Disease Traits and Relative Economic Values in Dairy Cattle using Simulation

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Abstract

A simulation model was developed to evaluate dairy cow daily margins with a focus on the effects of disease traits, including mastitis, lameness, cystic ovaries, displaced abomasum, ketosis, metritis, milk fever and retained placenta. The relationships among growth, feeding, production and health were represented in the simulation model such that all activities of the cow throughout its lifetime were monitored on a daily basis. The 220 genetic traits could be categorized as production, fertility, growth, conformation, disease and miscellaneous effects. All costs (feed, health, breeding) and income (production, calves, sale) due specifically to the cow were included. Effects of animal health were modeled as risk factors determined by the base risk of the population, parity number, disease in lactation, disease interrelationships, production levels and season. An incidence of disease can have an effect on daily milk, fat and protein yield, reproductive ability, feed intake, conception rate, probability of culling or death, growth rate, probability of another disease in the same lactation and most importantly cow daily margins. The program allows for changes to be made to the cow environment as well as to relative input and output costs. The simulation model allowed for all cost associations between disease traits and production. The objective of this study was to derive relative economic weights for the genetic traits specifically disease traits of cows as they influence a cows daily margins. Results indicated that disease traits were of low relative economic importance relative to 305-d protein yield, however, with increased incidences, their relative economic importance increased, with unfavorable effects on cow daily margins.

Introduction

An animals lifetime merit is a combination of genetic merit and economic value for each trait. Increasing production per cow and reducing the cost per unit of production has been the focus of dairy producers worldwide. Intense selection for production traits over the years has resulted in a compromise of animal health and welfare (Collard et al., 2000; Rauw et al., 1998). In recent years more emphasis is being placed on functional traits particularly disease traits (Miglior et al., 2005). Most countries have decreased their selection on yield traits and increased selection for health and fertility traits (Van Raden, 2005). Scandinavian countries have practiced selection for functional traits for several years. In Canada, the National Health Recording Project was launched in 2007 to record events associated with eight diseases in dairy cattle production, namely clinical mastitis, lameness, cystic ovaries, displaced abomasum, ketosis, metritis, milk fever and retained placenta.

Diseases in dairy cattle have a significant impact on cow profitability. Assessing its true impact is challenging as economic analyses are mired by an inability to fully describe all cost associations in the production system. To quantify economic losses, simulation models are useful as they allow for long horizons and are not limited by experimental design or lack of real data (Sørensen et al. 1992). Simulation allows for specifying biological parameters at the cow level. Simulations have been used to determine the relative economic impact of disease traits on dairy cow profitability, sometimes with a genetic component and often without a genetic component (Komlósi et al., 2010; Nielsen et al., 2006; Østergaard et al., 2003).

The economic value is the regression of net income on a unit increase in the trait when keeping other factors constant. Previous studies looking at derivation of economic values most often look at herd economics as opposed to individual genetic merit of animals. Economic values should be derived under optimum management (Goddard, 1983). Simulation allows for mimicking optimum dairy cattle production as well as examining profitability at the animal level. The objective of this study was to present a model that simulates the day to day activities of dairy cows and to derive relative economic values for disease traits using cow daily margins from birth to fourth calving.

The Simulation Model

Framework

The simulation unit was an individual animal. An animal unit was characterized into groups as not yet born, birth to 2 years of age, heifers due to calve, dry cows, cows in milk. All animals were monitored daily throughout their productive life. Every cow was allowed to live until its natural death or until 10 lactations were completed. The initial number of cows was 1000. Cows were culled only if the number of services to become pregnant within a lactation exceeded 4. All live female calves were kept and allowed to stay in the group, assuming unlimited resources. Therefore, after 21 simulated years, the total number of animals (males and females) through year 21 grew to 314,074. The reasons for this approach were to

1. Eliminate human management decisions that could affect associations of disease traits with other traits,
2. Build up numbers of animals because disease occurrences have very low frequencies, and
3. Observe disease traits throughout the life of a cow and over several years.

All daily animal activities were monitored and accounted for by up to 220 genetic traits, characterized as production, fertility, growth, conformation, disease, and miscellaneous. Due to a lack of availability of genetic variances and covariances for all possible pairs of traits, only about 110 traits actually contributed to the simulation. A list of all 220 genetic traits is given in Table 1. Phenotypes were created accounting for age, parity number, and season. Interrelationships among traits were also included, such as between production levels and diseases. All costs (feed, disease treatments, breeding) and income (milk production, calves) caused specifically by the cow were accumulated daily. At each calving the accumulated income and costs were saved and their difference was divided by the number of days between calvings to obtain cow daily margins.

Bulls for mating to cows were generated by a separate program in a traditional progeny test procedure with a 1 million cow population, 400 young bulls per year, and 50 proven bulls per year. Young bulls were obtained from the best dams in the population (based on lifetime profit index (LPI) values). Proven bulls were selected based on their lifetime profit indexes(LPI) from the daughter progeny test.
Proven and young sires were saved to a file for each year with their true breeding values (TBV) for the 220 traits. These were simply read into the cow simulation program to be used for matings at the appropriate times.

The cow simulation program was modularized. The initial modules read in all of the parameters, costs, risk factors for all of the 220 traits. Then the initial cow population is generated, as the base population, with genetic means of close to zero for all traits. The program then loops through 21 years, loops through 365 days per year, and loops through all active animals. Within each year a new group of proven and young sires is read into the program for use in matings. For each day, the weather conditions for that day are read in from a file. For each cow the following check modules (subroutines) are processed.

1. Update the ages and day counters for an animal. There are counters for days to being born, days in milk, days pregnant, days dry, days to breeding, days to calving, and days to involuntary culling.
2. Check the survival of the animal for that day.
3. Check if the animal is born.
4. Check if animal needs to be bred. If so, perform mating and determine success or failure of mating.
5. Check if the animal is to calve. If so, reinitiate counters, write out income and costs for prior lactation period.
6. Calculate the daily weight of the animal. Adjust for pregnancy, diseases, and heat stress.
7. Calculate the daily milk, fat, protein, and SCS, if in milk. Check for drying off. Adjust for pregnancy, diseases, and heat stress.
8. Calculate the amount of feed and water consumed, manure produced based upon weight and milk yields.
9. Check for new disease occurrence. Maximum of 3 diseases per animal at the same time allowed.

Genetic Traits

Daily production was simulated according to random regression models (Legendre polynomials of order 4) so that 24 h yields could be calculated daily. Production included milk, fat, protein, somatic cell score, lactose, omega 3 fatty acids and milk urea nitrogen for each of three lactations. With 5 parameters per trait per lactation, production traits accounted for 105 of the 220 genetic traits. Production was modified for number of days pregnant (Bohmanova et al. 2008), for the effects of diseases, and weather stress.

There were 28 conformation traits, also for each of three lactations, which allowed conformation to change with age of the cow. Growth curves for weight and height (von Bertalanffy 1957) were used to determine daily weights, with 3 parameters per animal. Weights were for non-pregnant, non-lactating cows under healthy conditions. Growth of the fetus was incorporated into the weight of the cow during pregnancy. Cow weights were further affected by lactation, heat and disease. Weight changes due to milk production throughout lactation were incorporated. A residual standard deviation of 1.5 kg per day was used for cows. Height was not very variable during the life of the animal and stops once mature height is achieved. From growth and production phenotypes dry matter intake was determined, but there was also an individual genetic component to feed intake. Dry matter intake (DMI) from birth to first calving was determined from Hoffman et al. (2008), while DMI for lactating cows was from formulas by Roseler et al. (1997). Feed costs were based on cost per dry matter. Three TMR rations (heifers, dry cow, and lactating cows) were applied. The constitution of the 3 rations were constant for this study.

Fertility traits were the same for young and old cows, but with different means. For traits observed more than once per animal, age and parity effects were added. The fertility traits were consistent with those used in the Canadian fertility trait evaluation system and defined as; age at first calving, non return rate (NRR), number of services, first service to conception, gestation length, calving to first service, calving ease and stillbirth.

Disease traits included mastitis, lameness, cystic ovaries, displaced abomasum, ketosis, metritis, milk fever and retained placenta. True genetic values were simulated as normally distributed variables, which were converted to risk factors for determining if an animal become diseased. Other traits included heat stress, milking speed, milking temperament, water intake and survival. Disease traits were simulated as normally distributed traits per animal, with genetic covariances among the traits. Each disease trait had a phenotypic variance of 100. To convert the normally distributed trait to a probability, 100 was added to the phenotypic trait value (genetic plus residual effects), and then divided by 100 to give a relative breeding value with a range of 0.5 to 1.5. Values greater than 1 increase the probability of occurrence of a disease, and less than 1 reduces the probability of occurrence. The range of the cow ratios varied with the disease and the heritability of that disease. Effects of diseases on cow daily margins were modeled as risk factors determined by the base risk, parity number, disease in lactation, disease interrelationships, season, body condition and production levels. Estimates of lactational incidences of diseases (Table 2) and predisposing factors were obtained from the literature. Days in milk of disease occurrence, duration of an episode of disease, effect of season of year on disease occurrence and the predisposing effect of one disease on another were obtained from Van Dorp et al. (1999). Other details about the disease traits are given in Tables 3 to 6. Effects of diseases on production,
weights, and reproduction were obtained from Østergaard et al. (2003). Income generated from a cow and expenses incurred are greatly affected by disease occurrence, treatment cost and time, persistency and effect of disease on probability of conception were obtained from Guard (1994).

Parameters

Genetic, permanent environment (PE) and residual parameters were gathered over two years from many sources, but values estimated from Canadian data were used wherever possible. Some studies report actual variances, but most studies only give heritabilities and correlations which need to be converted to some unit of measure. There were 24,090 possible covariances among the traits in each matrix. About 7300 covariances were unknown and were left as 0. The final matrices of order 220 were checked for positive definiteness. The negative eigenvalues were modified (Schaeffer, 2010) to be positive and the matrices reconstructed with those eigenvalues. The matrices must be positive definite before being used to simulate observations.

Management and Weather

Optimal herd management practices were assumed for all cows, without defining what the specific practices might be. Restrictions due to quota on milk production or size of the facility were assumed to not affect the performance of the cow. Perfect estrous detection and immediate disease detection were assumed in the simulation.

Daily temperature and humidity values for southern Ontario over 10 years were used in the simulation. If the THI was above 70 then cows were assumed to be under heat stress, and yields, feed intake and diseases were affected accordingly. There was no modification of traits for the possibility of extreme cold stress, but this could also be incorporated if those effects were known.

Economic Aspects

All money spent to care for a cow, that relate to the list of traits, and every source of income generated by the cow were recorded on a daily basis. Costs were constant over 21 years, meaning that the relative values of traits remained the same over time, and the effects of inflation, fluctuations in feed and energy prices over time were avoided. Costs related to equipment, facilities, interest rates, taxes, etc., that were not directly related to a cows genetic abilities for any traits, and therefore, did not affect the genetic ranking of cows were not considered. Costs and prices were based on 2010 values (Table 7). Total accumulated costs and income for a cow were saved to a file at each calving date, and then re-set to zero for the next calving interval. Thus, for a period from birth to first calving there was no income, but only costs.

Cows with first lactation records (122,943) and all subsequent lactations were used in the economic analyses. Only records up to the fourth lactation were kept because the average number of lactations is between 3 and 4 in Canada. Cow daily margins were calculated per calving period and expressed per day (daily margins) defined as:

$$\text{Margins} = (\text{Revenue} - \text{Costs})/\text{Days}$$

where, revenue was from milk, fat and protein sales, calves and carcass value, costs were from feeding, veterinary services, handling and labour, and days were the number of days in the interval being considered. Cow daily margins were calculated within and across parities (different intervals of time). Parity 0 was defined as the period from birth to calving, and parities greater then 0 were from one calving date to the next. Accumulated parity margins versus single parity margins explained the effects of the traits on cow daily margins more precisely.

To determine which of the genetic traits significantly affected cow daily margins GLMSELECT (SAS Institute) was used. Both Stepwise Forward, and Backward Elimination methods were used and gave the same final models. Variable Entry and Stay Significance levels were 0.15. Traits with p-values below 0.05 were regarded as statistically significant.

Economic values were derived for genetic traits using a regression model to study the relationship between a cows daily margins and its TBV (true breeding values). An economic value is the profit change when a given trait changes by one genetic unit and all other traits in the index remain the same.

$$y = \mu + yr + p + \sum_{i=1}^{m} b_i X_i + e$$

where,

y is the average daily margins of a cow observed from birth to fourth calving,

μ is the overall mean of the population,

yr is the effect of year,

p is the effect of parity,

b_i were regression coefficients on m genetic traits, X_i, (i.e. the true breeding values, TBV) and

e was the residual effect.

Relative economic values (REV) were derived for all traits and in particular disease traits. All trait economic values were made relative to the value of 305-d protein yield to compare various scenarios. The REV of traits to 305-d protein yield were categorized as having high (2), moderate (0.6 to 1.9) or low (0.5) importance (absolute values). Five (5) replicates of this study were done and relative economic values averaged over replicates.

Comparisons

The Lifetime Profit Index (LPI) is an index used in Canada that produces the relative profitability expected during the lifetime of future daughters. The LPI formula of 2009 involving about 28 traits was used to calculate an LPI value for each cow using their true breeding values (TBV). The LPI was then used to predict cow daily margins.

A second comparison was to use the same traits that were in the LPI formula, but to use regression to estimate new economic weights on those traits, different from the actual LPI weights. A difference in R^2 values would indicate which weights better predicted daily margins of cows.

The prices of milk, calf sales, salvage value, feed, water, labour, disease treatment, breeding and calving were the major contributors to income and cost. If some or all of the costs or incidences in the diseases were doubled, then the effect on the relative importance of traits on daily margins of cows could be observed. Thus, the sensitivity of the simulation model to price changes or changes in disease incidences could be quantified.

Results

Simulation Verification

A few summary checks were made on the simulation model. The average lactation milk yield of cows was 8,988 kg per year. Fat and protein yield was 356 kg on average per lactation. Days in milk averaged 315 days with an average calving interval of 385 days. Disease incidences were simimlar to the input parameters (Table 2). Feed efficiency as defined by Hutjens (2010) ranged from 1.3 to 1.5 for cows across parities. Mean daily margins varied within and among parities. Daily margins within parity ranged from \$11.80 to \$13.61 for parities 1 through 4 with optimum margins obtained in parity 3. Across parity (including the period from birth to first calving) daily margin peaked on average at \$7.74 in the 3rd parity.

Trait to Predict

Daily margins between calvings were used because they account for poor reproductive performance (breeding) which would lengthen the interval between calvings, and therefore, possibly lower daily margins. Daily margins also account for differences in ages at each calving. The first problem was to determine which cow daily margins should be predicted. Cow daily margins could be calculated within lactation periods, or accumulated over lactations. Regression models were fit for several different calculation methods. Within lactation daily margins could not be predicted very accurately with R^2 values in the 0.40 to 0.50 range. Accumulated daily margins gave much greater R^2 starting at 0.89 (Table 8). How many lactations should be accumulated? Daily margins from birth to parity 4 gave the greatest R^2 and going beyond parity 4 resulted in lower R^2. More cows were involuntarily culled after fourth calving. Thus, for the remainder of the study cow daily margins were based on accumulated revenues and costs from birth to fourth calving.

Canadian Lifetime Profit Index

The first study was to determine the accuracy of the Canadian LPI in predicting average cow daily margins from birth to parity 4. LPI values were computed for each animal, and the LPI value was regressed onto cow daily margins as a single variable with year and parity effects in the model. Irrespective of parity, 305-d milk and fat yields consistently maintained high and moderate relative economic values (REV) to 305-d protein yield, respectively. Age at first service, a component of daughter fertility, also gave moderate REV to 305-d protein yield. The LPI appears to serve its purpose well in predicting lifetime profitability of daughters with an R^2 of 0.89.

The LPI includes the genetic traits shown in Table 9. Keep in mind that the weights on traits in the LPI may not be optimal because these weights are determined via input from breed associations, individual dairy producers, and very little scientific input. The optimal weightings from regression on those traits are given in Table 9 with an R^2 of 0.914. The current LPI formula could, therefore, be improved, at least for the simulated data. The best set of traits to predict cow daily margins is given in Table 10 with an R^2 of 0.916, which is only slightly better than the LPI traits. The additional traits in Table 6 were front, chest, loin, weight, height, dry matter intake, fore udder placement, teat length, and body depth. The most highly significant trait is dry matter intake, which is the most difficult trait to collect in practice. The disease traits were forced to be included.

Miglior et al.(2005) found that profit indexes used in many different countries having different weights on various traits, tend to give very highly correlated results. That is, they tend to rank animals similarly. Thus, as long as the major revenue and cost traits are included in the index, the weighting of those traits does not seem very critical to ranking animals economically. Given that this was a simulation study and many of the genetic correlations were unknown, the Canadian LPI does not appear to need any modifications to make it better, except to possibly add dry matter intake if it can be collected efficiently.

Disease Traits

Shown in Table 6 are the REV of all disease traits to 305-d protein yield. Relative economic importance of disease traits were examined by adding all disease traits at the same time to the other significant traits. Mastitis, ketosis, metritis and retained placenta assumed negative REV to 305-d protein indicating that any numerical increase in mean value of these traits is economically detrimental and would result in decreased daily margins. In general, all disease traits assumed low relative economic importance to 305-d protein yield.

Although diseases seem costly when they occur to an individual cow, the frequency of their occurrence and the overall impact on the lactation are not that large when averaged over many animals in the population. Thus, their REV averaged over many animals, are low and not practically important. The incorporation of disease traits into the LPI is not urgent and may not be useful. Considering the efforts of the National Health Recording Program to collect information on diseases, and considering the lack of complete reporting of diseases, omitting disease traits from the LPI would not be a loss. Instead, perhaps an immune response test on each cow could be used in place of disease recording. This trait would give an idea of how cows might have different abilities to fight off diseases in a general sense, and the measure would be normally distributed with perhaps a higher heritability than any individual disease.

Sensitivity Checks

The incidences of diseases were doubled to observe the effect on prediction of cow daily margins. The mean daily margins decreased from $11.80 to $7.95, from birth to parity 4. Doubling the incidence of mastitis reduced average daily margins by 31%. The relative economic values for other traits changed when disease incidences were doubled. Milk and fat yields increased in REV, with modest increases in REV of weight, feet, foot, fore udder placement, dairy strength, age at first service, calving to first service, lactation persistency, and somatic cell scores. All other traits remained low in REV.

The incidence of each disease trait was doubled independently of the other diseases (Table 11). Doubling the incidence of mastitis increased the REV of all disease traits. In general, this was the trend for each disease, but the amount of increase varied for each disease. Mastitis, milk fever, and cystic ovaries had the greater effects on the other diseases. The R^2 of the models did not change except by 0.001 up or down.

Runs were made where the costs of treating disease traits were doubled, but incidences were kept at base levels. The REV were not significantly affected (results are not shown). Neither an individual increase in cost per disease nor a collective increase in costs across all diseases had much effect on the REV of diseases. Doubled feeding costs also did not result in changes to REVs of traits to 305-d protein yield.

Discussion

A simulation model was constructed to monitor the daily activities of dairy cows for 110 plus genetic traits, and to keep track of revenues and expenses for each animal individually over a 21 year period. The main objective was to study the importance of eight disease traits on cow daily margins, and to determine if disease traits should be included in the Canadian lifetime profit index. Many assumptions had to be made. Cows were assumed to be raised under optimal conditions where resources were unlimited, and where cows were allowed to live out their complete lives without too many culling rules. The genetic parameters that were used were assumed to be without error, but in fact, many genetic covariances were unknown because certain combinations of traits have never been studied together. All traits were generated as underlying normally distributed variables, but the disease traits, for example, had to be converted to probabilities or risk factors for use in the selection model. However, no other simulation model has considered more genetic traits at one time. Only one set of parameters were used in the simulation, and these were collected over two years from many sources. All prices and costs were from current reports and were held constant through the simulation period of 21 years.

Production traits (milk, fat, and SCS) were of large importance relative to 305-d protein yields. Dry matter intake also had a large REV, but this trait is not routinely captured in milk recording programs. Other studies have shown that milk yield continues to be of most economic importance to cow profitability (Visscher et al. 1994; Krupová et al. 2009; Komlósi et al. 2010). The relative economic importance of 305-d milk, fat and protein yields were found to be dependent on price ratios and feed costs.

Disease incidences observed were indicative of the base risk of the population. Disease incidences used in this study did not describe any particular location or management practice as estimates were taken from a variety of literature. Kelton et al. (1998) outlined suitable definitions for disease identification. All health traits were identified as being of low relative economic importance to 305-d protein yield with mastitis, ketosis, metritis and retained placenta assuming negative economic importance. Komlósi et al. (2010) found that clinical mastitis contributed 1% to the sum of the absolute values of the relative standardized economic weights over all traits and trait components. Somatic Cell Score (SCS), clinical mastitis and calving difficulty score also assumed negative economic values in other studies (Krupová et al. 2009; Komlósi et al. 2010). Further examination of the REVs of disease traits when incidences were doubled indicated that disease traits also increased their REV to 305-d protein yield. Most impact on daily margins was realized when mastitis, ketosis and metritis incidences were doubled. The simulated scenarios indicate that relative economic values for disease traits (mastitis, lameness, cystic ovaries, displaced abomasum, metritis, milk fever and retained placenta) vary depending on production system and disease incidences.

The simulation model ignored inbreeding and any kind of herd structure. Because animals were not culled vigourously, genetic trends were not of importance. Selection (via human decisions) tends to confuse the picture on relative economic values of traits. However, the current Canadian lifetime profit index appears to be suitable for use from this study, and disease traits do not need to be incorporated urgently unless incidences of diseases increase.

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Table 1

Genetic traits included in the simulation model.

Group	Name	Trait numbers
Production	Lactation 1, Milk (RR $a_0, ...a_4$)	1-5
	Lactation 1, Fat (RR $a_0, ...a_4$)	6-10
	Lactation 1, Protein (RR $a_0, ...a_4$)	11-15
	Lactation 1, SCS (RR $a_0, ...a_4$)	16-20
	Lactation 1, Lactose (RR $a_0, ...a_4$)	21-25
	Lactation 1, Milk Urea Nitrogen (RR)	26-30
	Lactation 1, Omega 3 FA (RR)	31-35
Production	Lactation 2, Milk (RR $a_0, ...a_4$)	36-40
	Lactation 2, Fat (RR $a_0, ...a_4$)	41-45
	Lactation 2, Protein (RR $a_0, ...a_4$)	46-50
	Lactation 2, SCS (RR $a_0, ...a_4$)	51-55
	Lactation 2, Lactose (RR $a_0, ...a_4$)	56-60
	Lactation 2, Milk Urea Nitrogen (RR)	61-65
	Lactation 2, Omega 3 FA (RR)	66-70
Production	Lactation 3+, Milk (RR $a_0, ...a_4$)	71-75
	Lactation 3+, Fat (RR $a_0, ...a_4$)	76-80
	Lactation 3+, Protein (RR $a_0, ...a_4$)	81-85
	Lactation 3+, SCS (RR $a_0, ...a_4$)	86-90
	Lactation 3+, Lactose (RR $a_0, ...a_4$)	91-95
	Lactation 3+, Milk Urea Nitrogen (RR)	96-100
	Lactation 3+, Omega 3 FA (RR)	101-105
Miscellaneous	All, Milking speed	106
	All, Natural survival	107
	All, Heat stress	108
	All, Body condition score	211
	All, Milking temperament	212
Growth	Birthweight	196
	Manure output	197
	Methane output	198
	Weight, A, B, K parameters	199-201
	Water consumption tendency	202
	Height, A, B, K parameters	203-205
	Dry matter intake, DMI to 90d	206
	DMI to 24 m	207
	DMI, A, B, K parameters	208-210
Disease	Mastitis	213
	Lameness	214
	Cystic ovaries	215
	Displaced Abomasum	216
	Ketosis	217
	Metritis	218
	Milk fever	219
	Retained placenta	220

Table 1 *continued.*
Genetic traits included in the simulation model.

Group	Name	Trait numbers
Conformation	Conformation, lactations 1, 2, 3	109-111
	Dairy strength	112-114
	Rump	115-117
	Feet	118-120
	Mammary system	121-123
	Stature	124
	Front	125-127
	Chest	128-130
	Body depth	131-133
	Loin	134-136
	Pin width	137-139
	Rump angle	140-142
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Table 2

Days in milk of likely disease occurrence, lactational incidences, and heritability of disease traits.

Disease	Earliest DIM	Latest DIM	Lactation 1	Lactation 2	Lactation 3+	Heritability
Mastitis	0	305	0.056	0.084	0.087	0.04
Lameness	0	305	0.021	0.025	0.025	0.10
Cystic ovaries	31	150	0.032	0.052	0.065	0.12
Displaced abomasum	0	150	0.005	0.005	0.011	0.14
Ketosis	0	30	0.003	0.005	0.011	0.06
Metritis	0	150	0.096	0.089	0.101	0.06
Milk fever	0	30	0.003	0.005	0.026	0.04
Retained placenta	0	30	0.013	0.019	0.022	0.05

Table 3

Odds ratios of diseases for 4 seasons of the year, increases or decreases probability of occurrence.

Disease	Winter	Spring	Summer	Fall
Mastitis	1.00	1.00	1.11	0.96
Lameness	1.00	1.04	1.00	1.00
Cystic ovaries	1.00	1.00	1.00	1.00
Displaced abomasum	1.00	1.18	0.82	1.00
Ketosis	1.00	1.50	1.70	1.30
Metritis	1.00	0.85	1.00	0.68
Milk fever	1.00	1.04	0.98	0.98
Retained placenta	1.00	1.30	1.20	1.10

Table 4

Odds ratios for increased probability of a disease occurrence given prior exposure to another disease.

Disease	Mastitis	Lameness	Cyst. Ov.	Dis. Ab.	Ketosis	Metritis	Milk Fever	Ret. Pl.
Mastitis	1.00	1.00	2.04	1.00	1.00	1.00	1.00	2.39
Lameness	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cyst. ov.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Dis. ab.	1.00	1.00	1.00	1.00	6.88	1.00	1.00	1.00
Ketosis	1.00	1.00	1.00	7.98	1.00	1.00	1.00	1.00
Metritis	1.95	1.00	2.77	1.00	2.20	1.00	1.00	1.00
Milk fever	1.00	1.00	1.00	2.62	2.51	1.00	1.00	1.00
Ret. pl.	2.13	1.00	1.00	1.00	1.00	3.53	1.00	1.00

Table 5
Effects of disease traits on production, weights, feed, and conception rate, in terms of reduced capacity and number of days affected.

	Production		Growth		Feed Intake		Conception	
Disease	Yield	Days	Weight	Days	Feed	Days	Rate	Days
Mastitis	0.95	305	1.00	0	1.00	0	1.00	0
Lameness	1.00	0	1.00	0	1.00	0	1.00	0
Cystic Ovaries	1.00	0	1.00	0	1.00	0	1.00	0
Displaced Abomasum	1.00	0	0.77	28	0.70	28	1.00	0
Ketosis	0.85	21	0.82	21	0.90	21	1.00	0
Metritis	0.87	14	1.00	0	1.00	0	0.62	119
Milk Fever	0.94	21	0.90	21	0.90	21	1.00	0
Retained Placenta	0.87	14	1.00	0	1.00	0	0.62	119

Table 6
Labour hours, drugs costs, probability of death for disease traits.

Disease	Labour	Drugs $	Pr(death)
Mastitis	1.00	15	0.011
Lameness	0.50	26	0.010
Cystic Ovaries	1.00	50	0.001
Displaced Abomasum	1.00	86	0.020
Ketosis	0.67	19	0.005
Metritis	0.67	20	0.015
Milk Fever	0.50	25	0.040
Retained Placenta	0.67	20	0.015
Dystocia	1.00	0	0.010

Table 7

Assumed prices and costs for some variables.

Variable	Amount
Income per kg milk	$0.04374
Income per kg fat	$9.92000
Income per kg protein	$7.16000
Milking labour, per minute	$0.15
Handling labour, per hour	$15.50
Manure removal, per kg	$0.77
Feed, milking cows, per kg	$0.23
Feed, dry cows, per kg	$0.19
Feed, heifers, per kg	$0.14
Water, per kg	$0.01
Young bull semen	$25.00
Proven bull semen	$35.00
Vet assistance, per hour	$325.00
Calving, slight assistance	$40.00
Calving, easy pull	$80.00
Calving, difficult pull	$135.00
Calving, caesarian	$400.00
Salvage value, female calf, per kg	$1.00
Salvage value, male calf, per kg	$0.50
Salvage value, cow, per kg	$1.20

Table 8
Relative economic values (REV) of traits for cow daily margins taken over different time periods.

Traits	Birth to parity			
	1	2	3	4
Lactation 1, 305-d Protein	1.00	1.00	1.00	1.00
Lactation 1, 305-d Milk	10.30	9.61	9.17	8.37
Lactation 1, 305-d Fat	1.72	1.44	1.36	1.21
Lactation 1, SCS	-0.07	-0.09	-0.09	-0.06
Lactation 2, 305-d Protein	0.11	1.00	1.23	1.17
Lactation 2, 305-d Milk	-0.05	6.13	5.05	4.42
Lactation 2, 305-d Fat	0.07	1.63	1.56	1.46
Lactation 2, SCS	-0.04	-0.09	-0.09	-0.10
Lactation 3+, 305-d Protein	0.50	0.29	0.34	0.36
Lactation 3+, 305-d Milk	-0.59	-0.32	3.78	4.96
Lactation 3+, 305-d Fat	-0.05	-0.13	0.56	0.84
Lactation 3+, SCS	0.07	0.07	0.04	0.00
Survival	0.06	0.01	0.04	0.05
Conformation	0.28	0.40	0.40	0.37
Front	0.13	0.17	0.20	0.19
Chest	0.12	0.21	0.40	0.45
Loin	0.02	0.09	0.17	0.21
Mammary system	-0.02	0.02	-0.01	-0.04
Feet	0.13	0.27	0.24	0.21
Foot	-0.34	-0.47	-0.46	-0.41
Dairy strength	-0.17	-0.34	-0.41	-0.40
Udder depth	-0.25	-0.32	-0.38	-0.40
Fore udder placement	0.10	0.22	0.28	0.28
Teat length	-0.20	-0.22	-0.30	-0.32
Body depth	-0.15	-0.16	-0.20	-0.22

Table 8 *continued.*
Relative economic values (REV) of traits for cow daily margins taken over different time periods.

Traits	Birth to parity			
	1	2	3	4
Age at first service	-1.75	-2.07	-2.05	-1.92
Non return rate	-0.02	0.18	0.22	0.25
Number of services	-0.25	-0.15	-0.04	0.03
First service to conception	0.05	0.00	-0.03	-0.05
Calving to first service	1.15	1.08	0.93	0.77
Lactation 1, persistency	0.08	0.01	-0.04	-0.06
Lactation 2, persistency	0.39	0.89	1.15	1.20
Lactation 3, persistency	-0.11	-0.27	-0.31	-0.33
Weight	-0.34	-0.43	-0.63	-0.69
Height	-0.09	-0.12	-0.03	0.04
Milking speed	-0.04	-0.02	-0.02	-0.01
Mastitis	-0.06	-0.11	-0.14	-0.10
Lameness	0.05	0.06	0.08	0.10
Cystic ovaries	0.00	0.08	0.11	0.08
Displaced abomasum	-0.01	0.04	0.06	0.06
Ketosis	0.07	0.03	-0.01	-0.01
Metritis	-0.03	-0.05	-0.05	-0.05
Milk fever	0.07	0.05	0.03	0.02
Retained placenta	-0.01	-0.03	-0.05	-0.05
R^2 of model	0.89	0.91	0.92	0.92
Residual variance	0.45	0.77	0.96	1.08

Table 9

Relative economic values (REV) of traits in the LPI in the prediction of cow daily margins from birth to parity 4.

Component	Traits	REV
Production	Lactation 1, 305-d Protein	1.00
	Lactation 1, 305-d Milk	4.81
	Lactation 1, 305-d Fat	0.56
	Lactation 1, SCS	-0.09
	Lactation 2, 305-d Protein	-0.58
	Lactation 2, 305-d Milk	3.13
	Lactation 2, 305-d Fat	1.77
	Lactation 2, SCS	-0.18
	Lactation 3+, 305-d Protein	0.81
	Lactation 3+, 305-d Milk	3.47
	Lactation 3+, 305-d Fat	-0.16
	Lactation 3+, SCS	0.20
Durability	Survival	0.09
	Mammary system	-0.09
	Feet	0.07
	Foot	0.09
	Dairy strength	-0.10
Health/Fertility	Udder depth	-0.04
	Milking speed	0.12
	Age at first service	-0.92
	Non return rate	0.13
	Number of services	0.07
	First service to conception	0.32
	Calving to first service	0.34
	Lactation 1, persistency	-0.05
	Lactation 2, persistency	0.35
	Lactation 3, persistency	0.35

Table 10

Relative economic values (REV) of all significant traits and disease traits in the prediction of cow daily margins from birth to parity 4.

Traits	REV	Additional Traits	REV
Lactation 1, 305-d Protein	1.00	Conformation	0.37
Lactation 1, 305-d Milk	8.37	Front	0.19
Lactation 1, 305-d Fat	1.21	Chest	0.45
Lactation 1, SCS	-0.06	Loin	0.21
Lactation 2, 305-d Protein	1.17	Weight	-0.69
Lactation 2, 305-d Milk	4.42	Height	0.04
Lactation 2, 305-d Fat	1.46	Fore udder placement	0.28
Lactation 2, SCS	-0.10	Teat length	-0.32
Lactation 3+, 305-d Protein	0.36	Body depth	-0.22
Lactation 3+, 305-d Milk	4.96		
Lactation 3+, 305-d Fat	0.84	Mastitis	-0.10
Lactation 3+, SCS	0.00	Lameness	0.10
Milking speed	-0.01	Cystic ovaries	0.08
Survival	0.05	Displaced abomasum	0.06
Mammary system	-0.04	Ketosis	-0.01
Feet	0.21	Metritis	-0.05
Foot	-0.41	Milk fever	0.02
Dairy strength	-0.40	Retained placenta	-0.05
Udder depth	-0.40		
Milking speed	0.12		
Age at first service	-1.92		
Non return rate	0.25		
Number of services	0.03		
First service to conception	-0.05		
Calving to first service	0.77		
Lactation 1, persistency	-0.06		
Lactation 2, persistency	1.20		
Lactation 3, persistency	-0.33		

Table 11

Relative economic values (REV) of disease traits in the prediction of cow daily margins from birth to parity 4 when the incidence of one disease trait is doubled.

Traits	Trait with doubled incidence rate			
	Mastitis	Lameness	Cyst. Ov.	Dis. Ab.
Mastitis	-1.09	-0.64	-0.91	0.11
Lameness	0.73	1.24	0.59	-0.11
Cyst. Ov.	-0.44	-0.20	-0.65	-0.78
Dis. Ab.	0.47	1.14	0.13	0.15
Ketosis	-0.12	0.07	0.21	0.71
Metritis	-0.67	-1.00	-0.14	0.21
Milk fever	0.40	-0.56	0.16	0.45
Ret. placenta	-0.24	-0.25	-0.08	-0.23
Traits	Trait with doubled incidence rate			
	Ketosis	Metritis	Milk fever	Ret. placenta
Mastitis	-0.60	0.35	-1.22	-0.08
Lameness	0.51	0.12	1.09	-0.10
Cyst. Ov.	-1.12	-0.30	-1.67	-0.02
Dis. Ab.	-0.28	0.17	0.34	0.12
Ketosis	1.31	0.06	1.15	0.16
Metritis	-0.54	0.15	-0.20	-0.03
Milk fever	0.07	-0.20	0.42	-0.06
Ret. placenta	-0.26	0.22	-0.28	-0.05