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BIO-ECONOMICAL MODEL APPLICATION IN CATTLE BREEDING

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ABSTRACT

Dairy production systems are complex and cannot be described by a single profit function. In a bio-economical model, relevant biological and economical aspects of the production system are described as a system of equations. These models describe the life cycle of a dairy cow, including inputs and outputs, as a function of biological traits and economic parameters. For the derivation of the economic values of Estonian Holstein dairy breed, a bio-economical model of a closed herd, which included the whole integrated production system was used. The total discounted profit for the herd was calculated as the difference between all revenues and costs that occurred during the whole life of animals born in the herd within one year and which were discounted to the birth year of these animals. Core elements of the program are modules describing the age distribution of the herd based on different possible fate of cows, the production level in each lactation and cost rations on a daily basis. Change of profit has been considered as a function of genetic change, not other changes of phenotype. Economic parameters reflect the marketing and management system in which genetic improvement will be expressed. Economic values for use in selection indexes were derived for milk-, fat- and protein production, length of productive life, calving interval and age at first breeding. Analysis of dairy production system with bio-economical model enables the breeders to find out revenues, costs and different parameters for dairy production system, and also to estimate milk production profit.

Key words: cattle / dairy cows / breeds / Holstein / milk production / breeding programs / economics / bio-economical model / profit / Estonia

UPORABA BIO-EKONOMSKEGA MODELA V GOVEDOREJI

IZVLEČEK

Različni načini proizvodnje mleka so kompleksni in jih ni mogoče opisati z eno samo dobičkovno funkcijo. V bioekonomskem modelu opišemo relevantne biološke in ekonomske vidike s sistemom enačb. Ta model opisuje življenjski cikel krav, vključno z vlaganji in pridelki, kot funkcijo bioloških lastnosti in ekonomskih parametrov. Za izračun ekonomske vrednosti črede estonskega holštajnskega mlečnga goveda smo uporabili bio-ekonomski model zaprte črede, ki je upošteval tudi integrirani način proizvodnje. Celotni dobiček za čredo smo izračunali kot razliko med prihodki in stroški, ki so nastali v celotnem življenjskem obdobju živali, ki so bile rojene v populaciji v obdobju enega leta po korekciji na rojstno leto. Glavni elementi programa so moduli, ki opisujejo starostno strukturo črede, različne lastnosti živali, raven proizvodnje v posameznih laktacijah in dnevne stroške. Razlike v dobičku smo pojmovali kot razlike v genetski vrednosti živali. Ekonomski parametric odražajo tržne razmere in sistem upravljanja, v katerem se izraža genetski napredek. Ekonomske teže, ki smo jih uporabili v modelu temeljijo na proizvodnji mleka, masti in beljakovin, dolžini proizvodnega obdobja, dobi med telitvama in starosti ob pripustu. Analiza prireje mleka z bio-ekonomskim modelom omogoča rejcem oceno stroškov, prihodka in dobička od prireje mleka v različnih proizvodnih sistemih.

Ključne besede: govedoreja / govedo / krave / molznice / pasme / holštajn / mleko / prireja / rejski programi / ekonomika / bio-ekonomski model / dobiček / Estonija

INTRODUCTION

Milk production in Estonia is an activity of increasing economic importance. Milk production accounts for nearly 30% of gross agricultural production. It is approximately as big as the share of dairy processing in food industry. As of 1st January 2005, herds with total of 100,991 cows were under milk recording, which amounted to 87.9% of the total number of milk cows. The milk yield in milk recorded herds has constantly increased over the recent years. The average milk yield per cow in 2004 was 6,055 kg. During 1995-2004 there has been a 2400 kg increase in average milk yield per cow. This has been achieved by the improvement of management conditions and by breeding. Breeding values for production, conformation and udder health traits for bulls and cows in Estonia are estimated by the Estonian Animal Recording Centre four times a year. BLUP test day animal model for production and udder health traits and the BLUP animal model for conformation traits for breeding value estimation are used. Data for Estonian Holstein Cattle has been included into the Interbull (International Bull Evaluation Service) Holstein evaluation for production traits since February 1998 and for udder health traits since May 2001. In the evaluation programme for young bulls of Estonian Holstein, ca 25 bulls are tested each year, parallel testing is carried out on 10-12 foreign bulls. The selection of bulls is made from among imported American and Canadian embryos, the Estonian Holstein best bull dams and imported young bulls. The sons of imported cows whose sires are world-known top-bulls, are often used. The bulls come mainly from USA, Canada, Germany and the Netherlands. It is compelling, therefore, to evaluate the possibility for the implementation of different breeding programmes within the Estonian Holstein population.

As a first step in developing such a programme a suitable breeding goal for the cattle population has to be defined, giving emphasis to production as well as to functional traits in order to achieve a more sustainable production. For a sustainable production, traits that have been identified as important for selection are also functional traits (Groen *et al.*, 1997). The term functional traits is used to summarise those characters of an animal which increase efficiency not by higher output of products but by reduced costs of input. Major groups of breeding goal traits belonging to this category are health, fertility, calving ease, efficiency of feed utilisation, and milkability.

When considering developing a criterion for selection in order to maximize the profit in the progeny generation, the basis of selection of parents is an important issue. In development of the breeding goal many alternative traits can be considered. From international trends in dairy cattle breeding, it is apparent that the Estonian dairy industry must move in a direction that puts more emphasis on functional traits in the selection programmes. This is reinforced by research findings pointing at the unfavourable associations between production and several functional traits in dairy cows, and by broad scientific and practical experience over a long period in the Scandinavian countries (Philipsson and Lindhé, 2003) and in Ireland (Dillon *et al.*, 2004). A breeding goal that consists of production traits and herd life is frequently used as a simplified breeding goal (Dekkers and Jairath, 1994). In such a breeding goal, traits associated with health, reproduction, and workability are compounded into the trait herd life. The advantages of such a breeding goal are that fewer economic and genetic parameters need to be estimated and that it is easier to explain it to producers (Dekkers *et al.*, 2004). Including herd life in the breeding goal can be profitable when genetic variance for herd life exists and when genetic changes improve the efficiency of the dairy cattle production system. The economic value of a trait expresses the extent that economic efficiency of production is improved by an increase of that trait at the moment of expression (Koenen *et al.*, 2000).

The aim of this paper is to estimate economic values for milk production, fat production, protein production, length of production life, calving interval and age at first service. for Estonian Holstein breeding programme and to describe economical aspects of dairy production system in Estonia using a of bio-economical model.

METHODOLOGY

In different countries there are differences in selection interests and in production circumstances. Due to this the theory of economic weights has been widely analyzed (Brascamp *et al.*, 1998; Groen, 1989; Groen *et al.*, 1997). The economic value of a trait has been defined as the change in profit of the farm expressed per average present lactating cow per year, as a consequence of one unit of change in genetic merit of the trait considered (Groen, 1989). According to the Report of an EAAP-working group (Groen *et al.*, 1997), it is not possible to come up with a "best" methodology in deriving economic values – what is the best, will depend on traits and production circumstances considered. The better method from theoretical point of view is not necessarily that is the most practical to implement. However, in deriving economic values it is very important to be aware of the fact that genetic improvement is a technological development. Aspects involved in deriving socio-economic benefits of technological developments should help to make appropriate choices when choosing a method to derive economic value.

The principal tool in methods to derive economic value is modelling. A model is an equation or a set of equations that represents the behaviour of a system. At one extreme of the continuum are those that are primarily biological process models to which an economic analysis component has been added (Brown, 2000). At the other are the economic optimisation models which include various bio-physical components as activities among the various choices for optimisation. Economic optimisation in its pure sense refers to systematically evaluating a number of alternative activities so as to determine the one which will result in the "best" or optimum performance – however "best" is defined and measured – and hence is a relative term. In the middle are the integrated bio-economic models. A multi-equation simulation model is referred to as bio-economic model (Groen *et al.*, 1997). Using simulated systems, economic values are determined by studying their reaction to a change of the endogenous element representing the genetic merit of the animal for a specific trait without changing other traits. With efficiency functions, this is performed by partial differentiation. With data simulations, possibilities of applying different processes, levels and sizes of the production system are numerous.

General model

For the derivation of the economic values of aggregate genotype traits for Estonian Holstein, a bio-economic model of a closed herd, which included the whole integrated production system of a dairy breed, was used (Wolfová and Wolf, 1996). The total discounted profit for the herd was calculated as the difference between all revenues and costs that occurred during the whole life of animals born in the herd within one year and that which was discounted to the birth year of these animals:

$$Z_T^0 = Z^0 S_{StFU}$$

$$Z^0 = \sum_{k \in \Omega} N_k (R_k q_{R_k} - C_k q_{C_k})$$

with
Ω={*BCa*, *CCa*, *FBu*, *BHei*, *CHei*, *CCo*1, *CCo*2+}
where
Z_T^0 = total discounted profit in the population of the given breed (closed herd)
S_{StFU} = number of standard female units (StFU = one cow place occupied during the entire year)
Z^0 = discounted profit per StFU
N_k = average number of animals in category *k* per StFU
R_k, C_k = average revenues and costs, respectively, per animal of category *k*
q_{R_k}, q_{C_k} = discounted coefficient for revenues and costs, respectively, in category *k*

The discounting coefficients for the revenues were calculated by the following equation:

$$q_{R_k} = (1+u)^{-\Delta t_{R_k}}$$

where
Δt_{R_k} = average time interval between the birth of animals of category *k* and the time of collecting revenues
u = discounting rate (expressed as a fraction).

The discounting coefficients for the costs were calculated in the same way and with the same discounting rate.

The not discounted profit (i.e., the average profit per year in the entire balanced system) was calculated by setting u=0 so that all *q*'s took the value 1.

The discounted economic weight of a given trait *i* was defined as the partial derivative of the total profit function for the closed herd with respect to the given trait, whereby all traits were assumed to take their mean values:

$$a_i = \left\{ \partial Z_T^0 / \partial x_i \big|_{\mathbf{x}=\boldsymbol{\mu}} \right\} / S_{StFU}$$

where
x_i = value of the trait *i* under consideration
x = vector of the values of all traits (dimension of x = number of traits)
μ = vector of the means of all traits.

Core elements of the program are modules describing the age distribution of the herd based on different possible fates of cows, the production level in each lactation and cost rations on a daily basis. Detailed definitions of all evaluated traits and complete description of the method and the individual models used for the calculation of economic weights can be found (Wolfová *et al.*, 2001). A computer program developed by Wolfová and Wolf (1996) was used for the calculations of economic values for the various traits. It was assumed that the number of breeding heifers was constant when increasing the length of production life in cows.

Revenues of the farm came from milk production, and beef production from bull calves and culled cows. Costs were divided into costs variable per cow, costs fixed per cow and costs fixed per farm. Variable costs included costs of feed, diseases, dystocia, milking, insemination, replacement and costs of producing bull calves. Fixed costs included costs of labour, milking, parlour, electricity, housing and milk recording.

The situation based on production and economic data of the joint stock companies in 2002 was defined for the Estonian Holstein population as presented in Table 1. The statistical data were taken from the Results of Animal Recording in Estonia (2002).

Table 1. Applied economical and biological parameters to derive economic values

Price of milk, EUR kg^{-1}	0.12	Length of pregnancy, days	278
Price for 1% protein content in milk, EUR	0.02	Calving interval, days	410
Price for 1% fat content in milk, EUR	0.01	Number of inseminations for pregnancy in cows	2.0
Price of one insemination, EUR	19.60	Interval between calving and 1st service in cows, days	83.3
305-day milk production in 1st lactation, kg	5539	Age of heifers at 1st service, days	624
Milk protein content, %	3.24	Discounting rate, % per year	10
Milk fat content, %	4.09		
Average number of lactations	4		
Maximum number of lactations	10		

Definition of traits

Reference values for traits under analysis are in Table 1. These reference values corresponded to the first lactation production level of Estonian Holstein cow, with the age at first calving of 30 months and 410-day calving interval.

Milk yield is defined as the amount of milk (kg) that is produced by one cow in the standardised first lactation (305 days) and that is corrected on average age at first calving and the average length of calving interval.

Milk fat is defined as fat amount (kg) produced by one cow in the standardized first lactation. It is assumed that the fat content stays constant over lactations.

Milk protein is defined in the same way as milk fat.

Length of productive life is defined as the average number of lactations per cow in the herd. Productive life is understood as functional productive life. This means that cows culled for low milk production are not included into the calculation of the average length of productive life. These culled cows form a special category of animals. For simplicity, it is assumed that this selection occurs only in the first lactation. When calculating the economic weight of the trait, it is assumed that changes in the length of productive life of cows are influenced by the improvement in the health conditions of cows.

As reaction upon an increased productive lifetime of cows, the scenario where all heifers suitable for breeding are mated, was taken into account for calculating the economic weight of length of productive life of cows. The heifers needed for replacement are selected during first lactation for their milk production. The increase in selection gain is taken into account in the calculations.

Cattle categories

The categories (k) of animals were the following:

BCa = breeding calves with rearing period from birth to 6 months of age (both males and females)
CCa = calves culled within 6 months of age (only calves not suitable for breeding)
FBu = fattening bulls, from 6 months of age to slaughter
BHei = breeding heifers (used for replacement of the cow herd) from the age of 6 months to 1st calving
CHei = heifers culled before calving (not suitable for breeding or not pregnant)
CCo1 = cows culled in the first lactation
CCo2+= cows culled in the second and later lactations.

RESULTS

After running the model for the initial situation, the average cow in the herd had an average herd-life of 4 years and was able to produce 5539 kg of fat-and-protein corrected milk per year from a potential phenotypic production of 5832.6 kg. The average present cow produced 227 kg fat and 179 kg protein per year. The program enables to derive costs and parameters (Table 2) for the Estonian Holstein population, economic weights of milk components and some functional traits (Table 3) and total profit per female standard unit. Milk and beef revenues represent 85.3% and 14.7% of the total revenues, respectively. Total profit per standard female unit in closed herd amounted to EUR 81.34. The most important traits to consider in the next steps towards introduction of net merit index in Estonian Holstein breeding schemes are protein production and length of productive life.

The length of life of dairy cow has substantial impact on the economic performance. The largest effect is probably that a longer average life decreases the cost of replacement per year. Also, a longer average life will lead to a higher production of cows in later high- producing lactations (Strandberg and Sölkner, 1996). An increased length of productive life from about three to four lactations increased milk yield per lactation or profit per year by 11–13% (Renkema and Stelwagen, 1979; Essl, 1984). Our aim should not be to improve longevity in itself. Our aim should be to improve the overall objective, which may be expressed as lifetime profit, efficiency or some other measure of utility. In doing so, we will probably also improve animals' ability to live longer by improving traits that determine longevity. However, the actually observed longevity may not change at all or may not change as much as expected from the changes in the other traits (Strandberg and Sölkner, 1996).

Table 2. Derived costs (EUR) and parameters for Estonian Holstein population

Fattening period of bulls, days	369	Number of calves born per standard female unit	0.96
Average length of production life of cows, days	1640	Number of calves per standard female unit	0.13
Age at first calving, days	928.8	Number of fattened bulls per standard female unit	0.37
Live weight of heifers at 1st service, kg	424	Number of heifers with 1st calving per standard female unit	0.29
Live weight of heifers at 1st calving, kg	579	Live weight of bulls at slaughter, kg	402
Feed cost per 1 kg milk with given fat and protein content, EUR kg^{-1}	0.02	Revenues from one fattened bull, EUR	206.17
Average culling rate in 2nd and later lactations	0.56	Revenues from annual milk production per cow, EUR	1198.41
Feed costs for gain d^{-1} per breeding calf	0.06	Feed costs for gain d^{-1} per fattened bull	0.08
Feed costs for maintenance d^{-1} per breeding calf	0.15	Feed costs for maintenance d^{-1} per fattened bull	0.25
Variable labour costs d^{-1} per breeding calf	0.07	Variable labour costs d^{-1} per fattened bull	0.05
Total costs d^{-1} per breeding calf	0.87	Total costs d^{-1} per fattened bull	0.61
Total costs for breeding calves per standard female unit	115.04	Total costs for fattened bulls per standard female unit	82.67

Longevity is an overall indicator of the suitability of cow relative to a given environment (Powell, VanRaden, 2003). The correlation between yield and longevity suggest that the traits influencing owner satisfaction change over time. In earlier years, culling was more for yield (correlation between milk yield and true longevity 0.67… 0.92 in 1966), whereas improvement for yield has sufficient that other traits are now more important (correlation 0.13 in 2002, Powell and VanRaden, 2003).

According to Rendel and Robertson (1950), a longer productive life in dairy cattle increases profit at farm level in four ways:

- by reducing the annual cost of replacements per cow in the herd;
- by increasing the average herd yield through an increase in the proportion of cows in the higher producing age groups;
- by reducing the replacements which have to be reared, and therefore allowing an increase in size of the milking herd for given acreage;
- by an increase in the culling possible.

The optimum replacement policy and the economic importance of longevity strongly depends on the relative magnitude of costs of growing (or buying) a replacement heifer versus the salvage value of a cow (Van Arendonk, 1985).

Table 3. Economic values[1] of milk components and some functional traits for Estonian Holstein cattle

Trait	Unit	305-day production	Economic value, EUR
Milk	kg	5539	0.059
Fat	kg	249	–0.32
Protein	kg	197	1.64
Length of productive life	lactation	-	13.72
Calving interval	day	-	–0.005
Age at first service	day	-	–0.03

[1] Economic values are expressed in EUR per unit of given trait and per standard female unit

CONCLUSIONS

Bio-economical modelling enables to calculate economic weights of milk production and functional traits on the level of closed herd which includes the whole cattle population of a certain breed in the given breeding area. Economic values presented here are mainly necessary for the construction of economic selection indexes for bulls or cows, but they can be used for other purposes as well. The model can also be applied in analysis of dairy production system, since individual costs and returns as well as total profit are calculated. Milk and beef revenues represent 85.3% and 14.7% of the total revenues, respectively. Total profit per standard female unit in closed herd amounted to EUR 81.34.

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