Assessing the Comparative Economics of a Biotechnology: Artificial Insemination Dairy Sires*,†

C. Richard Shumway
Robert W. Blake
David J. Leatham
Michael A. Tomaszewski

Much opportunity exists to increase economic returns from the artificial insemination, dairy sire selection decision. This article measures potential returns to producers with alternative objective functions, management and financial characteristics. The costs of wrong decisions from incorrect information are measured by differences between alternative sets of top-20 Holstein sires selected from more than 400 available. Correct specification of the objective function is most important. Determination of planning horizon and conception rate also merits allocation of some scarce management resources. Correct information about length of calving interval, female mortality rate, and opportunity cost of capital, however, is economically inconsequential.

INTRODUCTION

Biotechnology (the use of living organisms or their components in industrial processes) has the potential to set off a scientific and technological revolution in agriculture that could overshadow past accomplishments in this sector (Carter, p. 9[1]). Biotechnology encompasses a wide variety of biological methods including "genetic engineering." Genetic engineering of livestock is most often associated with the collection, transfer, splitting (cloning), and sexing of embryos; gene

---

*Texas Agricultural Experiment Station Technical Article 21324.

†The considerable assistance of Marsha Wilcox, Rex McMahon, Rick Baron, John LaBore, and Greg Rickard in programming and earlier sire selection computations is gratefully acknowledged.

The authors are, respectively, Professor of Agricultural Economics at Texas A&M University, Associate Professor of International Animal Science at Cornell University, Assistant Professor of Agricultural Economics at Texas A&M University, and Research Scientist and Dairy Extension Specialist at Texas A&M University.

Agribusiness, Vol. 3, No. 2. 207–220 (1987)
CCC 0742-4477/87/020207-14$04.00

splicing; sexing of semen; *in vitro* fertilization and cell culture; recombinant DNA (deoxyribonucleic acid) and gene transfer (Rutledge and Seidel, pp. 266–269;[2] Research and Education Association, pp. 2, 151–156[3]). Although genetic engineering seems esoteric, one technique has contributed greatly to livestock production for nearly 50 years—incorporation of superior germ-plasm into animal populations by artificial insemination (Olentine, p. 56[4]).

Artificial insemination likely will continue to be the major genetic engineering technique of the animal industry in the next decade (Research and Education Association, pp. 13–15[3]). Its economic benefits remain underexploited. Yet it is inexpensive, readily available, and poses the fewest barriers of any genetic engineering technique to widespread adoption.

Although artificial insemination (AI) with fresh semen was used for centuries, the development of good methods for freezing semen has made AI the primary tool for genetic improvement of cattle populations. Initially used in Europe to control sexually transmitted diseases, livestock AI was introduced into the US from Denmark in 1938. The primary goal of AI in the US has been genetic improvement, especially of dairy cattle (Foote, p. 14[5]).

Average milk yield of dairy cows in the US has doubled in the last 30 years, due both to improved management and genetic progress. Sire selection has increased milk yield per lactation about 100 lb/year from 1967 to 1984. Yet, this rate of genetic gain is only 33 to 45% of what is theoretically possible (Research and Education Association, pp. 13, 161;[3] Dickinson, pp. 67–68;[6] Everett, p. 63[7]).

Dairy producers are confronted with a complex decision-making problem in sire selection. Semen is available to all producers from several hundred progeny-tested AI bulls with widely varying genetic abilities in multiple traits and with disparate prices ($2 to $300/unit). Genetic improvement is a long-term investment, and sires often are chosen without a clear notion of their economic effects.[8] Choices are often made arbitrarily, by rule of thumb, or by recommendations of breed or AI organizations. The Holstein Association, for example, recommends the top 50 total performance index bulls; however, this index accounts only for predicted differences in milk yield, milkfat percent, and type score of daughters, and ignores the cost of semen. Several linear programming (LP) and selection index procedures have been proposed that include some economic aspects of the genetic investment problem.[9–11] As currently used, however, these procedures neither assess the cost of maximum genetic gain nor identify profit maximizing sires for a genetic investment program. Common arbitrary restrictions of LP optimizations (e.g., semen cost, repeatability, and individual trait goals) often unnecessarily limit potential net returns from genetic investment.

OBJECTIVES

The objectives of this article are (1) to measure the economic value of genetic options readily available to dairy producers with Holstein cows, and (2) to examine the sensitivity of these genetic choices to alternative producer objectives and economic, financial, and management conditions. The focus is on determining the cost of various sire selection errors. This orientation promotes inference about priorities for dairy herd management.

METHOD OF ANALYSIS

Although cost of semen is small compared to total farm inputs, investment in sire selection is important. The primary benefit is from genetic improvements of the offspring (i.e., herd replacements). These improvements are increased sales of milk and milk solids and more desirable type scores (conformation) of future cows. Positive economic returns from genetic selection, especially for milk, do not begin to accrue until at least three years after insemination of the dam. Net present value procedures with appropriate discounting are thus required to appropriately rank AI sires that vary in price of semen and in genetic transmitting abilities for multiple traits.

Because AI semen is frozen and disseminated throughout the US by well-established AI organizations, semen from all 403 proven AI Holstein sires are included in the empirical net present value (PV\$) analysis. Semen from these sires was available for purchase from January to July 1985.

Data include (1) January 1985 predicted differences (PDs) and repeatabilities (i.e., second moment measures) of milk yields, percent milkfat, and final type score for individual sires,[12] (2) January 1985 retail semen prices, and (3) 1984 US average milk and milkfat prices minus average hauling and government assessments.[12] The PDs are genetic evaluations published semiannually by USDA of the age-season adjusted progeny average of a sire deviated from the breed mean for a specified cow age class and genetic base year (currently 1982). The PD for type score (body conformation) is calculated by breed association.

In applying a net economic evaluation of multiple traits for purchasing semen, a major limitation is the lack of a clear economic value for type score. Subjective valuations must be used,[13,11] but opinions and objective functions of dairy producers vary widely and so likely do optimal sire selections. Also, market (e.g., interest rate on borrowed capital), herd financial (e.g., debt load, planning horizon) and management conditions (e.g., conception rate, calving interval, female mortality rate) may affect optimal sire selections of individual dairy herds.

The approach taken here is to consider alternative economic values for type score. For example, a 3:1 milk-to-type selection policy means that one standard deviation in PD for type score (PDT) is economically as valuable as 1/3 standard deviation in PD for milk income (PD\$), where the latter is computed as the value of PDs in milk yield and milkfat content using 1984 average US prices. Producers with this policy would receive a substantial share of net income from sale of registered stock or would perceive substantially reduced production costs from improvements of type score. Alternatively, for producers with a 1:0 selection policy, income is entirely from milk sales, and no adverse effects are expected by limiting selection intensity for type score to that practiced by AI organizations.

Net present values of proven sires are calculated using equations in the appendix for alternative milk-to-type selection policies, first-service conception rates, calving intervals, female mortality rates, real discount rates, and planning horizons. Specific alternatives examined are reported in Table I.

Prices of semen, milk, feed, and other inputs are assumed constant in 1985 dollars. Real rate of interest (i.e., the difference between nominal interest and inflation rates) was used as a proxy for the opportunity cost of capital to discount net returns. Real interest rates averaged about 2% in the 1960s and 1970s but abruptly rose to about 8% in the early 1980s. A lower bound on the real discount rate of 2% was used in anticipation that real rates could decline over the planning

Table I. Alternative Market, Financial, and Management Conditions Examined.

Variable	Unit	Alternatives Examined
Selections Policy	Weights on SD PD$: SD PDT[a]	1:0, 3:1
First-Service Conception Rate	Percent	30, 50
Calving Interval Length	Months	12, 13, 15
Female Mortality Rate from Birth to First Calving	Percent	5, 15, 25
Real Discount Rate	Percent	2, 3, 5
Planning Horizon	Generations of Descendants	1, 2, Infinite

[a] Codes used: SD is standard deviation, PD$ is predicted difference in milk and milkfat net income, and PDT is predicted difference in type score.

horizon to the historic average. An upper bound of 5% was used to test sensitivity of results to a continuation of recent experience.

Only marginal costs and returns from the sire selection decision need to be considered to accurately rank alternative semen investments. The stream of costs and returns is based on a typical herd situation: average herdlife of cows is three lactations; average age at first calving is 27 months; replacement females are born at the second calving of their dams; semen costs are incurred at the beginning of each calving interval; milk income is received and feed costs are incurred at the midpoints of lactations; marginal income over feed cost is 55% of milk income; income from male offspring is not dependent on sire; and differences in genetic values of descendants are not captured through recoverable differences in terminal stock value.

Net present value is calculated at time zero when the dam is first bred. Semen costs in subsequent years are discounted to present value because more than one calf is required to produce a herd replacement. The same price of semen is used in all years to estimate the PV$ corresponding to current transmitting abilities, but the same service sire is not required for subsequent breedings. New genetic information and prices for semen in subsequent years yield new net present values and, perhaps, different sire selections.

RESULTS

Means and ranges for PV$, PD$, PDT, and semen price for alternative selection policies are reported in Table II. The PV$ correspond to an infinite planning horizon, 3% real discount rate, 50% first-service conception rate, 13-month calving interval, and 15% female mortality rate. Because 20 service sires are sufficient choices for most commercial dairies, the remaining discussion emphasizes these highest-profit sires for each set of management and economic conditions.

Only 6 of the 20 highest-ranking PV$ sires under the 1:0 selection policy (and infinite planning horizon) appear among the 20 most-profitable bulls for the

Table II. Means and Ranges of Net Present Value (PV$), Predicted Difference Dollars (PD$), Predicted Difference Type Score (PDT), and Semen Price by Alternative Selection Policies for a 50% Herd Average Conception Rate, 13-month Calving Interval, 15% Female Mortality Rate, 3% Real Interest Rate, and Infinite Planning Horizon.

Variable	Milk:Type Selection Policy	Unit	Mean	Range High	Range Low
PV$	1:0	$(net)	108	327	−1698
	3:1	$(net)	145	384	−1558
PD$[a]		$(gross)	83	204	−90
PDT[b]		index	0.57	3.27	−3.15
Semen Price					
1:0 Selection Policy[a]		$	11.84	300	2.00
3:1 Selection Policy[b]		$	12.62	300	2.00

[a] Four hundred and three bulls; genetic base year for PD$ and PDT is 1982.

[b] Three Hundred and fourteen (of 403) bulls with PDT evaluations.

3:1 selection policy. In contrast, 16 appear among the 20 most-profitable bulls for a one-generation planning horizon.

It is evident that within the range of conditions considered, milk-to-type selection policy has greater impact than planning horizon on sire choices. It is not clear, however, what the costs are of errors in specifying selection policy, planning horizon, or other management parameters. Suppose, for example, that the producer goes out of business in 8 years (i.e., about the end of the daughter's expected productive life) without recovering the accrued differential value of the breeding herd. How much more discounted net income would have been made by selection for one generation instead of an infinite planning horizon? Are these costs symmetrical, i.e., is foregone income similar for producers who either (1) select sires for an infinite planning horizon but leave dairying in 8 years, or (2) select sires for a one-generation planning horizon but remain in business indefinitely? How do different errors compare in their economic effects? Answers to these questions will now be sought.

Focus is first directed to net present value as the decision criterion versus common criteria that ignore the time value of money. The costs of using incorrect management information are then estimated. The cost of a wrong decision is measured as the difference between discounted net income of the decision using incorrect perceptions and net income obtainable by using correct information.

Incorrect Decision Criterion

Table III contains present values of the net incomes foregone by ignoring the time value of money. Besides PV$, alternative decision criteria include three common ones in the sire selection literature—maximizing (1) PD$, which corresponds to maximizing gross income from increased milk production, (2) the ratio of PD$ to semen price, and (3) the Holstein Association's total performance index (TPI). The last one is a 3:1:1 weighted index of standard deviations in milk, milkfat percent, and type score PDs.

Table III. Cost of Selecting Bulls via a Decision Criterion that Ignores the Time Value of Money.[a]

Milk-to-Type Selection Policy	PD$	PD$/Semen Price ($)	TPI
	Decision Criterion		
1:0	249 (4.4)	77 (1.4)	290 (5.2)
3:1	285 (4.3)	120 (1.8)	242 (3.7)

[a]Cost is the average difference in net present value of lifetime income per average daughter for the 20 bulls actually selected and net present value for the 20 bulls that would have been selected had the producer used net present value as the decision criterion, assuming 50% herd average conception rate, 13-month calving interval, 15% female mortality rate, 3% real discount rate, and infinite planning horizon. Numbers in parentheses are ratios of cost to PV$ standard deviation with true decision criterion.

Cost of ignoring semen prices and not discounting net income, i.e., choosing bulls to maximize PD$ is $249 [equal to 4 standard deviations (SD) of profit] for a milk-to-type selection policy of 1:0. The cost of maximizing TPI is even greater at $290 (5 SD of PV$). Use of either decision criterion results in a cost which essentially negates any economic benefits from the genetic selection policy. Maximizing the ratio of PD$ to semen price reduces to $77 (1 SD of PV$) the cost of using a wrong decision criterion.

Greater is the cost of incorrectly choosing bulls to maximize PD$ or PD$/semen price for producers with a 3:1 milk-to-type selection policy. The PD$ and PD$/semen price decision criteria are, respectively, 15 and 55% more costly for a 3:1 selection policy than for the 1:0 policy. However, the cost of using TPI as the decision criterion for a 3:1 selection policy is 17% less than for the 1:0 policy.

For either selection policy, it is inconsequential whether the producer is mildly risk averse or a profit maximizer. Incorrectly perceiving the producer to be strongly risk averse instead of a profit maximizer incurs costs of up to $10. Because the standard deviations in PV$ for each of the top-20 bulls under each situation are small (3 to 19% of expected PV$), the mix of selected bulls is nearly the same for a profit-maximizing producer as for a strongly risk-averse producer who maximizes the lower limit of the 95% confidence interval of PV$.

Incorrect Management Information

Costs associated with using incorrect information about herd calving interval and female mortality rate are trivial. Identical bulls are chosen whether the calving interval is 15 or 12 months. The order of bulls within the top-20 subset differs but not the composition. Also, mortality rate has little effect (≤$1) on returns from sire selection. Consequently, no cost is attributed to the sire selection decision due to incorrect information about length of calving interval or mortality rate.

Table IV shows costs of choosing suboptimal bulls due to erroneous predictions

Table IV. Cost of Selecting Bulls with Incorrect Information about Real Interest Rate and Planning Horizon.*

True Information		Decision Based on:				
Real Interest Rate (%)	Planning Horizon (generations)	Real Interest Rate: Planning Horizon:	2% 1 gen	2% ∞ gen	5% 1 gen	5% ∞ gen
				($)		
2	1		-	7.10 (0.2)	0	2.50 (0.1)
2	∞		6.20 (0.1)	-	6.20 (0.1)	.80 (0.01)
5	1		0	8.85 (0.4)	-	3.60 (0.2)
5	∞		1.95 (0.04)	1.45 (0.03)	1.95 (0.04)	-

*Cost is the average difference in net present value of lifetime income per average daughter for the 20 bulls actually selected and net present value for the 20 bulls that would have been selected with correct information, assuming 1:0 selection policy, 50% herd average conception rate, 13-month calving interval, and 15% female mortality rate. Numbers in parentheses are ratios of cost to PV$ standard deviation with true information.

of the real discount rate (opportunity cost of capital) and planning horizon. For a one-generation planning horizon, the 20 most-profitable bulls remain the same for real discount rates of 2 to 5%. For an infinite planning horizon, selected sires vary a little with real discount rate, but errors in anticipating the opportunity cost of capital are only about $1.

The cost of misspecifying planning horizon is greater ($2–$7), and varies with discount rate ($2–$4 for 5% and $6–$7 for 2% real discount rate) and whether the discount rate is incorrectly anticipated. The effect of certain double errors, like assuming a low discount rate and short planning horizon but having a high discount rate and long planning horizon, is largely to cancel out the selection errors. Other double errors, however, increase the cost to $9 (0.4 SD of PV$).

Misspecification of Selection Policy and Incorrect Management Information

Cost sensitivity to planning horizon and conception rate of incorrectly choosing bulls by TPI is presented in Table V. The cost is greatest ($478, or 19 SD of PV$) for a short planning horizon and low conception rate. It is far more sensitive to conception rate than planning horizon. Cost is about 44% less when conception rate is 50% than when it is 30%, but only 10% less for an infinite planning horizon than for a one-generation horizon.

Costs of choosing wrong bulls by using incorrect selection policy, planning horizon, and conception rate are reported in Table VI. Least-costly mistakes are the double errors of assuming too short a planning horizon and too high a conception rate, or vice-versa. The effect of one mistake is almost exactly to cancel the effect of the other. Residual cost of these decision errors is trivial for either selection policy (5¢–75¢).

Minor costs ($2–$4) are incurred when the only mistake is to underestimate conception rate (Table VI). Overestimating conception rate is about twice as costly ($4–$8) as underestimating it.

Table V. Cost of Selecting Bulls by TPI for Alternative Planning Horizons and Conception Rates.[a]

True Information		
Planning Horizon (generations)	Conception Rate (%)	Decision Based on TPI ($)
1	30	478 (19.1)
	50	273 (8.8)
∞	30	431 (7.4)
	50	242 (3.7)

[a] See footnote a, Table IV. Other variables assumed: 3:1 selection policy, 13-month calving interval, 15% female mortality rate, and 3% real discount rate.

Table VI. Cost of Selecting Bulls via Wrong Producer Objective and with Incorrect Information about Planning Horizon and Conception Rate.[a]

True Information			Decision Based on:								
			Selection Policy:	1:0	1:0	1:0	1:0	3:1	3:1	3:1	3:1
			Planning Horizon:	1	1	∞	∞	1	1	∞	∞
Selection Policy	Planning Horizon (generations)	Conception Rate (%)	Conception Rate:	30	50	30	50	30	50	30	50
							($)				
					(0.3)	(0.3)	(1.0)	(1.1)	(1.7)	(2.1)	(2.7)
1:0	1	50		4 (0.1)	-	0.15 (.01)	5 (0.2)	26 (0.9)	27 (1.0)	32 (1.1)	39 (1.4)
1:0	∞	30		11 (0.2)	0.05 (0.001)	-	6 (0.1)	50 (0.9)	47 (0.9)	54 (1.0)	65 (1.2)
1:0	∞	50		26 (0.5)	4 (0.1)	3 (0.1)	-	61 (1.1)	47 (0.8)	49 (0.9)	54 (1.0)
3:1	1	30		23 (0.9)	23 (0.9)	24 (1.0)	32 (1.3)	-	8 (0.3)	14 (0.6)	23 (0.9)
3:1	1	50		32 (1.0)	25 (0.8)	25 (0.8)	19 (0.6)	4 (0.1)	-	0.75 (0.02)	4 (0.1)
3:1	∞	30		64 (1.1)	50 (0.9)	50 (0.9)	34 (0.6)	11 (0.2)	0.40 (0.01)	-	4 (0.1)
3:1	∞	50		88 (1.3)	67 (1.0)	66 (1.0)	36 (0.5)	30 (0.5)	7 (0.1)	2 (0.03)	-

[a] See footnote a, Table IV. Other variables assumed: 13-month calving interval, 15% female mortality rate, and 3% real discount rate.

Cost of incorrectly anticipating planning horizon depends on both selection policy and conception rate ($4–$14) but not systematically. With a 3:1 selection policy, for example, it is more costly to overestimate than underestimate planning horizon with a low conception rate, but more costly to underestimate than overestimate planning horizon with a high conception rate. The reverse is true for the 1:0 selection policy.

Costs are considerably higher ($23–$30, 0.5 to 1 SD of PV$) for both selection policies when the dual mistake is made of either over- or underestimating both planning horizon and conception rate. The more serious mistake is to underestimate both with a 3:1 selection policy.

Greater costs ($19–$88, 0.5 to 3 SD of PV$), however, generally are incurred when selection policy is misspecified, particularly in combination with other mistakes. The worst situation is to mistakenly assume a 1:0 selection policy while underestimating both planning horizon and conception rate.

SUMMARY AND IMPLICATIONS

Costliest mistakes in sire selection occur when producers seek to maximize some measure of genetic progress without considering the cost of semen. This is especially true for short planning horizons and low conception rates. The cost can be so great that the present value of semen from the selected sires is zero or even negative.

Semen from several genetically-elite sires is currently priced so high that it would not be rationally selected by commercial dairy producers seeking to maximize either profits or utility (including both profit and risk arguments). Semen from these sires would be selected only by producers who anticipate gain from the genetically-superior offspring as breeding stock, such as replenishing the stock of AI sires or raising elite dams (e.g., for embryo donors). Because semen from other genetically-elite sires is more reasonably priced, it is possible to greatly increase expected profits without large increases in risk.

The second most-costly error in sire selection occurs when producers appropriately consider semen cost and expected genetic improvements, but incorrectly value improvements in type score (body conformation) by using the wrong selection policy. Expected present value of incorrectly selected bulls is positive but is substantially reduced from that possible by using the correct selection policy. The cost of a wrong decision is further increased by simultaneous mistakes in planning horizon and conception rate.

Errors with negligible economic consequence include incorrect information about calving interval and mortality rate. The adverse consequence of under- or overestimating length of the planning horizon also can be offset by a corresponding over- or underestimation of conception rate. Costs of errors in anticipated opportunity cost of capital are small. The economic consequence of making independent errors in planning horizon or conception rate are intermediate in magnitude but closer to the costs of erroneous calving interval and/or mortality rate than to the cost of incorrect selection policy.

Perhaps the most important implication of this analysis is identification of priorities for use of scarce management resources. For the sire selection decision, greatest net returns may accrue to producers who consider net present value information before purchasing semen. Since such information is now readily available through dairy trade publications and DHIA, information cost to the producer is very low. Sire selections to maximize net present value also result in only slightly slower genetic progress than use of the most genetically superior bulls, so the aggregate industry effects are not serious.[15]

The next largest returns likely will accrue to producers who maintain accurate records on sources of income and who carefully consider how those sources are likely to change. For commercial milk producers who sell little or no breeding stock and who are basically content with conformation traits of the herd, it is economically consistent to place little weight on PDT in sire selection. For owners of registered Holsteins who earn (or could earn) as much as 1/4 of herd income from breeding stock sale or for producers where conformation problems reduce profits from milk, the 3:1 selection policy should help identify most profitable sires. Others may need slightly different weights for type score. The key is that it is a firm-level issue and can be correctly determined only from the unique characteristics of each farm. As such, and because of its economic impact, it is an important subject for allocating some scarce resources.

Determining average calving interval or female mortality rate for the entire herd or subsets of the herd, on the other hand, do not appear to justify allocation of any resources for the sire selection decision. The use of incorrect information for these variables has so little economic effect that improved information is not worth a substantial effort to obtain it.

This observation is consistent with other recent findings that shortening the length of the calving interval is not as important a management concern as previously thought. Holmann et al.[16] and Reyes et al.,[17] for example, both found that, with proper herd management, comparable annual net returns from milk production could be achieved with calving intervals ranging from 12 to 15 months. The results of this study suggest no reason, based on the sire selection decision, to dispute their conclusions that little economic incentive exists to devote scarce management resources to a reduction of the calving interval that currently averages 13.5 months in the US.

Unless the producer's real opportunity cost of capital will remain substantially out of the range considered here, little payoff is also likely from efforts to more precisely identify its magnitude.

Length of planning horizon and conception rate, however, do warrant some attention. Until better markets exist to accurately price breeding stock based on the economic value of differential genetic levels, it will be important for producers to carefully predict the likely life of their dairy businesses. Thus, an older farmer without an obvious successor to operate the dairy would be well advised to base the sire selection decision on a relatively short planning horizon.

Records required to maintain accurate information on average conception rate by age class of females in the herd are straightforward and consume little time. Value of this information in the sire selection decision, although not comparable to some other types of information, is probably sufficient to justify small expenditures of resources. Even if few records are kept, this is one meriting a high priority.

APPENDIX

The net present value (PV$) of semen when first breeding a cow is:

$$PV\$_j = B_1 P_j + (B_2 M_j + B_3 T_j) F_G, \qquad (1)$$

where

PV$_j$ is net present value of genetic contribution to all descendants (i.e., total worth of gene flow) of the jth sire;

P_j is price per unit of semen for the jth sire;

M_j is milk income over feed cost per lactation due to genetic change for a daughter of sire j [January 1985 mature-equivalent milk income per lactation is (PD milk (lb of milk with 3.5% milkfat) * \$.1220/lb) + (PD fat (%) * \$.0174/%/lb)];

$$T_j = w[(\mathrm{PDT}_j/\sigma_{\mathrm{PDT}})\sigma_{\mathrm{PD\$}}] \tag{2}$$

is net income from type score for a daughter of sire j corresponding to the specified milk-to-type selection policy;

$$B_1 = -n \sum_{t=1}^{3} (1 + i)^{-(t-1)(x/12)} \tag{3}$$

is the discounting factor for semen purchased over three lactations;

$$B_2 = \sum_{t=1}^{3} m_t (1 + i)^{-[(t-1)(x/12)+y]} \tag{4}$$

is the discounting factor for net income from milk of an average daughter for an average lifetime of three lactations;

$$B_3 = \sum_{t=1}^{3} (1 + i)^{-[(t-1)(x/12)+y]} \tag{5}$$

is the discounting factor for net income from type score of an average daughter;

$$F_G = \sum_{g=0}^{G-1} 2^{-g}(1 + i)^{-gh} \equiv \{2(1 + i)^h - [2(1 + i)^h]^{1-G}\}/[2(1 + i)^h - 1] \tag{6}$$

is the discounting factor for expected net income increases from G generations of descendants;

w is the weighting on PDT relative to a weighting of 1.0 on PD$ (for milk-to-type selection policies of 1:0, $w = 0$; and of 3:1, $w = 0.33$);

PDT$_j$ is PDT of the jth sire

σ_{PDT} is population standard deviation of PDT (0.77 for 314 Holstein bulls in January 1985);

$\sigma_{\mathrm{PD\$}}$ is population standard deviation of PD$ (\$36 for Holstein bulls in January 1985);

$$n = 100/\mathrm{CR}(1 - \mathrm{MR}/100) \tag{7}$$

is the average units of semen for each calving of the dam;

i is the real discount rate;

t is the lactation number;

x is the calving interval in months;

m_t is the reciprocal of the mature-equivalent factor and is used to adjust PD for milk and fat to daughter's actual yield in the tth lactation;

$$y = (2.5x + 26)/12 \tag{8}$$

is the number of years after first breeding the dam when the replacement daughter is expected to begin earning income [note: $2.5x + 26$ consists of $2x$ (time from first insemination to expected birth of replacement daughter) + 27 (age in months of daughter at her first calving) + $0.5x$ (midpoint of daughter's first calving interval) − 1 (one month to adjust from midpoint of daughter's first calving interval to midpoint of the lactation)];

g is generation number of descendant less one;

h is number of years between generations (3.33 and 3.5, respectively, for 13- and 15-month calving intervals);

2^{-g} accounts for the decay in net income due to Mendelian halving of germ-plasm from parent to offspring and to subsequent descendants;

CR is conception rate in %;

MR is mortality rate in %.

For an infinite planning horizon, Eq. (6) reduces to:

$$F_{\infty} = 2(1 + i)^h/[2(1 + i)^h - 1]. \tag{9}$$

See Wilcox et al.[18] and McMahon et al.[19] for additional details in calculating PV$ of semen and for evaluation of other alternatives.

REFERENCES

1. M. E. Carter, "Implications of Emerging Biotechnologies," *Southern Journal of Agricultural Economics*, *15* (1), 7–9 (1983).
2. J. J. Rutledge and G. E. Seidel, "Genetic Engineering and Animal Production," *Journal of Animal Science*, *57* (Suppl. 2), 265–272 (1983).
3. Research and Education Association, *Genetic Engineering*, Research and Education Association, New York, 1982.
4. C. Olentine, "Mendel's Son: Genetic Engineering," *Animal Nutrition and Health*, *38* (1), 56 (1983).
5. R. H. Foote, "The Artificial Insemination Industry," in *New Technologies in Animal Breeding*, B. G. Brackett, G. E. Seidel, and S. M. Seidel, Eds., Academic, New York, 1981, Chap. 2.
6. U.S. Department of Agriculture, *USDA-DHIA Active AI Sire Summary*, Agricultural Research Service, January 1985.
7. D. L. Bath, F. N. Dickinson, H. A. Tucker, and R. D. Appleman, *Dairy Cattle: Principles, Practices, Problems, Profits*, 2nd ed., Lea & Febiger, Philadelphia, 1978.
8. F. N. Dickinson, "Impact of DHIA Records on Efficiency of Dairy Cows," *Proceedings, Beef Cow Efficiency Forum*, East Lansing, MI, May 1984, pp. 63–72.
9. R. W. Everett, "Using Grade Holstein Bulls in A.I.," *Dairy Herd Management*, *22* (1), 63–66 (1985).
10. M. A. Tomaszewski and R. W. Blake, "What is Your Semen Investment Earning?" *Dairy Herd Management*, *20* (6), 20–24 (1983).
11. J. J. Bakker, R. W. Everett, and L. D. Van Vleck, "Profitability Index for Sires," *Journal of Dairy Science*, *63*, 1334–1341 (1980).
12. M. L. McGilliard and J. S. Clay, "Breeding Programs of Dairymen Selecting Holstein Sires by Computer," *Journal of Dairy Science*, *66*, 654–659 (1983).
13. M. Schneeberger, A. E. Freeman, and P. J. Berger, "Income and Risk for Dairymen Selecting Sires for Artificial Insemination," *Journal of Dairy Science*, *65*, 988–994 (1982).
14. H. D. Norman, B. G. Cassell, R. E. Pearson, and G. R. Wiggans, "Relation of First Lactation Production and Conformation to Lifetime Performance and Profitability in Jerseys," *Journal of Dairy Science*, *64*, 104–113 (1981).
15. R. W. Blake, C. R. Shumway, and M. A. Tomaszewski, "Select Sires for Profit with PV$ Sire Summary," *Dairy Herd Management*, *22* (4), 26–40 (1985).
16. F. J. Holmann, C. R. Shumway, R. W. Blake, R. B. Schwart, and E. M. Sudweeks, "Economic Value of Days Open for Holstein Cows of Alternative Milk Yields with Varying Calving Intervals," *Journal of Dairy Science*, *67*, 636–643 (1984).

17. A. A. Reyes, R. W. Blake, C. R. Shumway, and J. T. Long, "Multistage Optimization Model for Dairy Production," *Journal of Dairy Science, 64*, 2003–2016 (1981).

18. M. L. Wilcox, C. R. Shumway, R. W. Blake, and M. A. Tomaszewski, "Selection of Artificial Insemination Sires to Maximize Profits," *Journal of Dairy Science*, *67*, 2407–2419 (1984).

19. R. T. McMahon, R. W. Blake, C. R. Shumway, and M. A. Tomaszewski, "Selection of Young and Proven Holstein Artificial Insemination Sires to Maximize Profits," *Journal of Dairy Science*, *68*, 2303–2308 (1985).