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Economic values for production and functional traits in Holstein cattle of Costa Rica

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Abstract

Economic values for production traits (carrier, fat, protein, and dressing percentage) and functional traits (conception rate, survival rate, body weight, and rumen capacity) were calculated for Holstein cattle of Costa Rica. Economic values were derived using a bio-economic model that combined genetic potential performance, feeding strategies and optimum culling and insemination policies to obtain actual phenotypic performance. Two evaluation bases were considered: fixed herd-size and fixed milk-output. With a fixed herd-size economic values were 0.04 (carrier), 5.25 (fat), 3.95 (protein), 0.92 (dressing percentage), 1.30 (conception rate), 2.42 (survival rate), 0.81 (body weight) and 84.53 (rumen capacity). With a milk-output limitation, economic values for all traits except survival rate were lower than for fixed herd-size. The respective values were − 0.04, 3.53, 2.91, 0.88, 0.85, 3.18, 0.51 and 45.59. Sensitivity analysis indicated that economic values of fat, protein and rumen capacity increased significantly with higher prices of milk solids. Other traits were less sensitive to a change in price of milk solids. Changes in price of concentrate did not alter economic values significantly. Under a fixed feeding strategy, economic values for functional traits increased substantially, while those for production traits decreased. The results of this analysis suggest that genetic improvement of fertility, health and cow-efficiency traits will have a clear positive effect on profitability of Holstein cows in Costa Rica, especially when feeding conditions are not optimal.

Keywords: Economic values; Production traits; Functional traits; Dairy cattle; Costa Rica

1. Introduction

Milk production in Costa Rica is an activity of increasing economic and social importance. Costa Rica is the only country in Central America that is self sufficient for milk production, with a consumption per capita of 152 kg, among the three highest in

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Latin America (Umaña, 1998). There are currently 35 000 farms producing approximately 600 000 TM of milk per year, with an estimate of 60% of this milk being processed. Specialised dairy farms in the highlands are responsible for the production of a significant proportion of the processed milk. The total number of specialised dairy cows is above 200 000 head, of which about 80% are Holstein cows.

Although there has been a substantial increase in average milk yield per cow, this has been achieved mainly by the improvement of management conditions and to a lesser extent by breeding (Vargas and Solano, 1995b). In the past, breeding of specialised dairy cattle in Costa Rica has relied mainly on importation of germplasm from temperate countries. It is important to know whether there is compatibility among the breeding goal in Costa Rica and the exporting countries, in order to determine the weight that should be given to information from imported sires. Besides, there is some evidence of substantial genotype × environment (G × E) effect on the performance of imported sires (Syrstad, 1990; Stanton et al., 1991; Vargas and Solano, 1995b). It is compelling, therefore, to evaluate the possibility for the implementation of a local breeding programme within the specialised dairy cattle population.

A first step in developing such a programme would be to consider current and future production circumstances in the dairy sector in order to define the type of cow that will better suit the future market conditions. A suitable breeding goal for the local population has to be defined, given emphasis to functional as well as production traits, in order to achieve a more sustainable production (Olesen et al., 2000). For a sustainable production, traits that have been identified as important for selection are adaptability, reproduction, milk yield, and growth performance (Peters, 1993; Groen et al., 1997; Olesen et al., 2000). Some research has been addressed to the analysis of functional traits such as fertility (Boichard, 1990) and cow-efficiency (Groen and Korver, 1989; Vandehaar, 1998; Veerkamp, 1998; Koenen et al., 2000).

The theory of calculating economic values for situations with different selection interests and production circumstances has been extensively analysed (Brascamp et al., 1985; Smith et al., 1986; Gibson, 1989; Groen, 1989a,b; Amer and Fox, 1992; 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, 1989a). Production circumstances in Costa Rica indicate the importance of breeding workable cows that are able to efficiently use the abundant grass available, while still producing at a profitable level. Recently, a bio-economic model was developed for Costa Rican conditions (Herrero et al., 1996; Herrero, 1997; Vargas et al., 2001). The model combines aspects of nutrition, reproduction, production and economics at the animal and farm level, which makes it especially suitable for calculating economic values. The model predicts feed intake and cow performance on the basis of availability and quality of grass and other supplements; and optimises insemination and culling policies (Vargas et al., 2001). Costs and revenues are obtained on the basis of real phenotypic performance, which not only depends on genetic potential performance, but also on availability of feed resources and feed intake capacity. In the past, economic values have usually been estimated with models that derive feed intake from nutrient requirements only. The use of an integrated model, as developed by Vargas et al. (2001) could have an important impact on estimates of economic values for production, and especially for functional traits.

In the present study, biological and economic parameters reflecting the situation of Holstein dairy cattle in Costa Rica, were entered into the bio-economic model of Vargas et al. (2001). This model is used to determine economic values for production traits (milk and beef), and functional traits (survival rate, conception rate, body weight, and rumen capacity) under different production and price situations.

2. Materials and methods

This study was performed using the bio-economic model developed by Vargas et al. (2001). An additional section was added to calculate economic values, based on the principles given by Groen (Groen, 1989a,b). In this paper, the applied bio-economic model will be described in general terms. For more detailed information, readers are referred to Vargas et al. (2001). The general description of the model is followed by a description of the method used for calculating economic values. Subsequently, an accurate definition is given of the traits under analysis, the profit equation being applied, and the production circumstances for which the economic values were calculated.

2.1. General model

The present study used a normative approach (data simulation) to obtain the economic values for the traits under analysis. This approach is regarded as the most suitable when there is sufficient knowledge of the system under analysis (Groen et al., 1997). The availability of a bio-economic model adapted to the local production circumstances (Vargas et al., 2001) provided this knowledge and facilitated the analysis of different production circumstances. The selection interest assumed for this analysis was the maximisation of profit at the farm level (Groen et al., 1997). This interest was selected because output and input limitations for milk production in Costa Rica are usually imposed at the farm level. Besides, it is normally the farmer who takes breeding decisions.

The general structure of the model used for calculating the economic values is given in Fig. 1. The model started with a given genetic potential for milk and beef production of a dairy cow. Next, potential phenotypic performance was defined by a set of cow-states as defined by Vargas et al. (2001). Cow-states were specified by four class-variables: milk-yield level (15 classes), lactation number (12 classes), lactation stage (16 classes) and calving interval (six classes). Next, the potential phenotypic performance defined by the cow-states was entered into a dynamic model of digestion (Herrero, 1997; Vargas et al., 2001). This model predicted the actual phenotypic performance of the cow on the basis of potential phenotypic milk production, availability and quality of feeds; and genetic potential for cow-efficiency variables, i.e. body weight and feed intake capacity. Subsequently, the information on actual phenotypic performance was entered into a dynamic programming model to optimise voluntary culling and insemination policies at the herd level, given a certain genetic potential for cow-fertility traits, and economic parameters. From this model, the actual phenotypic performance of an average cow for a herd in equilibrium was obtained together with the average costs and revenues on a single-cow basis. This first part of the model was run for two different situations, i.e. an initial situation where the trait under analysis was set to its current value within the population, and a final situation in which a 1% increase in the genetic merit of the respective trait was assumed. Changes in genetic level were made for each trait separately, but the final phenotypic changes could involve more than one trait as a result of interactions between feeding, production, health and fertility.

2.2. Definition of traits

Reference values for traits under analysis before and after genetic increase are in Table 1. These reference values corresponded to a Holstein heifer of average production level in Costa Rica, with an age at first calving of 28 months and 1-year calving interval.

2.2.1. Production traits

This group included milk and beef traits. Milk traits considered in the present analysis were 305-day carrier (CARR), fat (FAT) and protein (PROT) yield of a Holstein heifer (see footnotes Table 1). Lactation yield was obtained from the average lactation curve for Holstein cows in first and later lactations. Lactation curves were obtained by fitting a diphasic model to test day records obtained from the local Holstein population (Vargas et al., 2000) with age adjustment factors obtained from Vargas and Solano (1995a). A total of 15 production levels were simulated on the basis of the average lactation curve following the methodology described by Vargas et al. (2001). Total protein yield (kg) and fat yield (kg) during the lactation were derived from total milk yield on the basis of average protein and fat content obtained from local data (AMHL, 1992; Vargas et al., 2000). Correction factors for age and stage of lactation for fat and protein yield were also obtained from local data (AMHL, 1992).

The only beef trait included in this analysis was dressing percentage (DRPR). Average dressing per-

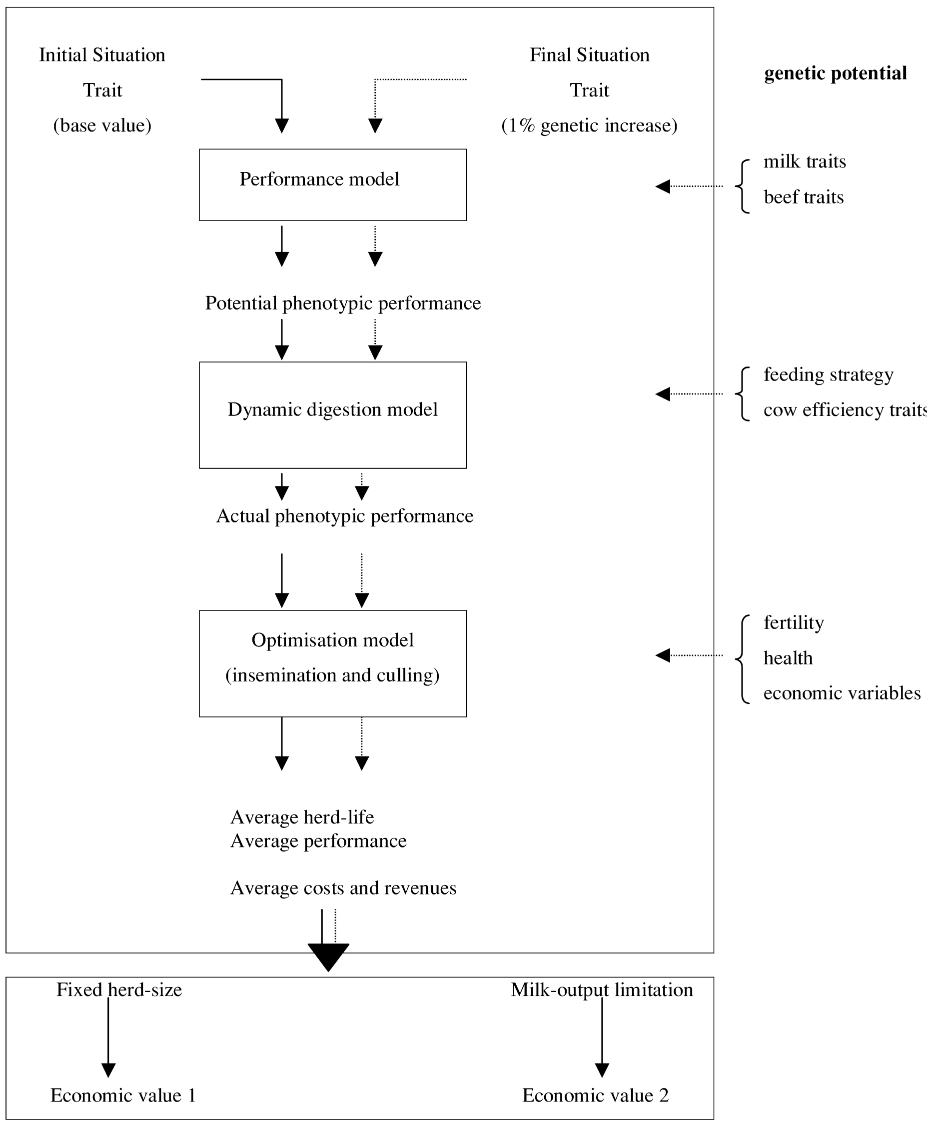

Fig. 1. General structure of the model used in the calculation of economic values for production and functional traits.

centage for the local population was obtained from data provided by slaughterhouses. Age adjustment factors for dressing percentage were not available for the local population, therefore, factors provided by Van Arendonk (1985) were used in this study. Genetic improvement of this trait was assumed by increasing the dressing percentage while keeping body weight at its original value.

2.2.2. Functional traits

Marginal conception rate (CR) for inseminated cows was selected as a fertility trait. This trait was defined as the probability of a cow to become pregnant after insemination, which was dependent upon parity number and month after calving. The conception probabilities used in this analysis were based on local data (Vargas et al., 2001).

Table 1
Reference values for the initial and final situation of genetic potential for production and functional traits considered for calculation of economic values

Parameter	Code	Reference value	
		Initial situation	Increase (1%)
Production traits			
Carrier (kg)	CARR	5170.30[a]	51.7
Fat yield (kg)	FAT	202.10[a]	2.0
Protein yield (kg)	PROT	157.80[a]	1.6
Dressing percentage (%)	DRPR	52.40[b]	0.52
Functional traits			
Marginal conception rate (%)	CR	36.60[c]	0.40
Survival rate (%)	SR	92.0[d]	0.92
Heifer body weight (kg)	BW	412.00[e]	4.1
Rumen capacity (kg DM)	RC	8.652[f]	0.087

[a] 28-month-old Holstein heifer, 1-year calving interval, producing 5530.2 kg 305-day milk yield, fat content 3.65%, protein content 2.85%.
[b] Average dressing percentage for a heifer = 52.4%.
[c] Marginal conception rate (to a single insemination) for a Holstein heifer, 2nd month after calving.
[d] Probability of a Holstein heifer not to be culled by mortality, health, disease or udder and teat problems.
[e] Heifer body weight (28-month-old).
[f] Obtained as $0.021 \times$ heifer body weight.

The trait selected as representative of health status was survival rate (SR). This trait was defined as the probability for a cow to stay in the herd in a specific lactation without being involuntarily culled for health reasons, e.g. mastitis, diseases, mortality, or udder and teat problems. Values used in this study were derived from involuntary culling rates calculated on actual lifetime records of the Holstein population in Costa Rica (Vargas et al., 2001).

The way in which cow-efficiency traits were included in this study deserves special attention. The traits chosen were body weight (BW) and rumen capacity (RC). Body weight was simulated by first fitting an age-dependent Brody function to data from the Costa Rican Holstein population (Solano and Vargas, 1997). Secondly, body weight changes within the lactation due to feed intake, or body-tissue deposition and mobilisation, with adjustment for effect of pregnancy, were simulated on the basis of a dynamic model of digestion (Herrero, 1997). This model allowed the estimation of body weight changes for situations with restricted feeding strategies, as described by Vargas et al. (2001). A genetic increase of heifer body weight was obtained by increasing the mature body weight parameter of the growth curve by one percent, i.e a shift in the entire growth curve.

Feed intake capacity of dairy cows depends on three factors, i.e. feed, management and animal factors (Bines, 1979). Feed factors are those related to feed composition and physical form; management factors are those related to feeding strategy, i.e. restricted vs. ad libitum; and animal factors are those related to production level, size, age, physiological stage and genetic merit for feed intake. Earlier studies calculating the economic value of feed intake capacity for dairy cows, e.g. Groen and Korver (1989); and Koenen et al. (2000) were based on bio-economic models in which actual feed intake is set equal to nutrient requirements norms. This assumption is not realistic for the production circumstances found in Costa Rica, where restricted feeding is the most common practice.

Rumen capacity in the present study was defined as the maximum load of dry matter in the rumen at any moment, as implemented in the dynamic model of digestion by Herrero (1997). This model estimated feed intake capacity on the basis of the allometric coefficient found earlier by Illius and Gordon (1991), in which dry matter content in the rumen scales to $0.021 \times$ body weight. Further adjustments are made taking into account animal factors other than size, i.e. production level and pregnancy; and feed and management factors. In order to simulate an increase in the genetic merit for rumen capacity the allometric coefficient was increased by 1%, this is assuming that the cow would be able to store a larger amount of feed without increasing body size.

2.3. Definition of the profit equation

The profit equation used in the present analysis was defined following the approach by Groen et al. (1997), i.e. variable and fixed costs were given on a cow and farm basis. The basic profit equation used in the calculation of economic values was as follows:

$$P = R - C \tag{1}$$

where P is the farm profit (US$/farm per year); R the farm revenues (US$/farm per year); and C the farm-costs (US$/farm per year).

Farm revenues (R) were calculated using the equation:

$$R = N \times [(\mathrm{KFAT} + \mathrm{KPRO} + \mathrm{KLAC}) \times \mathrm{pSOL} + \mathrm{KFAT} \times \mathrm{pFAT} + (\mathrm{CALF}/\mathrm{LIF} \times \mathrm{pCALF}) + (\mathrm{CAR}/\mathrm{LIF} \times \mathrm{pCAR})] \tag{2}$$

where N is the number of present cows in the herd (lactating + dry cows); KFAT the fat yield (kg/cow per year); KPRO the protein yield (kg/cow per year); KLAC the other solids (kg/cow per year); pSOL the price per kg of milk solids (US$); pFAT the extra-price per kg of fat yield (US$); CALF the average number of calves per cow per lifetime; pCALF the price new-born calves (US$); LIF the cow herd-life (year); CAR the average carcass weight of culled cows (kg); and pCAR the carcass price (US$/kg).

Costs (C) were derived from the following equation

$$C = N \times [\mathrm{CONC} \times \mathrm{pCON} + (\mathrm{FOR} + \mathrm{RFOR}) \times \mathrm{pFOR} + \mathrm{REP}/\mathrm{LIF} + \mathrm{LAB} \times \mathrm{pLAB} + \mathrm{SUNC}] + \mathrm{FIXF} \tag{3}$$

where CONC is the intake of concentrate (kg/cow per year); pCON the price of concentrate (US$/kg); FOR the forage intake (kg/cow per year); RFOR the residual forage (kg DM/cow per year); pFOR the price of forage (US$/kg); REP the price replacement heifer (US$/heifer); LAB the time non-contracted labor (h/cow per year); pLAB the price non-contracted labor (US$/h); SUNC the sundry costs (US$/cow per year); FIXF the fixed farm-costs (administration and financial costs; US$/farm per year).

CONC, FOR, RFOR and REP were considered variable cow-costs as they changed in relation to individual production. LAB and SUN were considered in this study as fixed cow-costs, this is, they were assumed equal for all cows in the herd and therefore changed only according to herd-size. Information on prices and costs per unit of production factor used in the present study is given in Table 2.

Forage produced within the farm was given a cost according to forage-production parameters and fertilisation practices normally found in highland dairies of Costa Rica (Herrero, 1997; Herrero et al., 2000). This calculation was made in order to get more accurate estimates of production costs per kg of milk. The total amount of forage produced at the

Table 2
Parameters used in the calculation of economic values

Parameter	Value
Price milk solids (pSOL, US$/kg)[a]	2.178
Extra-price kg fat yield (pFAT, US$/kg)[a]	0.331
Price concentrate (pCON, US$/kg)	0.16
Price forage (pFOR, US$/kg)[b]	0.0342
Price replacement heifer (REP, US$)	1000.0
Sundry costs (SUNC, US$/cow per year)	327.0
Fixed farm-costs (FIXF, US$/farm per year)[c]	9670.0
Price new-born calf (pCALF, US$)	30.0
Number of calves (CALF)	4.77
Carcass price (pCAR, US$/kg)	1.05
Labor costs (pLAB, US$/h)	1.20
Production of forage (kg green DM/ha per year)[b]	20.857
Stocking rate (AU/ha)	3.5

[a] Local payment system: US$2.178 × kg milk solids + US$0.331 × kg fat.

[b] Assuming 2000 kg DM/ha per grazing period with 150 kg/ha per year nitrogen fertilisation. Rest period between consecutive grazing periods set to 35 days (Herrero, 1997; Herrero et al., 1999).

[c] Fixed farm-costs: administration costs (US$3744/year), linear depreciation (US$2238/year) and 7.0% annual interest rate on investments (US$7432/year). Production factors (land, housing, machinery and labor) used for these calculations were only those directly related to production.

farm level was assumed as fixed. Estimates of forage consumed (FOR) vs. residual forage (RFOR) were also obtained in order to compare efficiency in the use of forage in relation to being improved and feeding strategy.

Rearing costs (feeding, labor, sundries) were all considered within the replacement costs (REP), assuming an unlimited external supply of heifers independent of genetic merit.

2.4. Feeding strategy and production limitations

As described in an earlier section, the actual performance of the cow also depended on the feeding strategy. For the present analysis, cows were assumed to have unlimited access to graze kikuyu grass (*Pennisetum clandestinum,* 600 g NDF/kg DM, 16% CP, 58% potential degradability of NDF and 3.8%/h degradation rate of NDF) while offered a supplementation based on a 4:1 milk-concentrate relationship. That is, a lactating cow was given 1 kg of concentrate (120 g NDF/kg DM, 570 g soluble carbohydrate/kg DM, 180 g CP/kg DM, 33% solubility of CP, 85% digestibility of CP, 30 g fat/kg DM) per 4 kg of potential phenotypic milk yield. This feeding strategy, denoted from here onwards as REL, was selected on the basis of previous research (Herrero et al., 1999; Vargas et al., 2001) which identified this milk:concentrate relationship as the most profitable on a farm basis.

Economic values for the traits described earlier were calculated for two different evaluation bases: fixed herd-size and fixed milk-output. Economic values for different evaluation bases were derived as described previously (Brascamp et al., 1985; Smith et al., 1986; Gibson, 1989; Groen, 1989a,b; Amer and Fox, 1992; Groen et al., 1997). For fixed herd-size, the economic values were derived from the equation

$$\mathrm{EV} = \left(\frac{1}{N}\right) \times (\partial R - \partial C) \qquad (4)$$

with EV being the economic value for the trait under analysis, N being the herd-size, and R and C as described in Eq. (1).

Next, economic values were re-calculated assuming a milk-output limitation, which is the current situation for most of the Costa Rican farms. For this case, the economic value of traits was obtained as

$$\mathrm{EV} = \left(\frac{P_2}{N_2} - \frac{P_1}{N_1}\right) + \mathrm{RF}\left(\frac{P_2}{N_2}\right) \qquad (5)$$

with P as defined in Eq. (1). Thus, P/N denoted the net profit per cow (US$/year) with subscripts 1 and 2 standing for the initial and final situation. RF was a rescaling factor (Groen, 1989b) introduced in order to account for a change in herd-size linked to the output limitation. That is, milk output was assumed fixed at the farm level, but the number of present cows changed as a result of the increment in the genetic merit for a certain trait. RF was therefore dependent on the production factor being limited, as discussed by Groen (1989b), and is given by the equation:

$$\mathrm{RF} = -1 \times [(F_2 - F_1)/F_2] \qquad (6)$$

where F stands for the factor being restricted, in this case milk output (kg/cow per year) before (1) and after (2) genetic improvement of the trait under analysis, respectively.

2.5. Change in prices and feeding strategy

Additional analysis was performed on the sensitivity of the economic values to changes in price of milk solids and concentrate. Changes of (±)20% with respect to the original values were considered under both evaluation basis: fixed herd-size and fixed milk-output. Changes were performed one at the time, keeping all other parameters at their original value.

Economic values were also recalculated for all traits assuming a change in the feeding strategy. The new strategy was selected on the basis of a previous study (Vargas et al., 2001), in which feeding strategies were compared on the basis of their efficiency to fulfil nutrient requirements of dairy cows in a wide range of production status. The strategy with the poorest performance, i.e. FIX, was selected for the recalculation of economic values assuming a fixed herd-size base of evaluation. According to strategy FIX cows were fed fixed quantities of 6, 4 and 2 kg of concentrate during 0–100, 101–200 and >200 days of lactation, respectively. As with strategy REL, cows were assumed to graze on kikuyu grass.

3. Results and discussion

3.1. Initial situation

After running the model for the initial situation, the average cow present in the herd was characterised (Table 3). This cow had an average herd-life of 4.92 years, and was able to produce 5929.4 kg of Fat-and-Protein Corrected Milk (FPCM) per year from a potential phenotypic production of 6055.6 kg FPCM per year. The average present cow produced 212.9 kg fat/year, 176.4 kg protein/year and 327.8 kg of other solids/year. Concentrate intake of the average cow was 1514.5 kg DM/year and forage intake was 2679.0 kg DM/year. Given that the energy content of concentrate was 5.61 MJ ME/kg DM and assuming an average energy content of 6.52 MJ ME/kg DM for kikuyu grass (Herrero, 1997; Herrero et al., 2000), this would mean that approximately 67.3% of the energy supply throughout the year was obtained from the forage. For culled cows, the average body weight in the initial situation was 551.3 kg, with a carcass weight of 283.5 kg.

The distribution of farm costs and revenues for the initial situation is given in Table 4. As observed, milk and beef revenues represent 94.8% and 5.2% of the total revenues, respectively. Variable cow-costs represent 46.9% of the total costs, with feed costs being the most important variable cost (24.1% of variable costs). Fixed cow-cost represented almost 33.7%, with sundry costs being the most important fixed-cost (23.6% of fixed per cow costs). Labor costs represented about 10% of the total costs. Production cost per kg of milk was about US$0.234. The current price paid to farmers is around US$0.275/kg milk (INFOAGRO, 2000). Therefore, the profit per kg of milk for the initial situation was about 18.0%, without considering revenues/costs from other by-products. These figures are close to profitability estimates of highlands dairies in Costa Rica (Vega Valverde, 1994).

3.2. Fixed herd-size

At the farm level, the increase of genetic merit of a certain trait under a fixed herd-size base of evaluation affected total revenues and variable cow-costs (Table 4). Due to the fixed number of cows assumed under this approach, fixed cow-costs and farm fixed-costs did not change after increasing genetic merit. Therefore, these costs did not have any effect on economic values. The economic value of a trait under this evaluation base was directly related to the marginal cow-profit.

It is important to note that economic values are expressed per unit change in the genetic potential for

Table 3
Initial potential and actual phenotypic performance of an average Holstein cow, and marginal changes after 1% increase in genetic merit for each production and functional trait

Parameter	Initial	Marginal (δ) change after 1% increase in genetic merit							
		CARR	FAT	PROT	DRPR	CR	SR	BW	RC
Herd-life (year)	4.92	0.14	−0.01	−0.01	−0.01	0.02	0.16	0.00	0.01
Potential FPCM[a] yield (kg/year)	6055.6	21.36	25.08	12.48	0.12	1.20	−4.92	0.00	0.12
Actual FPCM yield (kg/year)	5929.4	30.84	25.08	12.24	0.12	1.32	−5.16	9.12	24.84
Fat yield (kg/year)	212.9	−0.96	2.88	0.36	0.00	0.00	−0.24	0.36	0.96
Protein yield (kg/year)	176.4	−0.72	0.72	2.16	0.00	0.00	−0.12	0.24	0.72
Others solids (kg/year)	327.8	1.70	1.38	0.67	0.01	0.07	−0.28	0.50	1.37
Concentrate intake (kg DM/year)	1514.5	5.64	6.48	3.36	0.12	0.36	−1.20	0.00	0.00
Forage intake (kg DM/year)	2679.0	1.68	2.40	1.08	0.00	0.24	0.00	24.60	33.12
Residual forage (kg/year)[b]	3286.1	−1.68	−2.40	−1.08	0.00	−0.24	0.00	−24.60	−33.12
Body weight (kg)	551.3	1.26	−0.11	−0.01	0.08	0.08	−0.30	6.36	2.46
Carcass weight (kg)	283.5	0.56	−0.05	0.00	2.89	0.06	−0.10	3.26	1.25

[a] FPCM, Fat-and-Protein Corrected Milk Yield.
[b] Residual forage (kg/cow per year) was re-adjusted when herd-size changed as a result of production limitations.

Table 4
Initial distribution of costs and revenues per farm per year, and marginal changes and economic values after 1% increase in genetic merit for production and functional traits under a fixed-herd-size base of evaluation

Parameter	Initial	Marginal (δ) change after 1% increase in genetic merit							
		CARR	FAT	PROT	DRPR	CR	SR	BW	RC
Herd-size	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Milk revenues (US$/year)	81430.1	−14.1	589.9	353.7	0.7	7.9	−74.1	125.9	347.7
Beef revenues (US$/year)	4437.4	−119.1	9.3	8.3	36.1	−15.1	−137.9	30.2	8.0
(1)Total revenues (US$/year)	85867.6	−133.2	599.2	362.0	36.8	−7.2	−212.0	156.1	355.7
Feed costs (US$/year)	16697.3	48.0	55.9	28.6	1.0	3.3	−9.6	42.1	56.6
Residual forage costs (US$/year)	5619.3	−2.8	−4.2	−1.8	0.0	−0.4	0.0	−42.1	−56.6
Replacement costs (US$/year)	10160.9	−286.0	22.6	19.0	12.0	−36.0	−313.5	−10.3	−12.0
(a)Variable cow-costs (US$/year)	32477.4	−240.8	74.3	45.8	13.0	−33.1	−323.1	−10.3	−12.0
(b)Fixed cow-costs (US$/year)	23358.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(c)Fixed farm-costs (US$/year)	13414.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(2)Total costs (US$/year) ($a+b+c$)	69249.4	−240.8	74.3	45.8	13.0	−33.1	−323.1	−10.3	−12.0
Net effect[a] (US$/farm per year)	16618.1	107.6	524.9	316.2	23.8	25.9	111.1	166.4	367.7
Gross profit (US$/year) ($1-a-b$)	30032.1	107.6	524.9	316.2	23.8	25.9	111.1	166.4	367.7
Production cost (US$/100 kg milk)[b]	23.4	−0.2	−0.1	−0.1	0.0	−0.1	−0.1	−0.1	−0.1
Cow-profit[c]	600.6	2.2	10.5	6.3	0.5	0.5	2.2	3.3	7.4
Economic value[d] (US$/cow per year)		0.04	5.25	3.95	0.92	1.30	2.42	0.81	84.53

[a] Net effect: [δ milk revenues − δ beef revenues − δ variable cow costs].
[b] Production cost: total costs (US$/farm per year)/total milk yield (kg/100/farm per year).
[c] Cow-profit: Gross profit (US$/farm per year)/herd-size.
[d] Economic value: Net effect/initial herd-size/increment in trait (see Eq. (4) and Table 1).

a trait, and not per unit change in actual performance. Actual performance is the result of interaction between genetic potential and the environment, while the economic value should be expressed by definition in terms of expected change in genetic potential.

Our results indicated that CARR had an economic value close to zero (Table 4). Selection on CARR has an effect on cow-performance and optimum herd-life (Table 3). There is a significant increase in potential and actual phenotypic milk yield (Table 3). However, this increase occurred mainly within the non-valuable components of milk. The valuable components, i.e. fat and protein, actually decreased (Table 3), which is due to the increase in herd-life and the consequent change in herd composition. The increase in herd-life was caused by the fact that culling was performed at a later stage in lactation (216 vs. 206 days), due to increased production. Despite the decrease in milk and beef revenues, the economic value of CARR is still slightly positive, due to a significant reduction of replacement costs caused by decreased replacement rates. As observed in Table 3, there is also an increase in BW. This increase is caused by a higher availability of nutrients for body weight gain because, as stated earlier, the increase in milk yield is mainly in volume rather than solids. Economic values for CARR reported in the literature are usually negative (Gibson, 1989; Groen, 1989a,b; Steverink et al., 1994; Visscher et al., 1994; Pieters et al., 1997). Most of these studies, however, considered a negative base price for milk, and the decrease of replacements costs after genetic improvement was not included. Nevertheless, the economic value found in our study was also close to zero.

As expected, FAT and PROT resulted in positive economic values. Selection for FAT and PROT increased mainly milk revenues, and beef revenues to a lesser extent (Table 4). The increase in milk revenues was mainly related to an increase in average fat and protein yield (see Table 3). Feed costs also increased as a result of higher concentrate and forage intake, which were related to increased milk yield. Smaller effects on beef revenues were related to a minimal reduction in herd-life (Table 3). Notice that calf and carcass values are divided by herd-life in Eq. (3). The change in herd-life also causes the observed increase in replacement costs (see Eq. (4)). Earlier studies generally reported higher economic values for protein compared to fat (Gibson, 1989; Groen, 1989a,b; Steverink et al., 1994; Visscher et al., 1994; Pieters et al., 1997). The opposite situation was observed in our study, and this is because fat is paid at a higher price than protein in Costa Rica (see Table 2).

DRPR had a positive economic value of US$0.92 per 1% increase (Table 4). This economic value was caused mainly by the increase in beef revenues as a consequence of the increase in average carcass weight of culled cows (Table 3). There was also an increase in replacement costs, which was caused by the small reduction in herd-life. Due to the low carcass price (US$1.05/kg), the economic value for this trait was low, but still positive (Table 4).

CR had a positive economic value of US$1.30 per 1% increase. In our model, marginal conception probabilities are added during the optimisation process (see Fig. 1), therefore CR has an effect mainly on the optimal herd composition. CR directly affects herd-life and indirectly affects calf value, carcass value, and replacement costs Eqs. (2) and (3). As a result of an increase in CR, there is an increase in average herd-life (Table 3) that results in a decrease in replacement costs and beef revenues (Table 4). There is also a small increase in average milk yield and milk revenues (Table 3). This increase is caused by a slightly different distribution of cows within age-classes, as a result of the increase in herd-life. Methods and definitions used in calculating economic values for fertility differ substantially in previous research, making the comparison difficult. A previous study by Boichard (1990) found an economic value for CR that ranged from US$1.14 to US$2.14/cow/yr per 1% increase in CR, which is in agreement with our results.

SR also had a positive economic value of US$2.42 per 1% increase. The effect of an increased SR is mainly exerted through changes in herd composition, rather than changes in individual performance. When SR increases, the average replacement rate becomes lower and optimum herd-life increases (Table 3). Although cows are older on average, there are also more cows in late lactations and dry period, which reduces milk revenues. However, the reduction in revenues was compensated by a more significant reduction in replacement costs, which leads to a positive economic value (Table 4). That is, cows are more cost-effective, as can be seen from the positive cow-profit in Table 4. Rogers et al. (1988) reported an increase of US$22 in net revenue/cow per year, after a decrease of 2.9% in involuntary culling rates. Visscher et al. (1994) reported economic values for survival rate in the range of US$1.35 to US$4.9/cow/yr per 1% increase in SR, similar to what we found in the present study.

Important results of this study were the economic values for traits related to cow-efficiency, i.e. body weight (BW) and rumen capacity (RC). A low positive economic value was found for BW (Table 4). This value was mainly originated from increases in beef and milk revenues. Beef revenues increased as a result of the larger body size, but the marginal change was low as a consequence of the low carcass price. Increase in milk revenues originates in higher actual milk yield (Table 3). According to the results of the dynamic digestion model, cows with a higher BW were closer to their potential milk yield. In this study, intake of concentrate was defined according to potential milk yield (see Section 3.2) and remains constant before and after 1% increase of genetic merit for BW (Table 3). Therefore, the increase in milk yield was caused by the increase in forage intake. Large cows eat more than small cows, and this is an important factor when the production potential of the cow is not fully expressed due to size-related limitations. When forage plays a major role within the feeding strategy, the capacity of the cow to eat more becomes even more important. That is, in comparing two cows with the same genetic potential for milk production, the cow with the larger body size will have a bigger chance to eat a larger amount of forage. However, although the economic value for BW is positive, it is still low because the increase in body size is also related to increased requirements for maintenance. The increase in feed costs was caused by higher forage intake through rumen capacity, but this increase in feed costs is counterbalanced by an equal reduction in residual forage costs (Table 4). That is, the cows consume more forage, and less residual forage is left on the ground (Table 3). In previous studies, the economic value reported for BW was negative (Groen, 1989a,b; Steverink et al., 1994; Visscher et al., 1994; Koenen et al., 2000). These studies, however, were based on models that assumed a feeding strategy based on nutrient requirements only. Therefore, larger cows required more nutrients for maintenance, and the intake was increased resulting in higher feed costs. Recently, dynamic models of digestion, as used in the present study, are being developed. In these models, the approach followed is opposite to models based on nutrient requirements (see Illius and Gordon, 1991; Herrero, 1997). These models allow for the specification of a general feeding strategy for a herd, and the actual performance of the individual cows is calculated on the basis of feed availability, feed quality and the production potential of the cow. This characteristic is of great importance when analysing the effect of interaction between genetic potential and feeding level (Luiting, 1998). For the present analysis, cows were fed based on their potential milk yield using a fixed 4:1 milk-concentrate ratio. This means that the change in feeding costs after increasing BW was only associated with the increase in forage intake (potential milk yield does not change with increased BW), and forage is a cheaper food resource. Some authors stated that large animals have a greater advantage when cell wall digestion rates are low because of their longer retention time and hence more extensive digestion; conversely, the shorter retention times of small animals allow a lower extent of digestion of slowly fermenting forages (Illius and Gordon, 1991). For the present study, it seems that increasing BW by genetic means is still profitable for a pasture-based dairy production system with feeding strategies as previously described.

A genetic increase in RC also resulted in a positive economic value. This value was related to an increase in milk revenues originated in higher actual milk yield and higher forage intake (Table 3). In this case, the economic value is much higher than BW. This is because the increase is mainly in rumen capacity and not in body size. Maintenance costs therefore do not change significantly, as for BW. The increase in beef revenues was due to a larger body weight (Table 3), which was mainly related to a higher intake capacity and lower body weight losses during lactation. The dynamic model of digestion takes into account changes in body weight on a daily basis, therefore changes in intake capacity are reflected in the average BW. Feed costs increased as a result of a higher forage intake, but there was again an equal reduction in residual forage costs. Similar findings have been previously reported (Groen and Korver, 1989; Veerkamp, 1998). From a revision by Koenen et al. (2000), it was found that economic values for feed intake capacity reported in the literature ranged between US$0 and US$71.3 cow/yr per 1 kg increase in feed intake. Despite the difference in the way of measuring feed intake capacity used in our study, the results also indicate a high economic value for this trait, which stresses the importance of increased feed intake capacity for pasture-based dairy production systems.

3.3. Fixed milk-output

Increase of genetic merit of a trait under a fixed milk-output evaluation-base changed herd-size according to the re-scaling factor (see Eq. (6)). With a milk-output restriction, the reduction in herd-size was observed when the trait had an effect on the actual milk yield of the individual cow. The economic value for this situation can also be related to the profit per kg of the limiting factor, e.g. per kg of milk (Table 5). The economic value for a trait was negative when the profit per kg of milk was lower after increasing genetic merit. All economic values obtained under a fixed milk-output evaluation base were lower than those obtained for a fixed herd-size.

In general, fixed cow-costs are lower as a result of the decrease in herd-size. An exception occurs for SR, which causes an increase rather than a reduction in herd-size. Variable cow-costs and revenues from milk and beef present marginal changes according to the trait being improved.

CARR had a negative economic value (Table 5). There is a decrease in milk revenues that cannot be counterbalanced by the reduction in replacement costs. Improvement of FAT and PROT significantly increased the potential phenotypic milk yield (Table 3), and consequently caused a larger reduction in herd-size and marginal changes in revenues and costs. In our model, DRPR only affected beef production traits, and therefore there was only a

Table 5
Initial distribution of costs and revenues per farm per year, and marginal changes and economic values after 1% increase in genetic merit for production and functional traits under a fixed milk-output base of evaluation

Parameter	Initial	Marginal change after 1% increase in genetic merit							
		CARR	FAT	PROT	DRPR	CR	SR	BW	RC
Herd-size	50.0	−0.259	−0.211	−0.103	−0.001	−0.011	0.044	−0.077	−0.209
Milk revenues (US$/year)	81430.1	−435.4	244.4	185.2	−0.9	−10.2	−3.2	0.7	6.5
Beef revenues (US$/year)	4437.4	−141.4	−9.4	−0.9	36.0	−16.1	−134.2	23.3	−10.5
(1)Total revenues (US$/year)	85867.6	−576.8	235.0	184.3	35.1	−26.3	−137.4	24.0	−4.0
Feed costs (US$/year)	16697.3	−38.6	−14.6	−5.8	0.6	−0.4	4.9	16.4	−13.3
Residual forage costs (US$/year)	5619.3	20.8	15.2	7.6	0.1	0.6	−4.0	−35.0	−37.3
Replacement costs (US$/year)	10160.9	−337.0	−20.5	−2.0	11.9	−38.3	−304.9	−25.9	−54.5
(a)Variable cow-costs (US$/year)	32477.4	−354.8	−19.9	−0.2	12.6	−38.1	−303.9	−44.5	−105.0
Labor costs (US$/year)	7008.0	−36.3	−29.5	−14.4	−0.2	−1.6	6.1	−10.8	−29.2
Sundry costs (US$/year)	16350.0	−84.6	−68.9	−33.7	−0.3	−3.6	14.2	−25.1	−68.2
(b)Fixed cow-costs (US$/year)	23358.0	−120.9	−98.4	−48.1	−0.5	−5.2	20.3	−35.9	−97.4
(c)Fixed farm-costs (US$/year)	13414.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(2)Total costs (US$/year) ($a+b+c$)	69249.4	−475.7	−118.3	−48.3	12.1	−43.3	−283.6	−80.4	−202.4
Net effect[a] (US$/farm per year)	16618.1	−101.1	353.3	232.6	23.0	17.0	146.2	104.4	198.3
Gross margin (US$/year) ($1-a-b$)	30032.1	−101.1	353.3	232.6	23.0	17.0	146.2	104.4	198.3
Production cost (US$/100 kg milk)[b]	23.4	−0.2	0.0	−0.1	0.0	−0.1	−0.1	−0.1	−0.1
Profit per 100 kg of milk (US$)[c]	10.13	−0.03	0.12	0.08	0.01	0.01	0.05	0.04	0.07
Economic value[d] (US$/cow per year)		−0.04	3.53	2.91	0.88	0.85	3.18	0.51	45.59

[a] Net effect: [δ milk revenues − δ beef revenues − δ variable cow costs − δ fixed cow costs].
[b] Production cost: total costs (US$/farm per year)/total milk yield (kg/100/farm per year).
[c] Profit per 100 kg of milk: Gross margin (US$/farm per year)/total milk yield (kg/100/farm per year).
[d] Economic value: [δ cow-profit + RF × final cow-profit]/increment in trait (see Eq. (5) and Table 1).

minor change in herd-size after 1% increase in genetic merit (Table 5). Conception (CR) and survival (SR) are implemented within the optimisation model, and consequently only exert a minimal effect on milk yield by changing optimal herd composition (Fig. 1). Therefore, the change in herd-size after selection for CR and SR was also minimal (Table 5).

After selection for SR, a small increase of herd-size was observed. This increase occurs because the level of the restricted factors, i.e. concentrate-input and milk-output, is lower after selection (Table 3). The increase of survival rate results in a higher ratio between non-productive vs. productive days during the lifetime of an average cow after the optimisation process (Fig. 1); and this causes the reduction in both factors.

Efficiency traits (BW and RC) are implemented within the dynamic digestion model and therefore exert an effect on actual phenotypic milk yield, not on potential milk yield (Table 3). Genetic increase of BW and RC had a significant effect on actual milk yield and therefore caused a reduction in herd-size and economic values (Table 5).

3.4. Change in prices

Increasing the price of milk solids under a fixed herd-size base of evaluation caused a significant rise in economic values of FAT and PROT, and to a lesser extent, CR, BW and DRPR (Fig. 2). Economic value for RC also increased significantly (results not shown). Conversely, the economic value of SR decreased as the price of milk solids increased (Fig. 2). Economic value for CARR did not change (Fig. 2). With a fixed milk-output the sensitivity of economic values to changes in price of milk solids was lower (results not shown). However CARR, FAT, PROT, and SR still followed the same pattern. DRPR, BW and RC did not change; and CR showed a slight reduction. High sensitivity of economic

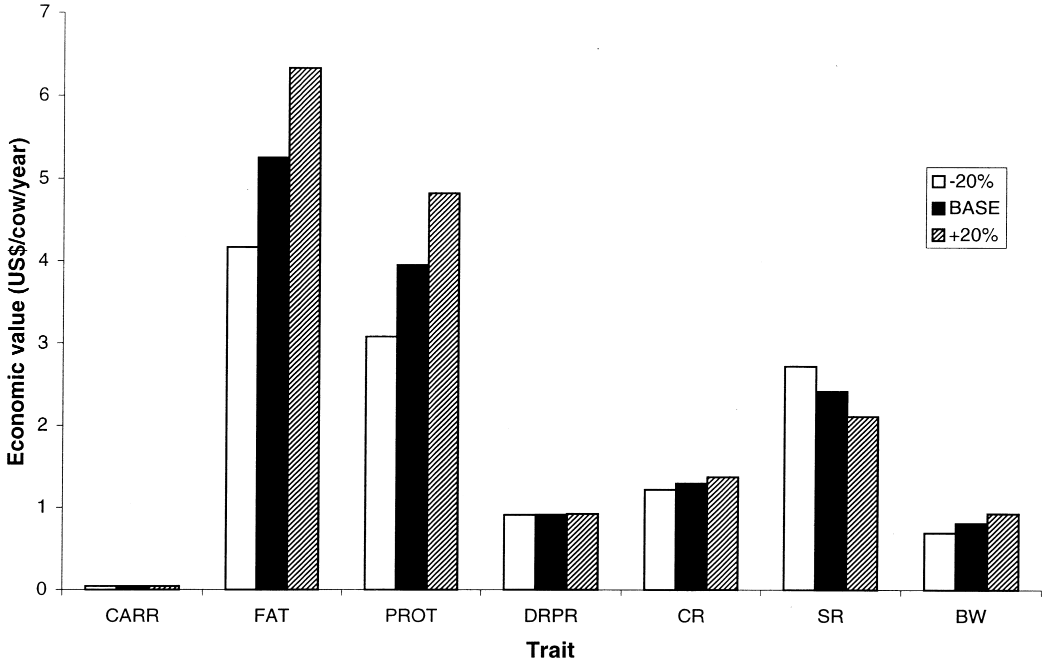

Fig. 2. Sensitivity of economic values for production and functional traits to changes in price of milk solids (US$/kg) under a fixed herd-size base of evaluation.

values to price of milk solids was expected, as a high percentage of farm income comes from milk sales. For this reason the economic value of the valuable milk components are affected the most. The reduction of economic values for some traits (SR, CR, and DRPR) can be explained from the results shown in Tables 4 and 5. As it was explained in previous sections, increased genetic merit for these traits results in a decrease of milk revenues due to an increase in the number of non-productive days. This reduction in revenues was even larger when the price of milk solids increased, which caused the decreasing trend in economic values.

Changes in concentrate price under a fixed herd-size of evaluation did not have major effects on economic values of any of the traits included in this study. Minor reductions in economic values of CARR, FAT, PROT, DRPR, and CR were observed, while SR increased slightly. Economic values of BW and RC did not change. With a fixed milk-output only the economic value for RC showed a significant increase. The minor changes in economic values caused by changes in price of concentrate are due to a rise in variable costs, with a consequent reduction of the net effect. Changes are small because a major part of the energy requirements of cows are obtained from forage, given the feeding strategy that was assumed.

3.5. Change in feeding strategy

Economic values obtained under a fixed herd-size base of evaluation with feeding strategy FIX were compared to the results obtained with feeding strategy REL (Fig. 3). Results are shown for all traits except RC. Economic value for CARR remained close to zero in both cases. Economic value for FAT and PROT were much lower for the poorest feeding strategy (FIX). This indicates that the genetic improvement of milk production traits is less profitable when the concentrate in the daily ration is limited. In other words, the production potential of the cow cannot be fully expressed. In contrast, the economic value for BW (Fig. 3) and RC (not shown) increased with the poorest feeding strategy. Economic values for RC were 84.53 and 189.04 for REL and FIX,

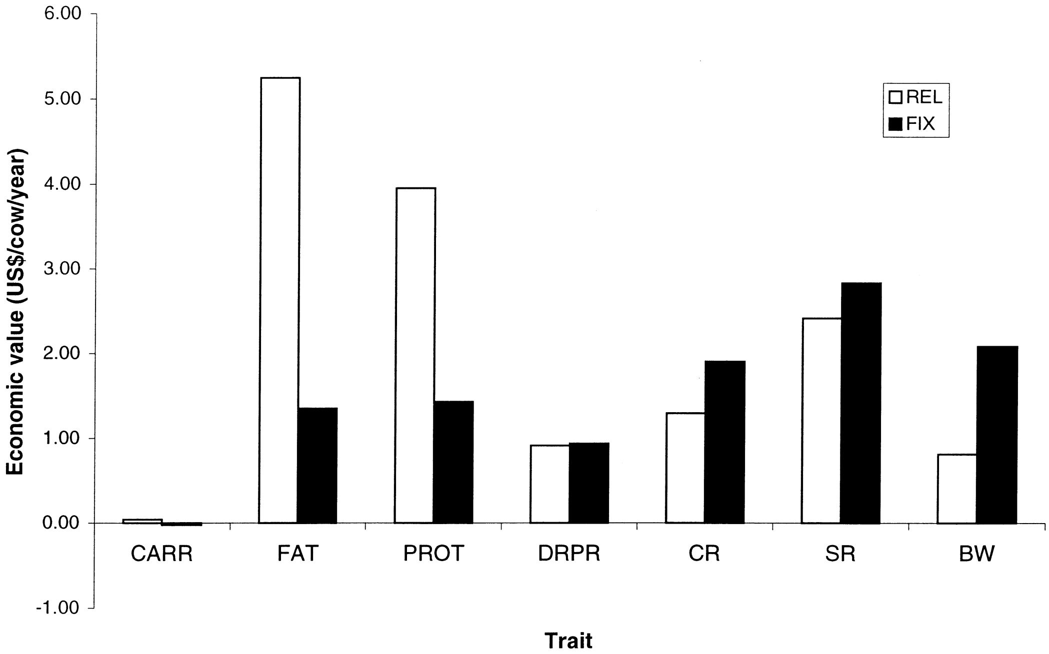

Fig. 3. Economic values for production and functional traits of Holstein cows grazing on kikuyu (*Pennisetum clandestinum*) and fed REL (milk:concentrate equal 4:1) and FIX (6, 4 and 2 kg of concentrate during stages 0–100, 101–200 and >200 days of lactation, respectively).

respectively. This indicates that genetic improvement of traits related to grazing capacity is more profitable when there is a restriction in the amount of concentrate fed in the ration. Economic value of DRPR did not change significantly. Economic value of CR and SR also increased significantly with strategy FIX, which indicates that the genetic improvement of these traits also becomes more profitable under less favourable environmental conditions.

4. Conclusion

Results found in this study provide important information about the type of traits that should be considered in a breeding goal for Holstein dairy cattle in Costa Rica. These results can also be compared against the past and current trends in dairy breeding within Costa Rica to identify possible inconsistencies.

The economic values found for milk production traits indicate that a major weight should be given to fat in relation to protein. The current payment system used in Costa Rica has higher price for fat compared protein. This pricing system deviates from that in a large number of other countries. Changes in the relative prices of fat and protein will affect the observed economic values. However, changes in this payment system are not foreseen in the near future, as the local dairy industry is oriented towards fat products. Currently, most of the semen entering the country is coming from USA, where the selection index gives twice as much emphasis to protein compared to fat. Vargas (2000) found that the correlation between the aggregate genotype for the USA and Costa Rica was very high (0.987). This indicates that the economic impact of the fat and protein prices on the direction of genetic improvement will be limited. Impact on ranking of individual bulls is expected to be larger.

From our results it is also clear the importance of survival and conception rates as traits with positive economic values. Inclusion of health traits within the selection index in USA was done only recently. The economic values for these traits are determined mainly by indirect effects, such as the reduction of replacement rates (and replacement costs), changes in the distribution of cows among age-classes or changes in the relative number of non-productive vs. productive days during the entire life of the cow. Although the importance of breeding for survival and fertility is clearly recognised world-wide, this becomes even more important in a developing country, where sanitary controls are less efficient and the incidence of diseases and fertility problems is higher.

Our results suggest that body weight, and especially feed intake capacity, are both traits with a positive economic value for production circumstances found in Costa Rica. Inclusion of these cow-efficiency traits in a selection index is not currently performed in USA. According to our results, these traits become even more important as the amount of forage in the daily ration increases, which is the situation found in specialised dairies of Costa Rica. Use of concentrate is not likely to increase in these farms, due to the high costs involved. On the other hand, forage can be produced at a relatively cheap price. Therefore, breeding of efficient grazers becomes of capital importance, in order to make a more efficient utilisation of this abundant feed resource. It is important to define the optimum size of a dairy cow for the production circumstances found in Costa Rica, in such a way that consumption of forage can be maximised. Our results indicate that breeding for higher body weight and especially rumen capacity can still further increase the profitability of a Holstein cow in Costa Rica.

Results found in this study also indicate that the model used was able to simulate some of the important relationships among genetic potential of a cow and its final phenotypic performance. Important interactions between breeding, nutrition, health and reproduction can be adequately translated into economic considerations at the farm level. This becomes especially important when analysing highly variable and unpredictable production systems, such as found in Costa Rica. However, further parameterisation and refinement of the model are necessary in order to improve consistency.

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