, and economic factors that determine productivity of dairy and beef operations are reviewed. Improved sire evaluation programs, more efficient artificial insemination, and effective natural service are discussed and related to the present and future impact of dairy and beef bulls. Potential benefits of heterosis, artificial control of reproduction, improved bull management, computers, and multidiscipline research also are suggested. The dramatic impact of artificial insemination on genetic improvement and profitability of most commercial dairy herds is outlined. The uncertain expansion of beef artificial insemination is examined. Comparisons of dairy and beef industries indicate that expectation of similar results from the same animal breeding technologies are unwarranted. Dairy artificial insemination is and should continue to be economically feasible for commercial operations. Commercial beef producers will use little artificial insemination and rely on natural service bulls until precise human control of conception in the bovine is cost effective.

INTRODUCTION

Improved efficiency of dairy and beef production depends on development of useful management practices based on research technology. In the last 40 yr, average milk production per cow in the United States (US) has increased 260% (58). Research in male reproductive physiology, which made possible commercial use of genetically superior dairy sires by artificial insemination (AI), has been cited (20, 47, 50, 57) as a major factor in this accomplishment.

No great improvement can be documented for average beef production per cow during the past 40 yr. Many factors influence the comparative performance of dairy and beef industries, but an obvious contrast is that about 60 to 70% of dairy versus 3 to 5% of beef cows are bred by AI. Why doesn’t the beef industry take advantage of current breeding technology in the same way the dairy industry does? What factors dictate the rate and scope of assimilation of new reproduction and genetics research? This paper is intended to outline and contrast scientific facts and practical realities of dairy and beef industries that dictate breeding technologies. Emphasis will be placed on circumstances that led to the present status of dairy and beef bulls and on future developments that could increase the economic impact of bulls.

BACKGROUND AND PRESENT STATUS

Bulls can have an enormous impact on both genetic improvement and reproductive efficiency of herds. To determine successful management techniques that will increase the economic impact of bulls, it is necessary to review the differing production environments of dairy and beef industries.

Genetics

Selection and crossbreeding experiments in dairy (17, 26, 57) and beef cattle (17, 21, 22, 26, 37) have demonstrated the importance of both additive and nonadditive (heterotic) genetic effects. Results with dairy cattle (57) indicate a 5 to 20% positive heterosis for livability and production traits, but Holstein cows generally produce more milk than crossbreds. In contrast, crossbreeding beef cattle (22, 37) yields a 20 to 25% increase in total
beef output with no beef breed demonstrating superiority in all growth and carcass traits.

Fundamental differences of dairy and beef selection programs arise because milk production is the major trait of importance for dairy, whereas beef producers consider growth, carcass, and reproductive traits equally important. Milk production is moderately heritable (.25) (57), whereas growth and carcass traits are more highly heritable (.40 to .50) (64). Milk production can be measured only through a progeny test of sires' daughters because it is a sex-limited trait. In contrast, growth rate can be measured on both sexes, carcass merit can be measured by family testing, and reproductive rate in beef populations can be improved through crossbreeding.

Separate performance testing and sire evaluation programs have developed in each industry. Dairy selection programs have focused (57) on increasing milk production. Beef selection programs have evolved based on more varied information that gives registered breeders and commercial producers a much wider latitude to define their own breeding goals (60). Dairy programs concentrate on improvement within breed, which can be applied directly to unregistered purebred cows in commercial herds. Because the majority of commercial dairies milk Holsteins, selection efforts can be concentrated even more on that one breed. Beef programs also have emphasized improvement within breed but selection efforts have been less intense than in dairy because no breed dominates in commercial herds.

Dairy sire evaluations were based on Dairy Herd Improvement Association (DHIA) records as early as 1925 (54), and sire evaluation methods have undergone constant review and revision since that time. Present methods include the use of Modified Contemporary Comparisons for milk and Best Linear Unbiased

### TABLE 1. Mean annual and cumulative sire genetic trends for production traits of selected dairy and beef breeds.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dairy PD a</th>
<th>Beef EPD b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Milk</td>
<td>Fat</td>
</tr>
<tr>
<td>Mean annual genetic trend</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown Swiss</td>
<td>+18.6</td>
<td>+.9</td>
</tr>
<tr>
<td>Holstein</td>
<td>+34.0</td>
<td>+.9</td>
</tr>
<tr>
<td>Jersey</td>
<td>+31.8</td>
<td>+1.2</td>
</tr>
<tr>
<td>Beef d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angus</td>
<td>+.4</td>
<td>+1.2</td>
</tr>
<tr>
<td>Hereford</td>
<td>+.7</td>
<td>+1.5</td>
</tr>
<tr>
<td>Simmental</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cumulative genetic trend</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown Swiss</td>
<td>+92.5</td>
<td>+4.3</td>
</tr>
<tr>
<td>Holstein</td>
<td>+156.5</td>
<td>+4.2</td>
</tr>
<tr>
<td>Jersey</td>
<td>+159.2</td>
<td>+5.9</td>
</tr>
<tr>
<td>Beef d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angus</td>
<td>+5.4</td>
<td>+16.9</td>
</tr>
<tr>
<td>Hereford</td>
<td>+10.4</td>
<td>+20.8</td>
</tr>
<tr>
<td>Simmental</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

aPD = Predicted Difference as of January 1, 1981; PD$ based on the national average milk price in 1979. (Source: DHI Letter 56:3.)

bEPD = Expected Progeny Difference as of January 1, 1982; PD$ based on the national average beef price in 1979; NA = not available; (Source: breed association summaries).

cSires in service 1970 to 1975.


Prediction (BLUP) procedures for milk, type, and calving ease (57). A variety of beef cattle improvement programs developed from 1940 to 66 but had limited individual success until the Beef Improvement Federation was formed in 1967 to standardize performance programs (61). The first beef sire summary was published in 1971 by the American Simmental Association. During the past decade, beef breed associations gradually have assumed responsibility for recording field performance data as the basis for national sire evaluation programs. Present beef sire evaluation methods (60, 61), like those of dairy, rely heavily on linear model and BLUP procedures.

Recent sire genetic trends for selected dairy and beef breeds are in Table 1. Trends are all positive and indicate improvement of the genetic potential for production of milk and beef. The dairy results represent a substantial improvement (46) of rate of genetic progress compared to earlier years because of more effective sire sampling (13, 30) and evaluation (56) methods. Beef genetic trends only recently have become available in some breeds on a national basis.

Reproduction

Mating systems available to commercial dairy and beef producers (Figure 1) range from completely natural service to total AI. Because AI potentially offers much larger selection differentials for economic traits, genetic lag (8) of performance between elite registered herds and commercial herds is less through AI than through natural service.

The dairy industry already was attempting to identify genetically superior sires through natural service bull cooperatives (54) when the first AI organization was established in 1938. The tremendous growth (35) of the number of cows inseminated over the past four decades confirms that AI has become an integral part of the commercial dairy industry.

Until the advent of frozen semen in 1953 (12), widespread beef AI was impractical. Much of the first beef semen processed was used to breed dairy heifers with little emphasis placed on genetic beef traits. Beef AI increased slowly until 1967 when a demand for European breeds stimulated (61) a dramatic increase of performance testing and AI.

The number of US dairy cows in production has declined 53% since 1940 (Figure 2) with about 60 to 70% currently bred artificially. This may be attributed largely to the substantial genetic advantages (Table 2) of dairy AI bulls (48). During this same period, the number of beef cows increased 265% with approximately 3 to 5% currently bred AI (Figure 2). Progeny tested beef sires available through bull studs (Table 2) can be considered above average for growth rate in their respective breeds.

Nutrition for cows (7, 15, 18, 52, 63) influences the success or failure of breeding programs. This is particularly true with AI. Because dairies usually are located in areas of high quality forage and grain production, availability of nutritious feeds is not a major problem. Nutrition for beef cows often is marginal because they usually are maintained on lower quality forages and little or no grain. The primary problems that limit the economic impact of dairy bulls are estrus detection and timing of insemination. Interval to first insemination accounts for over 70% (12) of the variation of days open for dairy cows. In addition to problems of estrus detection and timing of insemination, beef cow herds often experience low nutritional conditions that discourage normal estrous activity. Low energy before or after calving delays onset of estrus
and can result in 10 to 20% (7, 18, 63) lower conception rates.

Research to increase estrous activity and conception rates on first service of dairy and beef females has been stressed. Estrus synchronization was achieved commercially in 1980 when a product based on the luteolysin prostaglandin F2α (PGF2α) was introduced into the US market.

Physiology of dairy (1, 12, 24, 59) and beef (2, 3, 23, 40, 55, 65) bulls has been documented, and some variation among breeds of growth rate, puberal traits, spermatozoal output, sexual activity, and fertility has been discovered. Improved management procedures (4) have increased the number of high quality spermatozoa collected for AI. Prerequisites for maximizing spermatozoal output per bull are proper nutrition, adequate sexual preparation, and high ejaculation frequency. Laboratory techniques (12) have been improved so that semen can be preserved and extended more efficiently for more effective inseminations. Major innovations have included addition of antibiotics and glycerol to semen, frozen semen, and packaging of semen in straws. Measuring testes-scrotal circumference of living bulls allows selection for spermatozoal production. Methods for evaluation of semen quality (12) include tracking motile spermatozoa by time exposure photography and use of acrosome retention tests.

Research on reproductive performance of bulls under pasture mating conditions is limited. Blockey (9, 10) determined that a bull rarely mates with the same estrual female more than once and that servicing capacity (number of services during a 1-h mating test) of bulls affects herd fertility. He also found that serving capacity is unrelated to social ranking among bulls of the same age.

Sixty percent of US beef herds have breeding seasons greater than 120 days, and half of these breed for more than 210 days before bulls are removed (11). One bull is maintained for an average of only 22.5 (11) cows! Recent experiments (44) demonstrated that this number of exposures is unrealistically low.

Economics and Management

Adoption of new breeding technology is linked closely to the level and stability of farm income (14, 34, 62). Wide economic differences between dairy and beef operations result from different management and marketing systems.

Dairy farming is regionalized mostly in the northeastern US, the Great Lakes states, and California. Production of beef is spread throughout the southeastern, southwestern, midwestern, and western US. In these areas, climate allows year-round management for milk production but favors seasonal management for beef production. Operating costs for modern dairies are high because of labor, capital equipment, and land ownership costs. In most cases, beef herds are grazed on land that is fit for little else. Beef cows often are managed as scavengers,
TABLE 2. Mean transmitting ability of progeny tested sires of selected dairy and beef breeds.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dairy PD&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Beef EPD&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active AI bulls&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Non-AI bulls</td>
</tr>
<tr>
<td></td>
<td>n Milk</td>
<td>(kg) ($)</td>
</tr>
<tr>
<td>Dairy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown Swiss</td>
<td>44 +391.5 +103</td>
<td>281 +107.0 +27</td>
</tr>
<tr>
<td>Holstein</td>
<td>728 +496.2 +124</td>
<td>7844 +44.9 +7</td>
</tr>
<tr>
<td>Jersey</td>
<td>85 +490.8 +133</td>
<td>826 +135.2 +35</td>
</tr>
<tr>
<td>Beef</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angus</td>
<td>49 +5.7 +13.4 +19</td>
<td></td>
</tr>
<tr>
<td>Hereford</td>
<td>2 +7.4 +13.7 +20</td>
<td></td>
</tr>
<tr>
<td>Simmental</td>
<td>61 +1.3 +3.6 +5</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>PD = Predicted Difference as of January 1, 1981; PD$ based on the national average milk price in 1979. (Source: DHI Letter 57:1.)

<sup>b</sup>EPD = Expected Progeny Difference as of January 1, 1982; PD$ based on the national average beef price in 1979; (Source: breed association summaries).

<sup>c</sup>Progeny tested sires available through artificial insemination (AI) organizations; beef sires required to have both 205-day weaning and 365-day yearling data listed.

utilizing lower quality forages and crop residues that otherwise would be wasted. Compared to dairy, this type of production environment does not require much labor or capital investment. Intensive management of dairy enterprises and their characteristic steady cash flow usually make them primary sources of income. In contrast, seasonal management and cash flow of beef enterprises commonly make them supplementary sources of income.

Market structure has a major impact on efficiency of markets and profitability of production (34, 49). The fluid milk market can be described best as a bilateral oligopoly (49, 62) where a few large marketing cooperatives bargain with a few large processors to set the price for milk. Over 80% (27, 28, 34) of the fluid milk marketed since 1960 has been marketed through cooperatives that use federal milk marketing orders as the basis for bargaining. The market for beef feeder calves is based indirectly on the live slaughter and dressed beef market where a large number of producers lack the bargaining power to deal with a much smaller number of meat processors. Bargaining cooperatives and government price supports do not exist in the beef business.

Comparative economic data (Table 3) have

TABLE 3. Mean total income, expense, return to labor, and net profit per cow for US dairy and beef enterprises.<sup>a</sup>

<table>
<thead>
<tr>
<th>Item</th>
<th>Dairy</th>
<th>Beef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income, $</td>
<td>1280</td>
<td>1419</td>
</tr>
<tr>
<td>Expense, $</td>
<td>1272</td>
<td>1332</td>
</tr>
<tr>
<td>Return to labor, $&lt;sup&gt;b&lt;/sup&gt;</td>
<td>271</td>
<td>413</td>
</tr>
<tr>
<td>Net profit, $</td>
<td>8</td>
<td>87</td>
</tr>
</tbody>
</table>

<sup>a</sup>Economic Research Service Statistics based on extensive surveys of dairy and beef producing regions; comparative data not available for years prior to 1977; 1981 dairy data are preliminary.

<sup>b</sup>Return to family labor and operator management.
been available only since 1977. Dairy and beef enterprises have operated with different income and profitability.

DISCUSSION

A belief persists that beef producers can and will become as economically successful as dairy producers if only they will adopt the same progeny testing and AI technologies. However, the situation is not that simple. Dairy and beef cattle, so physiologically similar, require radically different management (Table 4).

Pedigree evaluation of young sires and culling of inferior progeny tested bulls is responsible for most of the genetic progress of dairy populations (53, 57). Less time-consuming methods are available for identifying superior beef bulls. Performance testing and selection of the top performing bulls and heifers as herd replacements each year (annual sequential selection) reduce genetic generation interval and speed improvement of the highly heritable beef traits. An effective beef bull progeny test is a sib performance test of sons in the next generation (60). Data from these tests can be incorporated with the pedigree maternal breeding values of relatives to allow selection of yearling bulls to sire the next calf crop. This concept can be applied nationally through AI in registered herds because many beef bulls are capable of producing 500 units of semen of adequate fertility (23) by 15 mo of age.

Before AI, consistent identification of superior sires across herds was impossible because of confounding effects of individual herd environments on progeny performance. Artificial insemination eliminated this problem by allowing the use of many genetically different sires in a great number of herds. Thus, although widespread use of superior sires generally is considered the most important benefit of AI, its most important contribution is that it paved the way for application of advanced sire evaluation methods (57, 60). Identification of superior dairy and beef

<table>
<thead>
<tr>
<th>Item</th>
<th>Dairy</th>
<th>Beef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of selection program</td>
<td>single trait</td>
<td>multiple trait</td>
</tr>
<tr>
<td>Heritability of trait(s)</td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Sire evaluation program</td>
<td>established/very defined/ mixed model/BLUP</td>
<td>new/descriptive/ mixed model/BLUP</td>
</tr>
<tr>
<td>Favored breeding program</td>
<td>purebred/mostly Holstein</td>
<td>crossbred/many breeds</td>
</tr>
<tr>
<td>Advantage(s)</td>
<td>DHIA records/USDA sire summaries</td>
<td>performance test both sexes</td>
</tr>
<tr>
<td>Limitation(s)</td>
<td>sex-limited trait/progeny test</td>
<td>few herds test/use AI</td>
</tr>
<tr>
<td>Reproduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artificial insemination</td>
<td>70% bred AI</td>
<td>3 to 5% bred AI</td>
</tr>
<tr>
<td>Natural service</td>
<td>30% bred natural/mostly heifers</td>
<td>95+% bred natural</td>
</tr>
<tr>
<td>Advantage(s)</td>
<td>cow nutrition/close management</td>
<td>heterosis</td>
</tr>
<tr>
<td>Limitation(s)</td>
<td>estrus detection/no heterosis</td>
<td>estrus detection/cow nutrition</td>
</tr>
<tr>
<td>Economics and management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geography and climate</td>
<td>moderate-highly productive</td>
<td>moderate-marginaly productive</td>
</tr>
<tr>
<td>Type of management</td>
<td>intensive/continuous</td>
<td>extensive/seasonal</td>
</tr>
<tr>
<td>Labor requirement</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Capital requirement</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Market structure</td>
<td>bilateral oligopoly/government supports/farmer coops</td>
<td>buyer oligopoly/no supports individual sellers</td>
</tr>
<tr>
<td>Type of enterprise</td>
<td>primary/continuous cash flow</td>
<td>supplemental/seasonal cash flow</td>
</tr>
</tbody>
</table>

*Traits typical of well managed commercial dairy and beef operations; summary descriptive of industry-wide circumstances and practices and not necessarily all individual herd situations.*
sires in registered herds is of little value unless the superior germ plasm can be transmitted to commercial herds. This transfer cannot occur with maximum efficiency under conditions of total natural service. Use of AI in commercial herds can help overcome the handicap of long generation interval in cattle and reduce genetic lag (8) between registered and commercial herds.

Short term prospects for increased commercial dairy AI appear good. Because dairy sire summaries for calving ease (31) now are available, producers will be able to choose dairy bulls that minimize calving difficulty. Estrus synchronization utilizing PGF₂α should reduce the labor requirement for estrus detection and improve timing of inseminations. Thus, incentives are reasonably high for dairy producers to breed heifers as well as cows by AI.

Short-term prospects for beef AI are not good. The geographic, climatic, economic, and managerial constraints on beef operations impose almost insurmountable barriers to widespread commercial use of AI. Improved growth rate of progeny alone cannot justify economically the use of beef AI on a one-time basis. The big benefits of beef AI will have to come, as they have in dairy operations (50), through cumulative effects of saving daughters to develop herds that are genetically superior for economic traits. But the incentive to use AI is not great in a beef industry characterized by unpredictable markets and instability of cattle ownership (6).

The success of PGF₂α in beef operations is questionable because it will not induce estrus in the 40 to 50% (63) of beef cows that usually are not cycling at the desired time of treatment. Studies on the economic feasibility of PGF₂α use in beef cows are inconclusive. At least one report (5) estimated that the labor requirement for beef AI could be reduced by as much as 75% if PGF₂α is used for synchronization. Other workers (51) estimated the cost of a well-managed PGF₂α synchronized AI program at $30 to $50 per pregnancy versus a $20 cost with natural service. Labor costs for handling cattle and estrus detection were excluded from these calculations.

Long-term prospects for commercial AI, especially in beef cattle, will depend on the cost effectiveness of AI and degree to which ovulation can be controlled. Although estrus synchronization with PGF₂α has given a measure of control over estrous cycles, conception rates following synchronized, fixed-time inseminations are lower (12) than inseminations following estrus detection.

Although heritabilities of reproductive traits are believed to be low (25, 57), this belief may be a misconception stemming from our inability to identify those quantitative traits that affect reproduction. Testes-scrotal circumference has been identified as an inexpensive and reasonably reliable predictor of spermatozoal output of young bulls (2, 19, 33, 36, 59). Also, heritability of testes-scrotal circumference is moderate to high (.30 to .70) (19, 36). More recent work (39) indicates that breed, mean 365-day testes-scrotal circumference in bulls is highly correlated (−.98) with breed and mean age at puberty in heifers. Thus, testes-scrotal circumference appears to have potential as a genetic selection criterion that could improve the reproductive potential of both bulls and heifers. Geneticists and physiologists should identify other traits that could be used to select for improved reproduction.

CROSSES AMONG HOLSTEIN AND OTHER DAIRY BREEDS SOMETIMES HAVE (41) DEMONSTRATED TOTAL ECONOMIC SUPERIORITY OVER STRAIGHTBRED HOLSTEINS BECAUSE OF IMPROVED CALF SURVIVAL AND GROWTH. BUT BECAUSE OF THE HEAVY EMPHASIS PLACED ON MILK PRODUCTION, DAIRY CROSSBREEDING IS ALMOST NONEXISTENT IN THE US. CROSSES AMONG BEEF BREEDS CONSISTENTLY HAVE DEMONSTRATED ECONOMIC ADVANTAGES OVER STRAIGHTBREDS FOR IMPROVED CALF SURVIVAL, GROWTH RATE, AND MATERNAL PERFORMANCE. DESPITE THIS, ONLY ABOUT 25% OF US COMMERCIAL BEEF COWS ARE CROSSBRED (11). INCREASED INTEREST IN THE CREATION OF NEW (SYNTHETIC) DAIRY AND BEEF BREEDS MAY STIMULATE THE USE OF CROSSBREEDING (32, 57). SYNTHESES COULD BE SPECIALIZED ROTATIONAL OR SPECIFIC CROSS SIRE LINES AND ADAPTED TO SPECIFIC (I.E., TROPICAL) PRODUCTION ENVIRONMENTS.

Production and economic simulations in dairy (43, 45) and beef (16, 29, 38) give beginning insights to understanding individual decisions and problems facing commercial producers in each industry. Uniform recommendations for both industries are not feasible. For example, a total AI breeding program can be recommended for dairy operations because management conditions and economic ad-
vantages for dairy AI bulls favor AI. However, beef management conditions are different, and a clear economic advantage is difficult to demonstrate for beef AI bulls. This is because most beef AI bulls are privately owned, custom collected, and used for a variety of reasons that may or may not reflect economic value.

**FUTURE PROSPECTS**

Scientists have developed a variety of technologies to maximize productivity of bulls. Which of these technologies will be practiced? The following predictions are based on the assumption that a majority of commercial producers will operate their cattle operations as business enterprises. Personal, traditional, and moral perceptions of producers have not been considered.

**Sire Evaluation and Germ Plasm Transfer**

Bulls will continue to be the major means of genetic improvement. Rate of improvement will depend on how sire evaluation programs are structured and degree of human control achieved over reproductive functions. Dairy selection programs will continue to focus on milk production. Progeny testing will remain the major means of dairy sire evaluation but will be refined by increasing selection intensity of young sires, increasing the number of young sires tested, increasing the number and size of DHIA tested herds, improving young sire sampling procedures, and applying new statistical methods. Artificial insemination will continue to be the dominant mode of germ plasm transfer to commercial dairy herds.

Selection goals for beef bulls will become more defined, emphasizing calving ease and 365-day weight. Beef sire selection programs will be based on performance testing and sequential selection programs rather than dairy style progeny tests. Breeds suited for rotational crossbreeding will become dominant. Artificial insemination will have an expanded and essential role in genetic improvement of registered beef herds, but genetic improvements in registered herds probably will be passed to commercial herds by natural service until less costly and more effective AI techniques are available.

Selection programs in both industries will become sufficiently sophisticated to enable selection on profitability per cow as well as on biological traits. Adding some measure of growth rate to dairy sire summaries could improve selection opportunities to increase beef production. Selection for improved reproductive fitness is likely and could be based on measurements of the testes-scrotum in yearling bulls or other physiological characteristics related to improved reproduction. Dairy and beef AI sire predicted differences for conception (pregnancy) rate may become commonplace.

**Bull Physiology and Management**

Bull management will be improved through the use of accurate, simplified individual bull serving capacity and fertility tests in combination with accurate, inexpensive, on-farm pregnancy tests. So long as natural service bulls retain the economic advantages of lower breeding and labor costs, they will have some use in the dairy industry and retain their dominant position in the economically unstable beef industry. Expanded studies of natural service bulls will define better their reproductive potentials and limitations. Effects of pasture size, land topography, social ranking of bulls, sexual behavior of bulls, breed variation in servicing capacity, and reproductive capacity of crossbred bulls will be evaluated and incorporated into natural service recommendations.

**Artificial Control of Reproduction**

Reproductive physiology research will stimulate production of biologically active hormones by recombinant DNA. Research into biochemical and hormonal mechanisms that control follicular development and ovulation will be intensified. Interrelationships among these mechanisms and their dependence on different blood nutrient levels will be determined. This information, combined with control of spermatozoal maturation and transport in the female reproductive tract, could lead to the development of sophisticated AI techniques that totally control the female reproductive function and the fertilization process over a wide range of herd managerial and nutritional conditions. When such AI methods are both technically possible and economically feasible for commercial herds,
the days of the natural service bull will be numbered.

Superovulation, ova transfer, in vitro oocyte maturation, in vitro fertilization, embryo transfer, frozen embryo, and cloning technologies, if cost effective, could have major implications for germ plasm transfer. Sexing of semen and embryos should become a reality. Use of these new technologies could bring about the commercial development of synthetic dairy and beef breeds. Replacement heifers could be produced from only the most genetically superior parents. Crossbreeding utilizing exclusively F₁ male and female lines would become economically feasible, and such animals could be introduced into herds with minimum risk of exposure to disease.

Heterosis

Dairy crossbreeding might become a reality if synthetic breeds can be developed that equal Holsteins in milk production or offer other unique production advantages. Economically viable beef herds will be crossbred. In the immediate future, planned rotational crossbreeding programs will be based largely on existing beef breeds. However, crossbred bulls and synthetic breeds uniform in mature body size, growth rate, and maternal ability will play an increasingly important role. Brown Swiss, Holstein, and Jersey breeds are potential contributors to synthetic beef breeds. Commercial producers that want to use breeding programs based on F₁ males and females will have to await major advances of the artificial manipulation of cow reproductive capacity. However, F₁ crossbreds and straightbreds from crossbreeding experiments could be used to establish the physiological and biochemical basis for heterosis in cattle. A molecular understanding of heterosis could lead to identification of physiological characteristics (i.e., blood antigens, enzymes, hormones, blood metabolites) that could act as genetic selection criteria or aid control of reproduction.

Computers and Record Systems

On-farm computers and computer terminals interfaced with central processors will provide rapid access to vital technical and economic information. Dairies will rely on daily computer summaries that include data on cow identification, milk yield, and physiological characteristics. These summaries will make it easy to monitor the nutritional, health, and reproductive status of individual cows. In beef herds, seasonal data on cow identification, breeding, calving, and pregnancy status could be merged with data on unique environments of individual herds. Computer simulation programs, utilizing both probablistic and deterministic models, then could be used to allocate available production resources (i.e., cows, herd bulls, feed, facilities, labor, and AI technology) for maximum reproductive and economic efficiency.

Multi-Discipline Research

Increased specialization in genetics, reproductive physiology, and economics has created islands of knowledge. Yet cattle operations function according to interrelationships among these areas. Therefore, it will be necessary for scientists to establish bridges of communication between areas of specialization. Management recommendations should be reviewed jointly by geneticists, physiologists, and economists. Higher quality cooperative research could include widespread use of computer simulations that would test hypotheses and measure the potential impact of research. Research scientists should take an active role in seeing their results applied to avoid confusion and maximize the impact of the bull.

Predictions will not come true by themselves. Only people can turn predictions into realities. In the final analysis, the future of the bull in the dairy and beef industries will be dictated by the actions of producers. These actions, in turn, will be influenced by the economic, personal, traditional, and moral attitudes of producers.

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