January 1978

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ABSTRACT

The expected change in dollar return from incorporating milk, fat, and protein records in a selection index (Index 1) was compared to that from an index utilizing just milk and fat records (Index 2) under pricing systems paying for milk, fat, and protein.

Dollar return 1 was superior to dollar return 2 when there was either no payment for protein or high payment for protein. For sire selection the expected changes in dollar return for the two indices were equal at a price for protein of \$.88 per kg whereas for cow selection the returns were equal at a protein price of \$2.65 per kg. At all other protein prices for both sire and cow selection, dollar return 1 exceeded dollar return 2.

Economic analyses of the costs and potential benefits of dollar return 1 compared to dollar return 2 were made for a variety of protein prices and costs of protein testing. Selection programs leading to dollar return 1 have a small economic advantage over those programs for genetic improvement leading to dollar return 2 when the cost of measuring protein is low or nil. Testing costs above \$.01 per cow per month overwhelm the difference in economic return. Furthermore, realistic payments for protein lead to less economic advantage than no payment. Measuring protein has its greatest advantage at unrealistically high prices for protein. Increasing the genetic trend in milk yield above 45 kg will increase the economic feasibility of protein testing.

Received June 27, 1977.

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INTRODUCTION

Protein testing is receiving renewed attention in the dairy industry. Since protein testing services are a potential cost to the dairyman, the objective of this paper is to address the question: If routine protein testing is to be a part of recording for Holstein cows, how much can the dairyman afford to pay for the service? A by-product of the study is a demonstration of the utility of selection index methodology in deriving answers to such questions.

METHODS

The gross monetary benefit from protein measurement is given by the difference between the expected changes in Dollar Return (DR) through the alternative use of 1) a selection index including measurements on milk, fat, and protein yield with payment based on all traits or 2) an index including just milk and fat yield but where payment again is based on all three traits. Accordingly, returns from the following selection indices were computed:

$$\text{Index 1: } I_1 = b_{1m}x_m + b_{1f}x_f + b_{1p}x_p = \mathbf{b}_1'\mathbf{x}_1$$

where $\mathbf{b}_1'$ is a row vector of selection index weights pertaining to the traits milk (m), fat (f), and protein (p) yield, and $\mathbf{x}_1$ is a column vector of phenotypic recordings on the three traits.

Following Henderson (2), an estimate of $\mathbf{b}_1$ is:

$$\hat{\mathbf{b}}_1 = \mathbf{P}_1^{-1}\mathbf{G}_1\mathbf{a} \quad [1]$$

where $\mathbf{P}_1$ is a (3 × 3) phenotypic variance-covariance matrix, $\mathbf{G}_1$ is a (3 × 3) genotypic variance-covariance matrix, and $\mathbf{a}$ is a column vector of relative economic values of the three traits. With $\hat{\mathbf{b}}_1'$ computed, an estimate of DR through I_1 is:

$$DR_1 = \tau(\hat{\mathbf{b}}_1'\hat{\mathbf{P}}_1\hat{\mathbf{b}}_1)^{.5}$$

where τ is a factor for intensity of selection. In this study, τ was set equal to .1273 which corresponds to a genetic gain of milk yield of 45 kg per cow per year when selection is for

that trait alone. In cases where the components of DR_1 are desired, the procedure detailed by Van Vleck (4) can be employed.

Index 2: $I_2 = b_{2m}x_m + b_{2f}x_f = b_2'x_2$

where b_2' is a row vector of index weights pertaining to the traits milk (m) and fat (f) yield, and x_2 is a column vector of phenotypic recordings on the two traits.

With payment based on milk, fat, and protein yield, an estimate of b_2 is:

$$\hat{b}_2 = P_2^{-1} G_2 a \qquad [2]$$

where P_2 is a (2 × 2) phenotypic variance-covariance matrix, G_2 is a (2 × 3) genotypic variance-covariance matrix, the extra column reflecting payment for a trait not included in the index, and a is the same column vector as before.

Similarly, an estimate of DR through I_2 is:

$$DR_2 = \tau(\hat{b}_2'\hat{P}_2\hat{b}_2)^{.5}.$$

The genotypic and phenotypic variance-covariance matrices in equations [1] and [2] were based on the generally-accepted estimates of variance and covariance parameters in the Holstein breed (5). These estimates are in Table 1; the genetic correlations are .66, .82, and .77 between milk and fat, milk and protein, and fat and protein. Since the difference DR_1 minus DR_2 increases as genetic correlations between protein and the other traits decrease, results were compared where genetic correlations were less than published estimates. Accordingly, genetic correlations were decreased progressively by .1, thereby changing elements in both genotypic and phenotypic matrices. For relative economic values, comparisons between DR_1 and DR_2 were for varying protein prices with a base price for milk of $22.04 per 100 kg, $.22 a point for fat percentage above and below 3.5% fat, and $.00 to $.44 a point for protein above and below 3.2% protein. These prices are equivalent to a value of fat yield of $2.20 per kg and values of protein yield of $.00 to $4.41 per kg. The comparisons were not only for selection of cows but also for selection of sires with 50 tested daughters per sire.

TABLE 1. Genotypic (phenotypic) variances and covariances for the traits milk, fat, and protein yield measured in kg.

Trait	Milk	Fat	Protein
Milk	507,789 (2,031,040)	13,633 (71,988)	12,629 (62,525)
Fat		843 (3,371)	483 (2,437)
Protein			467 (2,225)

Measurement of the economic advantage of selection by Index 1 over selection by Index 2 must taken into account the cost (C) per year, the return (R) per year, and the discount rate (D) for a program over *n* yr. The sum of the returns minus the costs over *n* yr is the economic advantage of the program per cow for the *n* yr. Starting a program requires one generation of matings for genetic improvement. A generation in dairy cattle is 5 yr; therefore, genetic trend will start in yr 6 as follows:

Years	Cost	Return
1	$C \times (1+D)^{n-1}$	0
2	$C \times (1+D)^{n-2}$	0
.		.
.		.
.		.
5	$C \times (1+D)^{n-5}$	0
6	$C \times (1+D)^{n-6}$	$R \times (1+D)^{n-6}$
7	$C \times (1+D)^{n-7}$	$2R \times (1+D)^{n-7}$
.		.
.		.
.		.
n	$C \times (1+D)^{n-n}$	$(n-5)R \times (1+D)^{n-n}$

The costs of protein measurement (C) are discounted to the yr *n* and summed over all years. The return (R) is the economic advantage of DR_1 over DR_2 due to selection starting in yr 6 and discounted to yr *n*. It is defined as the yearly difference in income over feed costs between DR_1 and DR_2 and is additive. The economic advantage of Index 1 over Index 2 is the discounted returns summed over *n* yr minus the discounted costs summed over *n* yr. The economic advantage was calculated for combinations of *n* = 10, 15, 20, 25; D = .05, .06, . . .,.12; C = 100, .01, . . .,.15 dollars per cow per month; and R = .00, .02, .04, . . .,.20 dollars per cow per year.

RESULTS AND DISCUSSION

The results of cow selection and sire selection comparing DR_1 with DR_2 are in Tables 2 and 3. Intensities of selection were identical for cow and sire selection. The results were compared for various genetic correlations between traits.

The results in Table 2 for cow selection compare dollar return in selecting for three compared to two traits (Index 1 vs. Index 2) for various prices of protein. Cow selection for milk and fat produced a gross progress of $9.21 ($DR_2$) per generation in the absence of protein payment. By selecting for milk, fat, and protein, but without protein payment, a gross progress of $9.62 ($DR_1$) per generation resulted. The additional $.41 per generation is due to the correlated responses in milk and fat yield by including protein in a selection index. As the relative economic value of protein was increased, the differences between the two selection programs narrowed until they were equal at $2.65 per kg of protein. The difference then increased to $.19 at $4.41 per kg for protein. The same pattern of small differences at intermediate protein prices and large differences at the extremes was uniform across the range of genetic correlations. As genetic correlations were reduced, the differences between the programs became larger. This is to be expected since the traits act more independently and measurement of protein is more valuable at all prices of protein.

The results for sire selection in Table 3 were for 50 daughters per sire. The increased accuracy in estimating genetic merit of the sires is demonstrated through higher dollar returns for sires compared to cows. Moreover, the pattern of differences between DR_2 and DR_1 was different from that for cows. When protein was $.88 per kg, selection by Index 2 produced identical results to selection by Index 1. In all other cases, selection by Index 1 was superior to selection by Index 2 in gross economic return. In cow selection, DR_1 and DR_2 were equal at protein prices of $1.76 to $2.65 per kg. In sire selection, the two programs were equal at $.88 per kg for protein. This implies that in combining cow and sire selection, the smallest differences between the two selection programs would occur at $.88 to $2.65 per kg of protein.

In Tables 4 and 5, the dollar differences

TABLE 2. Gross dollar returns per generation from cow selection for milk, fat, and protein compared to selection for milk and fat at different prices of protein and varying genetic correlations.

Genetic correlations				Price of protein per kg					
Milk-fat	Milk-protein	Fat-protein		$.00	$.88	$1.76	$2.65	$3.53	$4.41
.66	.82	.77	a)	9.62	9.20	8.92	8.79	8.81	9.00
			b)	9.21	9.01	8.87	8.79	8.77	8.81
.56	.72	.67	a)	9.43	8.75	8.30	8.15	8.29	8.73
			b)	8.79	8.48	8.26	8.14	8.11	8.20
.46	.62	.57	a)	9.26	8.30	7.69	7.52	7.83	8.56
			b)	8.38	7.95	7.64	7.48	7.48	7.62
.36	.52	.47	a)	9.14	7.87	7.07	6.89	7.40	8.46
			b)	7.96	7.41	7.02	6.83	6.85	7.09
.26	.42	.37	a)	9.04	7.46	6.44	6.28	7.01	8.42
			b)	7.55	6.87	6.38	6.17	6.24	6.61
.16	.32	.27	a)	8.99	7.08	5.82	5.65	6.67	8.45
			b)	7.15	6.31	5.74	5.51	5.67	6.19

[a]Selection for milk, fat, and protein.

[b]Selection for milk and fat.

TABLE 3. Gross dollar returns per generation from sire selection for milk, fat, and protein compared to selection for milk and fat at different prices of protein and varying genetic correlations.

Genetic correlations				Price of protein per kg					
Milk-fat	Milk-protein	Fat-protein		$.00	$.88	$1.76	$2.65	$3.53	$4.41
.66	.82	.77	a)	16.77	16.49	16.31	16.27	16.34	16.55
			b)	16.74	16.49	16.27	16.09	15.97	15.90
.56	.72	.67	a)	16.21	15.76	15.51	15.47	15.63	15.99
			b)	16.17	15.76	15.42	15.15	14.94	14.81
.46	.62	.57	a)	15.63	15.02	14.68	14.63	14.89	15.42
			b)	15.57	15.02	14.54	14.15	13.87	13.69
.36	.52	.47	a)	15.03	14.24	13.80	13.76	14.11	14.84
			b)	14.96	14.24	13.62	13.12	12.77	12.55
.26	.42	.37	a)	14.43	13.43	12.88	12.84	13.31	14.25
			b)	14.32	13.43	12.66	12.04	11.61	11.38
.16	.32	.27	a)	13.81	12.58	11.90	11.86	12.47	13.62
			b)	13.66	12.58	11.65	10.92	10.42	10.20

[a]Selection for milk, fat, and protein.

[b]Selection for milk and fat.

listed in Tables 2 and 3 have been converted to percent dollar advantage for Index 1 over Index 2. If correct genetic correlations are .66, .82, and .77, measuring protein for selection has its greatest advantage when no payment is for protein. Measuring protein had minimum advantage when protein payments were $1.76 to $2.65 per kg. If the true genetic correlations are less than the published figures, the advantage of measuring protein increases.

The results in Table 5 for sire selection show almost no gross economic advantage of including protein in a selection index except where protein had an economic value of $2.65 to $4.41 per kg. As the genetic correlations decreased, the advantage increased, especially for higher values of protein.

Cow and sire selection were combined in Table 6, with 76% of the total progress from sire selection and 24% from cow selection (1). Gross income from milk, corrected for fat and protein content, is proportional to the quantity of milk. Therefore, the additional percent in gross income can be converted to additional milk. The superiority of selection by Index 1 over selection by Index 2 was $.76\Delta G(V_S)$ +

TABLE 4. Percent increase in gross dollars in selecting cows for milk, fat, and protein over selecting for milk and fat.

Genetic correlations			Price of protein per kg					
Milk-fat	Milk-protein	Fat-protein	$.00	$.88	$1.76	$2.65	$3.53	$4.41
.66	.82	.77	4.5	2.1	.6	.0	.5	2.2
.56	.72	.67	7.3	3.2	.5	.1	2.2	6.5
.46	.62	.57	10.5	4.4	.7	.5	4.7	12.3
.36	.52	.47	14.8	6.2	.7	.9	8.0	19.3
.26	.42	.37	19.7	8.5	.9	1.8	12.3	27.4
.16	.32	.27	25.7	12.2	1.4	2.5	17.6	36.5

TABLE 5. Percent increase in gross dollars in selecting sires for milk, fat, and protein over selecting for milk and fat.

Genetic correlations			Price of protein per kg					
Milk-fat	Milk-protein	Fat-protein	\$.00	\$.88	\$1.76	\$2.65	\$3.53	\$4.41
.66	.82	.77	.2	0	.2	1.1	2.3	4.1
.56	.72	.67	.2	0	.6	2.1	4.6	8.0
.46	.62	.57	.4	0	1.0	3.4	7.4	12.6
.36	.52	.47	.5	0	1.3	4.9	10.5	18.2
.26	.42	.37	.8	0	1.7	6.6	14.6	25.2
.16	.32	.27	1.1	0	2.1	8.6	19.7	33.5

$.24\Delta G(V_c)$, where V_s and V_c are corresponding values from the first lines of Tables 4 and 5 divided by 100, and ΔG is the genetic trend per year. The values in Table 6 are defined as fat- and protein-corrected milk. With a 22.7 kg genetic trend in fat- and protein-corrected milk, there was a .279 kg advantage in genetic trend per year for Index 1 compared to Index 2 if there was no payment for protein. As the payment for protein increased, there was a decline in the advantage of Index 1 over Index 2 followed by an increase when protein was priced above \$1.76 per kg. These advantages of Index 1 over Index 2 are in gross kg of fat- and protein-corrected milk per year. The net advantage must take into account the additional feed to produce the extra product. The net per kg of milk is .57 × gross per kg (3).

The economic advantages of Index 1 over Index 2 for n = 25, D = .10, and all combinations of R and C are in Table 7. The net economic return per cow for 25 yr is given relative to the net economic advantage of Index 1 over Index 2 for various costs of measuring protein. As an example, with a genetic trend per cow per year of 68 kg of milk (Table 6), Index 1 had a .838 kg of milk advantage at \$.00 payment for protein. If milk sells for \$.22 per kg and income over feed costs is .57 of the total advantage, then DR_1 exceeds DR_2 by \$.105. For the \$.10 in the left column of Table 7, there will be a \$43.00 net 25-yr advantage of Index 1 over Index 2 if the cost of measuring protein is \$.00. At a protein measurement cost of \$.03 per cow per month, the 25-yr advantage is \$7.60, and at \$.05 per cow per month, it is −\$16.00. In Table 6 for genetic trend of 68 kg, if the industry pays \$1.76 per kg for protein, there is a \$.025 (.201 × .22 × .57) advantage of Index 1 over Index 2. For the \$.02 in the left column of Table 7, there will be a \$8.60 net return over 25 yr for Index 1 over Index 2 if the cost of measuring protein is \$.00. A cost of \$.01 or more per cow per month will result in negative net dollar returns per cow over 25 yr. Realistic figures for genetic trends and payments for protein indicate that the costs of measuring protein must be \$.01 per cow per mo

TABLE 6. Additional kg of fat- and protein-corrected milk per year using Index I versus Index 2.

Kg of genetic trend per year	Price of protein per kg					
	\$.00	\$.88	\$1.76	\$2.65	\$3.53	\$4.41
22.7	.279	.114	.067	.190	.424	.826
34.0	.419	.171	.101	.284	.635	1.238
45.4	.558	.229	.134	.380	.847	1.651
56.7	.699	.286	.168	.474	1.059	2.064
68.0	.838	.343	.201	.569	1.271	2.477
113.4	1.397	.571	.336	.948	2.118	4.127

TABLE 7. Net dollar return per cow for a 25-yr program of selecting for milk, fat, and protein over a selection for milk and fat with a discount rate of 10%.

Net economic genetic trend advantage of 3-trait selection over 2-trait selection	Cost per cow per month of measuring protein					
	$.00	$.01	$.02	$.03	$.04	$.05
$.00	$ .00	$-11.80	$-23.60	$-35.40	$-47.21	$-59.01
.02	8.60	-3.20	-15.00	-26.80	-38.61	-50.41
.04	17.20	5.40	-6.40	-18.20	-30.00	-41.81
.06	25.80	14.00	2.20	-9.60	-21.40	-33.21
.08	34.40	22.60	10.80	-1.00	-12.80	-24.61
.10	43.00	31.20	19.40	7.60	-4.20	-16.00
.12	51.60	39.80	28.00	16.20	4.40	-7.40
.14	60.20	48.40	36.60	24.80	13.00	1.20
.16	68.80	57.00	45.20	33.40	21.60	9.80
.18	77.40	65.60	53.80	42.00	30.20	18.40
.20	86.00	74.20	62.40	50.60	38.80	27.00

or less and the milk pricing structure must pay little or nothing for a kg of protein for the dairyman to make a net return on measuring protein. A milk price structure with protein payments low or nil, or above $2.65 per kg, can result in a net economic return to the dairyman if the costs of measuring protein are low or nil.

A 25-yr program was used in Table 7 because programs of 10 through 20 yr show almost all negative net dollar returns for costs of measuring above $.00 per cow per month. There is always a net economic advantage for $.00 costs of measuring protein. Lower discount rates will increase the net returns, but a discount rate as low as .05 will not alter the conclusions.

CONCLUSIONS

Selection programs employing measurements on milk, fat, and protein have a small economic advantage over programs employing measurements on milk and fat, but not protein, when the costs of measuring protein are nil or low. At realistic genetic trends of 34 to 68 kg of fat- and protein-corrected milk, costs above $.01 per cow per mo will overwhelm potential returns. Furthermore, realistic protein payments of $.88 to $2.65 per kg result in less economic advantage compared with measurements on all three traits but with no payment for protein. This stems from the high genetic correlations among the traits and the price structure of milk. Through indirect selection, the genetic correlations are responsible for improvement in protein in response to measuring milk and fat. The traditional price structure for milk pays for the weights of milk and its constituents. For example, a price of $22.05 per 100 kg and $.22 per point of fat above 3.5% results in $.143 per kg of milk and $2.20 per kg of fat. A price of $22.05 per 100 kg, $.22 per point of fat above 3.5% and $.18 per point of protein above 3.2% results in $.0869 per kg of milk, $2.20 per kg of fat, and $1.76 per kg of protein. The addition of protein resulted in a drop in the price per kg of milk. This contributes to the decreased advantage of three-trait selection over milk and fat selection as the price for protein increases to $1.76 per kg. Measuring protein has its greatest advantage at unrealistically high prices for protein. Increasing the genetic trend for milk will increase the economic feasibility of a genetic program paying for protein testing.

This study analyzed the merit of including measurements on milk protein in selection programs. Economic justifications for measuring protein for a genetic program are possible when costs of measurements are low or nil, protein payments are nil or unrealistically high, or genetic trends are higher than currently have been attained in large populations. Consideration was not given to how much in transportation costs could be saved by shipping milk with lower water content, whether manufacturing costs could be reduced if milk has less water, or

if there is an optimum composition of milk for maximum milk sales. (If the industry must attain such an optimum in order to survive, then entirely different economic weights must be applied to the problem.)

ACKNOWLEDGMENTS

The authors gratefully acknowledge Eastern Artificial Insemination Cooperative, Inc., P. O. Box 518, Ithaca, NY 14850, for the financial support of this project.

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