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PREDICTION OF ADDITIVE GENETIC VALUE OF DAIRY CATTLE

2. MULTITRAIT SELECTION INDEX BASED ON COW'S OWN RECORDS

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Abstract. Some theoretical viewpoints of calculating Smith-Hazel selection indexes are given as to dairy cattle breeding value estimation for milk production traits. Selection index method was applied for selection of Estonian Black-and-White cows for milk yield, milk fat, and milk protein production. On the basis of generalized genetic and phenotypic parameters of a population, several variants of selection indexes were calculated.

For the phenotypic selection on the basis of a deviations of cows' milk yield, fat and protein production per lactation from the herdmates' average, the following index was recommended:

$$SI = -1.77 \times \text{milk kg} + 42.65 \times \text{fat kg} + 85.01 \times \text{protein kg}.$$

In this index the price of milk protein was estimated twice higher than that of milk fat. If the protein price was three times higher than the price of fat, the index was:

$$SI = -2{,}45 \times \text{milk kg} + 42.47 \times \text{fat kg} + 126.83 \times \text{protein kg}.$$

Changes in economic values of traits affected the regression coefficients of an index.

Key words: selection index, dairy cattle, breeding value estimation.

INTRODUCTION

In the previous part of this article (Teinberg, 1993) the principles of predicting additive genetic value of dairy cattle on the basis of pedigree index were considered. It is a first step in estimating the breeding value of an animal to be evaluated. In this part of the paper we are discussing the multitrait linear selection index (SI) based on animals' own records.

A basis for constructing selection indexes — Fisher's (1936) discriminant function — was originally developed for differentiating species in taxonomy. Smith (1936) applied this function to design an index for the selection of plant lines. Hazel (1943) extended the index procedure for the selection of animals. Hazel's paper from 1943 can be considered as a classical one in selection index theory, as it first defined a method of estimating genetic variances and covariances needed to calculate index linear regression coefficients (weights) and, secondly, he defined the term "aggregate genotype" as a linear combination of genetic values of several selection traits, each weighted by their relative economic values. Therefore the linear unrestricted SI is often called Smith-Hazel index (Lin, 1978; Pirchner, 1983).

In livestock improvement a breeder must always pay attention to several selection criteria, to many selection traits. It depends upon breeding objectives, also on economically useful, measurable characters of animals.

Comparing different selection methods (tandem selection, independent culling levels, index selection) Hazel and Lush (1942) already showed that index selection is the most efficient method in maximizing the improvement of an overall genetic-economic value. The theoretical evaluation of the relative efficiency of these three selection methods was confirmed experimentally by Sen and Robertson (1964) in *Drosophila*, Doolittle et al. (1972), Eisen (1977) in mice and Scheinberg et al. (1967) in *Tribolium*. Later, Kempthorne and Nordskog (1959) introduced the idea of a restricted selection index which restricts the genetic changes of certain traits. Many other types of constrained selection indexes were proposed by Tallis (1985), Harville (1974, 1975), Hill (1981), Pirchner (1983), Henderson (1984), and others. All of these indexes are based on the relative economic values of component traits. It was found that the relative efficiency depends upon the number of traits selected, on their relative economic values, their heritabilities, phenotypic and genetic correlations between selection traits, and selection intensity. A comprehensive review of the SI theory is given by Young (1961), Yamada et al. (1975), Itoh and Yamada (1986, 1988), Lush (1961), Henderson (1963), Rønningen (1974), James (1981, 1982), Gjedrem (1967, 1968), Hill (1981), Cunningham (1972, 1975), and by Lin (1978).

The objective of this paper is to give a review of the basic theory of SI, and summarize its applications in dairy cattle selection, especially in Estonia, for the selection of cows and bulls for genetic improvement of several quantitative characters.

SELECTION INDEX THEORY

Here we present only the basic principles of constructing SI, referring to the reviews noted before. Some viewpoints of the theory of linear SI are also considered in our previous works (Тейнберг, Каск, 1980; Teinberg, 1978).

Suppose we have m traits of economic importance ($Y_1, \ldots Y_m$) and n traits to be used in selection ($X_1, \ldots X_n$). Principally, some traits may be among the Y's but not the X's, and vice versa. Let P be the $n \times n$ phenotypic covariance matrix of the X's, Q the $m \times m$ genetic covariance matrix of the Y's and G the $n \times m$ genetic covariance matrix between the X's and Y's. When $m=n$, then G and Q are identical.

Let a be the vector of economic weights, so that breeding value (aggregate genotype) is

$$H = a'y$$

and b be the vector of index coefficients so that the index is

$$I = b'x,$$

where y and x are the vectors of Y's and X's, and the prime (') denotes the transpose. Then the optimum index weights are given by (James, 1982)

$$b = P^{-1}Ga$$

and the variance of the index is

$$\sigma^2_I = b'Pb = a'G'P^{-1}Ga.$$

The variance of breeding value is

$$\sigma^2_H = a'Qa,$$

and since $Cov(HI) = \sigma^2_I$, the correlation between index and breeding value is

$$r_{HI} = \sigma_I / \sigma_H.$$

The response to selection with standardized selection differential i is then

$$R_{HI} = i r_{HI} \sigma_H = i \sigma_I.$$

If we consider two different objectives, H_1 and H_2, with vectors of economic weights a_1 and a_2, their genetic correlation is

$$r_{H_1H_2} = \frac{a'_1 Qa_2}{[(a'_1 Qa_1)(a'_2 Qa_2)]^{0.5}}.$$

The index coefficients, i.e. the vector b, needed to construct the SI, are derived such that the correlation between I and H is a maximum, or that $\sum(H-I)^2$ is a minimum. The correlation between I and H is

$$r_{IH} = \frac{b'Ga}{[(b'Pb)(a'Qa)]^{0.5}}.$$

The statistical properties of the SI are given by Henderson (1963, 1984), also by Williams (1962) and Nordskog (1978).

As stated before, the use of a SI would be expected to lead to maximum genetic gain. Index selection has been used extensively in practice, but there are still some potential problems associated with the use of this method. The main problems are:

1) Changes of genetic parameters due to selection. Index selection would reduce the genetic and phenotypic variance of the traits included, it also reduces respective covariances. Therefore, the SI should be a dynamic index, not a static one. It needs periodical recalculation (Lin, 1976; Bruns, Harvey, 1976; McMillan et al., 1973; Кузнецов, 1992);

2) Sampling errors of parameter estimation. Phenotypic and genetic parameters, required for the computation of a SI, are sample estimates with various sampling errors and the SI itself is an estimated index. Inaccurate estimation of population parameters could bias estimates of theoretical gains. Simulation studies on a computer have demonstrated that if the parameter estimates deviate only slightly from the real parameter, the use of estimated SI is justified (Harris, 1963). Pease et al. (1967) reported that estimation errors of genetic correlations (r_G) have larger effect on SI than errors in estimating heritability (h^2). The effect of erroneous parameters on index selection depends upon the number of traits selected, the relative economic weights, levels of parameters, and selection intensity;

3) Evaluation of relative economic weights. It is difficult to establish a proper economic value of different traits, using direct economic analysis or multiple regression analysis. However, certain degree of variation in relative economic weights will not change SI or expected response too much. As economic values do change from time to time, there is a need of periodical reconstructing of the SI as well.

Gjedrem (1967, 1972), as a result of simulation studies, came to the conclusion that traits with high heritability, but without economic importance, having close correlation with non-measurable important traits, must be included into the index.

Theoretically, SI can be a non-linear function of selection traits. Non-linear (quadratic, cubic) indexes have also been constructed (Rønningen, 1971), but they are too complex for practical use.

MATERIAL AND METHODS

Hazel's basic method with modifications (Cunningham, 1969; Басовский et al., 1976; Teinberg, 1978) was used in constructing SI. We used the following genetic and phenotypic parameters for calculating SI, proposed initially by Hazel (1943):

Trait	Heritability h^2	Phenotypic standard deviation s_P	Relative economic value a
1.	h^2_1	s_{P_1}	a_1
2.	h^2_2	s_{P_2}	a_2
3.	h^2_3	s_{P_3}	a_3
. . .	. . .	. . .	. . .
n	h^2_n	s_{P_n}	a_n

and correlation matrix:

Trait	Phenotypic correlation r_P	Genetic correlation r_G
1×2	$r_{P1\times2}$	$r_{G1\times2}$
1×3	$r_{P1\times3}$	$r_{G1\times3}$
. . .	. . .	. . .
$1\times n$	$r_{P1\times n}$	$r_{G1\times n}$
2×3	$r_{P2\times3}$	$r_{G2\times3}$
. . .	. . .	. . .
$2\times n$	$r_{P2\times n}$	$r_{G2\times n}$
etc.		

The elements of phenotypic and genetic matrices $(i\times j)$ were calculated as

$$P_{ii}=s^2_{P_i},$$

$$P_{ij}=Cov(P_iP_j)=r_{P_iP_j}\cdot s_{P_i}\cdot s_{P_j},$$

$$G_{ii}=s^2_{G_i}=h^2_i\cdot s^2_{P_i},$$

$$G_{ij}=Cov(G_iG_j)=r_{G_iG_j}\cdot\sqrt{h^2_i}\,s_{P_i}\cdot\sqrt{h^2_j}\cdot s_{P_j}$$

As an example, matrices for calculating SI for three selection characters are:

$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix}=\begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix}^{-1}\cdot\begin{pmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{pmatrix}\cdot\begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix}$$

or in an abbreviated form

$$\vec{b}=P^{-1}G\vec{a}.$$

A special computer programme for personal computer was written for computations of indexes (Тейнберг, 1974).

Table 1

Genetic and phenotypic parameters used in SI calculations

Trait kg	h^2	s_P	a EEK/kg	Correlations genetic\phenotypic 1	2	3
1. Milk yield	0.3	700	1.2—3.0		0.9	0.9
2. Milk protein yield	0.4	20	31.6—79.0	0.8		0.9
3. Milk fat yield	0.4	30	15.8—237.0	0.8	0.8	

First calculations of SI for dairy cattle in Estonia were made already in 1968 (Teinberg, 1968; Тейнберг, 1971, 1974). From 1985 on, a regular application of SI was started in dairy cattle breeding value prediction (Тейнберг, 1985). Indexes were computed for best herds to estimate the breeding value of cows (their ranking) on the basis of milk, milk fat and protein yield, and also for the progeny test of insemination bulls.

The selection traits used in calculated indexes varied in subsequent years. In 1970s most of SI were calculated for three traits: milk yield, fat percentage, and protein percentage in milk. Later (in 1980s) we added fat and protein yield, body mass and milking speed (Тейнберг, 1985). From 1993 we concentrated on three selection characters — milk yield, protein yield and fat yield during a 305-day control lactation.

Economic values were calculated on the basis of milk kg price being 1.2 Estonian kroons (EEK), standard milk being with 3.8 per cent fat and 3.0 per cent protein content. If 38 kg fat price is 1.2 EEK, 1 kg fat price is 31.6 EEK, accordingly. The price of protein was derived from the fat price, varying the fat—protein price ratio from 3 : 1 to 1 : 3.

For calculating genetic and phenotypic parameters, the milk recording data of Estonian Black-and-White cows (250 000 cows) were used. Totally, over 300 SI variants were calculated.

In the last indexes (computed in December, 1993) we used the parameters presented in Table 1.

Heritabilities were calculated, using half-sib progeny groups, also genetic correlations (Teinberg, 1978; Шталь et al., 1973; Becker, 1985).

RESULTS AND DISCUSSION

A well-defined **breeding goal** which will hold minimum ten years in the future, should be the basis for a reliable selection index. Such a breeding goal includes prices of milk and its components, also the other measurable selection traits of a dairy cow.

From the beginning of 1993, in connection with the introduction of a new milk recording and breeding value estimation system (BLUP, see Teinberg, Uba, 1992), also breeding goals and selection traits for Estonian dairy cattle were fixed. **Three main production traits** were recommended for including into cows' selection index: **milk yield** (kg during a 305-day lactation), also **milk protein** and **milk fat yield**. As an example we took Dutch INET (net guilder index; see Wilmink, 1989 and Reurink, 1991). In this index milk protein has the highest weighing factor (three times higher than that for a fat kg), supposing that protein will be the most evaluated milk component in the future years. Dutch breeders are paying much attention not only to INET, but also to the kg protein and the protein percentage transmission, functional conformation (udder, legs and feet), and also to protein/fat ratio in milk (increasing protein and decreasing fat content; see Vos, 1992). As a result of a well-established breeding goal, Dutch breeders have got excellent results: the average milk yield of the Black-and-White herdbook population in 1990/91 (over 730 thousand cows) was 7 390 kg milk per 315-day lactation, with 4.47 per cent fat, 3.47 per cent protein, 586 kg fat + protein, and 1,860 g per lactation day fat + protein. The average milk production of all milk recorded dairy cows in Holland in 1990 (1 304 667 cows) was 6 873 kg, with 3.46 per cent protein and 238 kg protein per lactation. Dutch breeders use the breeding value index (INET). INET=−0.15×milk kg ("carrier")+2×fat kg+12×protein kg, which is very simple to use and is calculated as classical Hazel's index.

If this Dutch INET in guilders (NLG) is converted into Estonian kroons (1 NLG=7.147 EEK) we get:

$INET_{EEK} = -0.15 \times 7.147$ milk kg $+ 2 \times 7.147$ fat kg $+ 12 \times 7.147$ protein kg $= -1.072$ milk kg $+ 14.294$ fat kg $+ 85.764$ protein kg.

In this index the ratio of economic values of protein and fat was established 3 : 1. Production of protein gives higher net returns than the production of fat. The energetic value of one kg of fat is much higher than one kg of protein, which will cause higher feed costs for fat. In addition, protein is a more valuable product than fat (Wilmink, 1989). The Dutch INET index converted into Estonian kroons was also recommended for comparative estimating breeding value of cows besides the index computed on the basis of our genetic parameters.

Selection for index (practically for protein kilograms) will lead to a slight increase in the protein percentage of milk and almost zero change in fat percentage of milk as the genetic correlation between protein kilograms and protein percentage is positive (0.143), but between protein production and fat per cent practically zero or slightly negative (Тейнберг, 1974).

Main variants for SI calculated for selection on the basis of milk yield, milk fat and milk protein production are performed in Table 2.

Table 2

Economic values and regression coefficients for some selection indexes

SI variants number	Economic values (EEK)			Regression coefficients b_i		
	milk kg	fat kg	protein kg	milk kg	fat kg	protein kg
1.	1.2	31.6	94.7	−1.456	25.514	76.111
2.	1.2	31.6	63.2	−1.066	25.620	51.070
3.	1.2	31.6	31.6	−0.674	25.727	25.950
4.	1.2	31.6	15.8	−0.478	25.780	13.390
5.	1.7	44.7	44.7	−0.953	36.393	36.710
6.	2.0	52.6	52.6	−1.121	42.825	43.197
7.	2.0	52.6	105.2	−1.773	42.648	85.011
8.	2.0	52.6	157.8	−2.425	42.470	126.826
9.	3.0	79.0	79.0	−1.685	64.316	64.875
10.	3.0	79.0	158.0	−2.664	64.050	127.675
11.	3.0	79.0	237.0	−3.643	63.784	190.476

If the relative economic value for milk fat and protein production was taken equal, or protein was priced 2 or 3 times higher than fat, always regression coefficient of SI for milk yield was negative, for fat and protein kilograms they were positive. It can be explained by the fact that increased production of milk without protein and fat (so-called "carrier") causes economic losses, it costs some money.

As it can be seen in Table 2, the absolute and relative prices of milk, milk fat and milk protein affect the regression coefficients of an index. For practical use in perspective we recommend the index where milk price was fixed at 2.0 EEK/kg, milk fat price 52.6 EEK/kg, and milk protein price twice higher — 105.2 EEK/kg. The index (variant 7) was:

$$SI = -1.77 \times \text{milk kg} + 42.65 \times \text{fat kg} + 85.01 \times \text{protein kg}.$$

Also the index No. 11 (Table 2) can be recommended, if the relative price of protein will be established three times higher than that of fat, and milk price will be 3 EEK/ kg. Still it will be unlikely in the nearest future, but realistic enough in 3—5 years:

$$SI = -3.64 \times \text{milk kg} + 63.78 \times \text{fat kg} + 190.48 \times \text{protein kg}.$$

At present, when the price of 1 kg of milk paid to a farmer is only 1.2 EEK, and prices of fat and protein are equal, the index applied must be (No. 3):

$$SI = -0.674 \times \text{milk kg} + 25.73 \times \text{fat kg} + 25.95 \times \text{protein kg}.$$

Milk, fat and protein kilograms in the index are actually the deviations of these from cow's herdmate average (all other cows in the same herd, year and lactation number).

Example for the calculation of an index for a cow with the production in 305-day lactation: 6 500 kg milk, 260 kg milk fat (4.0 per cent) and 195 kg milk protein (3.0 per cent). Herdmate average is: 5 500 kg milk, 210 kg milk fat and 165 kg milk protein. The differences are: 1 000 kg milk, 50 kg fat and 30 kg protein.

Using the SI number 7 (Table 2) we get the cow's relative breeding value index:

$$SI = -1.773 \times 1\,000 + 42.648 \times 50 + 85.011 \times 30 = 2909.73 \text{ EEK}$$

and index by INET (in EEK):

$$INET = -1.072 \times 1\,000 + 14.294 \times 50 + 85.764 \times 30 = 2215.62 \text{ EEK}$$

which is smaller due to the lower relative economic value of milk fat in the Dutch index.

The average SI of daughters can be used for the estimation of the breeding value of a bull.

Comparing our results with those of other authors who have calculated SI for the selection on the basis of milk, milk fat and protein yields, it can be concluded that it is necessary to have protein price equal to that of fat, or 2—3 times higher, so that the selection for protein would be economically worthwhile; this also includes determining milk protein per cent (Brascamp, Minkema, 1972).

As to economic weights and their influence upon index coefficients (b_i), our results confirmed the statement of Vandepitte and Hazel (1977), also Harris (1963): changes in relative economic values ±50 per cent change the SI regression coefficients only slightly.

We used the average genetic correlations and heritabilities given in literature and obtained from our previous investigations (Тейнберг, 1974, 1983, 1986), as recommended by Hill (1981), Hill and Thompson (1978), and Mäntysaari et al. (1984).

Our selection indexes are quite similar to the Dutch official INET index, which is considered as one of the best in Europe for estimating the breeding value of cows for milk production traits.

Selection indexes are being used in establishing the breeding value of cows in best herds of Estonian Black-and-White breed, also for evaluating insemination bulls on the basis of their daughters' average index. This principle was used from 1985 on, but now it is modified, using new selection index.

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PIIMAVEISTE ADITIIVSE GENEETILISE VÄÄRTUSE PROGNOOSIMINE

2. Lehma enda toodanguandmetel põhinev selektsiooniindeks

Rein TEINBERG

On esitatud Smithi-Hazeli selektsiooniindeksi (SI) arvutamise teoreetilised põhimõtted ja vaadeldud SI kasutusvõimalusi piimaveiste aretusväärtuse hindamisel mitme tunnuse järgi. Konkreetsed SI variandid on arvutatud eesti mustakirjut tõugu lehmade valikuks piimatoodangu ning piima rasva- ja valgutoodangu põhjal. Üldistatud geneetiliste ja fenotüübiliste parameetrite põhjal arvutatud SI väärtused on toodud tabelis 2.

Lehmade valikuks kolme piimajõudlusomaduse põhjal on soovitatud indeksit (piima hind 2.00 EEK/l):

SI = —1,77×305-päevase laktatsiooni piimatoodangu hälve kg+42,65 ×piimarasvatoodangu hälve kg+85,01×piimavalgutoodangu hälve kg.

Indeksis on piimavalku hinnatud kaks korda kõrgemalt kui piimarasva. Kui suhe on 3 : 1, näeb indeks välja järgmine:

SI = —2,45×piim kg+42,47×rasv kg+126,83×valk kg.

Tunnuste suhtelise majandusliku väärtuse (ka aretuseesmärgi) muutmine mõjutas indeksi regressioonikordajaid.

ПРОГНОЗИРОВАНИЕ АДДИТИВНОЙ ГЕНЕТИЧЕСКОЙ ЦЕННОСТИ У МОЛОЧНОГО СКОТА

2. Селекционный индекс, базирующийся на собственной продуктивности коровы

Рейн ТЕЙНБЕРГ

Рассматриваются теоретические принципы вычисления селекционного индекса (СИ) Смита—Хейзеля применительно к селекции молочных коров по нескольким продуктивным признакам. Варианты индекса были вычислены для трех селекционных признаков: удой за 305-дневную лактацию, количество молочного жира и белка.

На основании обобщенных генетических и фенотипических параметров популяции был вычислен ряд вариантов индексов, основные из которых приведены в табл. 2.

Для фенотипической селекции по удою, количеству жира и белка был рекомендован следующий индекс:

СИ = —1,77 × удой, кг + 42,65 × молочный жир, кг + 85,01 × молочный белок, кг.

В этом индексе белок оценен в два раза выше жира. Изменения относительной экономической ценности признаков отражались в коэффициентах регрессии индексов.