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Full Length Research Paper

Effect of length of productive life on genetic trend of milk production and profitability: A simulation study

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Longevity is an important economic trait in dairy cattle. Including this trait in a breeding scheme, increases profit. The aim of this study was to evaluate the relationship between length of productive life (LPL), genetic trend of milk production and profitability of herds. LPL has been defined as time from first calving to culling.A Dynamic stochastic model was used to simulate dairy herd system. This model consisted of biological characteristics such as reproduction, genetic and economic components. Both discrete (time-oriented) events such as freshening and breeding as well as continuous processes such as milk production and feed consumption were simulated individually for each animal. The basic characteristics of the animal component included pedigree, genetics, age at calving, number of service per conception, number of lactations and LPL. Other characteristics included time-oriented characteristics such as weight, age, physiological status, lactation stage, open days, pregnancy days, estrus cycle, service date and feed requirements. The herd was described as several animal groups: young stock (<1 year old), heifers (>1 year old) and several groups of lactating and dry cows. Increasing mean LPL of herd from 35 to 65 months over 20 years resulted in decreased herd genetic merit of milk from 2025 to 1751 kg and mean of herd genetic trend per year was decreased from 101.24 to 87.56 kg, because of increased generation interval. Increasing LPL resulted in increased profit. Increasing LPL was associated with decreased costs for raising replacement heifers and sale of surplus heifers increased. The ratio of cumulative discounted profit (CDP) for herds with 40, 45, 50, 55, 60 and 65 months of LPL to the lowest level of LPL (35 month), were 1.22, 1.43, 1.55, 1.68, 1.79 and 1.90 respectively across time.

Key words: Length of productive life (LPL), profitability, genetic trend, herds simulation.

INTRODUCTION

Several mathematical models have been published to provide comprehensive descriptions of the biological characteristics of a herd or other specific components of the systems, such as nutrition (Bywater and Dent, 1976), reproduction (Boneschanscher et al., 1982; Oltenacu et al., 1980), health (James, 1977), or genetics (Groen, 1988). Other models emphasize management strategies (Dijkhuizen et al., 1986; Congleton, 1984; Sorensen, 1989) or replacement decisions in relation to production and prices (Van Arendock, 1985; Gartner, 1981; Herrero and Berry, 1982; Groenendaal et al., 2004). These aspects play an important role for assessing how biologically sensitive the cattle system is to various production aspects. However, limitations and problems associated with the application of those models, at farm level, occur as they are built to analyze the implications of management changes in average farms or in specific sites and ideal conditions. The animal is the main physical component and provides the basis for the dynamics of the production system. It must have all the necessary attributes in relation to inputs including feed and outputs including milk, meat and offspring production. In livestock production, longevity is an important trait that affects profitability (Leon-Velarde and Quiroz 2001). Several studies (Jagannatha et al., 1998; Larroque and Ducrocq, 2001) have shown that this moderately heritable trait plays a considerable role in the farm economy by increasing the profit realized per cow.

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MATERIALS AND METHODS

Dairy Herd Sim 1.0 was used for the analysis (Honarvar, 2009). The Dairy Herd Sim is a dynamic stochastic model that describes the biological, reproduction and genetic characteristics as well as return and cost of dairy cows. The population had overlapping generations. The basic characteristics of the animal component included pedigree, genetic, age at calving, number of service per conception, number of lactations and herd life. Other characteristics included time-oriented characteristics such as weight, age, physiological status, lactation stage, open days, pregnancy days, estrus cycle, service date and feed requirements. The herds including several animal groups: young stock (<1 year old), pregnant and no pregnant heifers (>1 year old) and several groups of lactating and dry cows.

Milk production

Incomplete Gamma function which was proposed by Wood (1967) was used to describe milk production over lactation period. Mathematical equation of incomplete Gamma function is as below:

$$y_t = at^b e^{-ct}$$

Where, y_t is the milk yield (kg/day) at day t and a, b and c are parameters which determine the shape of the curve. Lactation curve parameters of the first, second and later lactations were estimated using Proc Nlin of statistical analysis system (SAS) software, for about 2 million test-day records from Iranian dairy herds.

Body weight

Body weights (BW) for lactations one and later by month in milk and month of pregnancy were calculated using the function described by van Arendonk (1985b) fitted on the body weight data described by the NRC (2001). These BW data were used when calculating dry matter (DM) feed intake and salvage values for culled cows. Body weight was calculated as a function of age, lactation and pregnancy following Korver et al. (1985):

$$BW_{t_d t_l t_p} = A \times \left[1-(1-YM/A^{1/3})\exp(-kt_a)\right]^3 + p_1 t_l p_2^{-1} \exp(1-t_l p_2^{-1}) + p_3 t_{pc}^3$$

Where, $BW_{t_a t_l t_p}$ is the cow's body weight (kg), t_a is her age in days, t_l is the number of days in lactation, t_p is the number of days pregnant, A is mature live weight (kg), y_0 is birth weight (kg), k is a growth rate parameter, p_1 is the maximum decrease of live weight during the lactation (kg), p_2 is the number of days during the lactation with the minimum live weight (kg) and p_3 is a pregnancy parameter; $t_{pc} = t_p - 50$ when $t_p - 50 > 0$, otherwise $t_{pc} = 0$.
The pattern of growth in calves was determined by the following function (Koenen and Groen, 1996):

$$y_t = A\,(1 - b\ \exp(-kb\ \ t))^3$$

Where, y_t is body weight (kg) at age t (days), A is asymptotic mature body weight (kg) and B is a constant of integration and kb is maturation rate.

Table 1. Abortion risk (%) per each month (mo) of pregnancy (prg) within parities.

Prg (mo)	Parity 1	Parity 2	Parity ≥ 3
2	0.45	1.15	1.81
3	0.82	2.52	3.20
4	1.29	2.42	2.65
5	2.14	2.63	2.23
6	1.32	1.92	1.53
7	0.96	1.48	1.28
8	1.02	1.49	1.39

Abortion

Embryonic mortality after 42 to 260 days was considered to be an abortion. The abortion risk for each month of pregnancy was calculated by SAS 9.1, proc Lifereg from data of Holstein dairy cows in Iran. Table 1 shows the abortion risk (%) per each month of pregnancy (prg) within parities.

Reproduction

Reproduction is part of the life cycle of the animal and determines the dynamics of the herd. Pregnancy rate (PR) is a function of conception rate (CR) and estrus detection rate (EDR). Estrus cycle is one of the time-oriented reproductive characteristics for each open cow and heifer. Estrus cycle ranges from 18 to 24 days. CR, EDR and estrus cycle period were sampled from a random uniform distribution between 0 and 1. For all cows, the voluntary waiting period (VWP; the first part of the lactation during which no insemination occurs) was set to 45.
Calving interval is usually calculated as:

$$CI = vwp + PL + 21/(EDR \times CR)\ .$$

Since it can be affected by abortion risk, it can therefore be revised as follow:

$$CI_i = vwp + PL + 21/(EDR \times CR) + \sum_{j=2}^{8}(R_{ij}\,(j \times 30 + 21/(EDR \times CR))$$

Where, CI_i = Calving interval for i^{th} parity (d), VWP = Voluntary Waiting Period (d), EDR = estrus detection rate (%), CR = conception rate (%), LP = length of pregnancy (assumed to be 274 d), j = pregnancy month, EDR and CR were sampled from a random uniform distribution, R_{ij} = is abortion risk for i^{th} parity and j^{th} month of pregnancy. Figure 1 shows the simulation process of the reproductive cycle including the main reproductive components of the model.

Simulation of LPL

Longevity is a trait with a significant impact on the profitability of a dairy cow. An improvement in longevity can result in decreased replacement costs and a higher proportion of mature cows in a herd. This allows the cow an opportunity to achieve mature production levels (Essl, 1998).

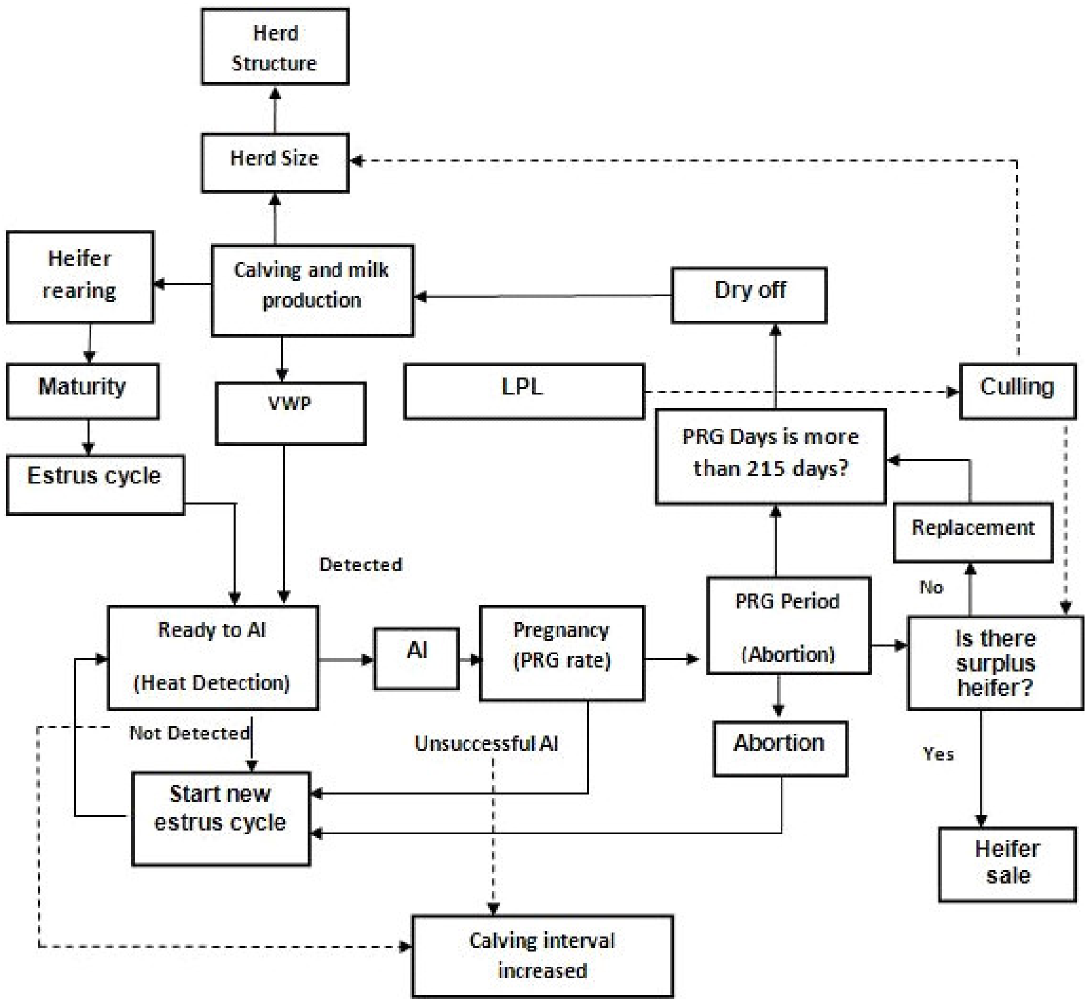

Figure 1. Simulation process of the reproductive cycle. PRG = Pregnancy; AI = artificial Insemination; VWP = voluntary waiting period.

In order to simulate length of productive life (LPL), culling probability distribution should be known at each month after first calving. To do this, the results reported by DeVries et al. (2004) were applied in the present simulated model. Mean and variance of LPL varies by changes in culling probabilities. Therefore, the culling probabilities were multiplied by a range (0.1 to 5 stepped by 0.01) constant factor (cf) to generate 490 different populations in which LPL levels differed. Increase in cf led to decrease in LPL. There was an exponential relationship between cf and average LPL in simulated populations as shown in Figure 2. Also, there was a nonlinear relationship between mean and variance.

Culling probabilities per month were less for animals with higher breeding values of LPL. So, animals with greater breeding values had lower cf and vice versa.

Proc NLIN of SAS was used to detect the mathematical relationship between cf and the initial phenotype of (SAS Institute, Inc., Cary, NC). This equation was defined as follows:

$$cf_i = b_1 P_i + b_2 e^{(b_3 P_i)}$$

Where, cf_i is the corresponding coefficient for animal i, b_1, b_2 and b_3 are coefficient of regression, the constant e is the base of the natural logarithm and P_i is initial phenotype of i_{th} animal.

The curve is divided to several sections to increase the precision. Table 2 shows the estimated regression coefficients for different parts of curve. This equation was used to convert each initial phenotype of LPL (P_i) to the expected culling probability per each month after calving. Finally, each cow will be culled based on its culling probabilities, *t* months after first calving (ultimate phenotype).

Other inputs and prices

Prices were derived from various farms to obtain realistic returns and costs as observed in Iranian dairy industry. NRC (2001) was used to calculate dry matter intake (DMI), protein and energy requirement for calves, heifers, dry and lactating cows. The 15 milk production classes were calculated as described by van Arendonk (1985a) with the lowest class equal to 70% of the average daily milk production and the highest class equal to 130%. DMI was a function of milk production class, body weight and pregnancy days. All transition of physiological status between and within each month was calculated individually. Typically, yearly veterinarian costs per

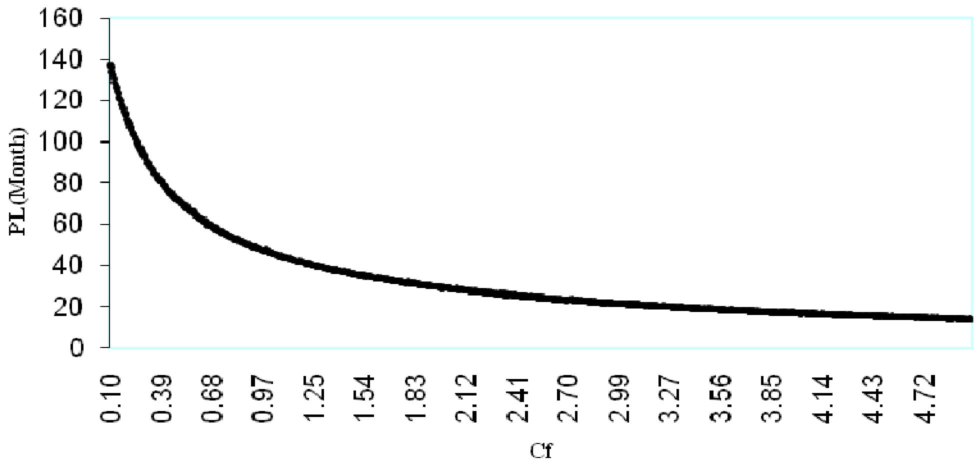

Figure 2. Nonlinear relationship between LPL and cf*. *Constant factor (cf) multiplied by the culling probabilities were a range (0.1 to 5).

Table 2. Regression coefficients for different levels of LPL per month (mo).

LPL(mo)	Regression coefficients		
	b_1	b_2	b_3
70 and more	-0.0001	2.3350	-0.0234
35-70	0.0025	5.8644	-0.0300
30-35	0.0077	8.8892	-0.0604
25-30	0.0113	10.4931	-0.0684
21-25	0.0157	11.9597	-0.0764
17-21	0.0272	14.7114	-0.0909
15-17	0.0439	17.5814	-0.1069
14 and less	0.0425	17.6751	-0.1068

cow were estimated at € for an average first lactation cow and increased by 5% for each lactation. Groenendaal et al. (2004) assign 33% of these costs to first month, 11% to the second and third months and 5% to the later months of each lactation. Table 3 shows herd data including parameter values used for parameter in the model.

RESULTS AND DISCUSSION

Several herds with different levels of LPL (35, 40, 45, 50, 55, 60 and 65 month) were simulated to evaluate the genetic trend of milk yield and herd profitability across time. The relationship between initial phenotype of LPL (P_i) and culling probability per month after first calving is presented in Figure 3. Animals with greater P_i had lower constant factor (cf) and culling probability, and were expected to remain longer in the herd.

Proportion of remained animal in herds with 35, 45, 55 and 65 LPL months were 0.653, 0.742, 0.808 and 0.857 for two years after first calving and 0.450, 0.570, 0.675 and 0.738 for three years after first calving, respectively. Kaplan-Meier survivor curves of different levels of LPL are shown in Figure 4.

Herd genetic merit for milk increased by simulation years because cows and heifers were bred to sires with milk genetic trend of 150 kg per year. Increasing mean LPL of herd from 35 to 65 months over 20 years resulted in decreased herd genetic merit of milk from 2025 to 1751 kg (Figure 5).

Mean genetic trends for milk yield in simulated herds with different levels of LPL are presented in Figure 6. Mean of herd genetic trend per year decreased from

Table 3. Herd data including parameter values used for parameter in the model.

Variable	Parameter value, price, or unit	
Replication	40	
Breeding period	10	Year
Simulation period	20	Year
Herd size (including female calf, heifers and cows)	About 6000	Head
Residual variance of milk	757000	kg^2
Genetic variance of Milk	292852	kg^2
Herd Structure	**Depends on LPL mean**	
Birth weight	42	Kg
Mature live weight	600	Kg
Heat detection rate	50	%
Conception rate	40	%
Voluntary waiting period	45	Day
Cow mortality	5	%
Calf mortality	5	%
Age at first calving	24	Month

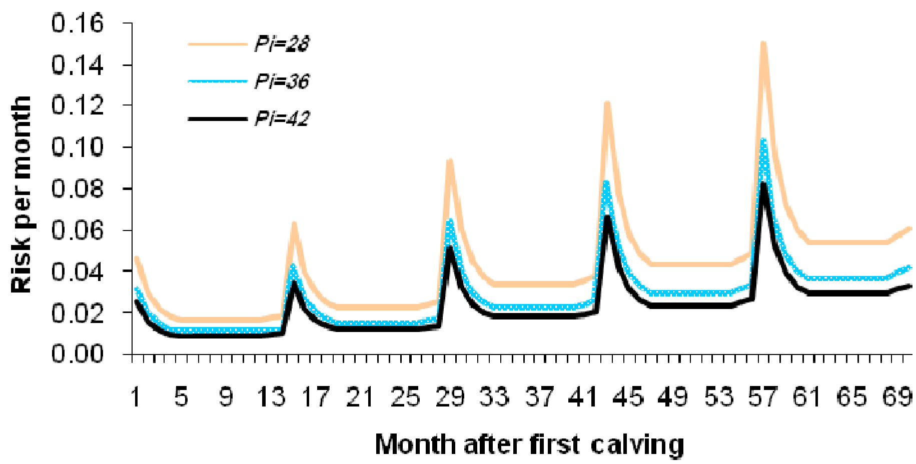

Figure 3. Relationship between initial phenotype of LPL (P_i) and culling probability per each month after first calving*. *Relationship between LPL (P_i) and culling probability for first five lactations (Calving interval was assumed to 14 months). Animals with greater P_i had lower cf and culling probability, and were expected to remain longer in the herd.

101.24 to 87.56 kg with increasing LPL mean form 35 to 65 months, because of increasing generation interval.

Herd structure varied by increase in LPL levels. Since proportion of mature cows increased with increasing LPL level (Figure 7). When LPL level increased from 35 to 65 months, proportion of cows (parity number) changed from 0.362 to 0.217 (1), 0.269 to 0.193 (2), 0.178 to 0.162 (3), 0.102 to 0.129 (4), 0.051 to 0.099 (5) and 0.037 to 0.198 (6 to 12). Increasing LPL had two simultaneous consequences: increasing LPL levels led to decrease in milk BV and increase in the proportion of mature cows in herds. Therefore, an interaction exists between these consequences. Although herds with higher LPL levels had more mature cows proportion, older cows had less genetic merit in comparison to heifers. Regarding the mentioned interaction, herds with higher LPL levels had less milk production levels. This fact could be obviously revealed when genetic trend of milk increases. Milk yield per cow per month on average for simulated herds with different levels of LPL are shown in Figure 8.

The total net income for the system was calculated as the sum of daily income from milk, male calves, culled cows, heifers and other products minus cost including feed, veterinary and health, labor, livestock supplies, real estate and equipment repairs, home expenses, trucking and miscellaneous. Unit prices and costs considered for

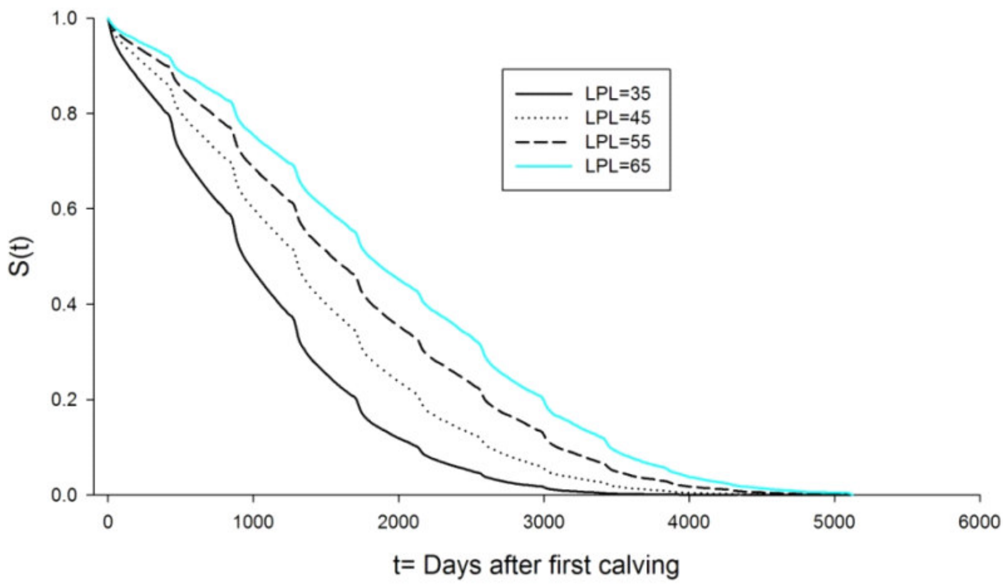

Figure 4. Kaplan-Meier survivor curves of different levels of LPL. S (t) is the Probability of survival*. *Proportion of remained animal in herds with 35, 45, 55 and 65 LPL months over days after first calving.

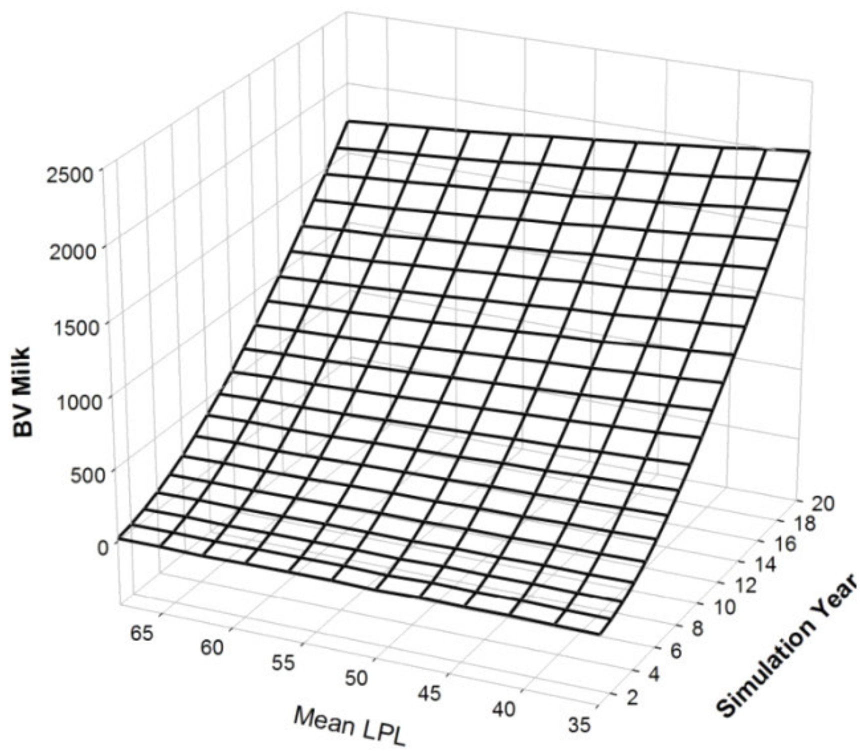

Figure 5. Genetic trends for milk production over 20 years for simulated herds with different means of LPL. Increased LPL led to decrease in milk breeding values due to prolonged generation interval over years.

calculation of profit are summarized in Table 4.

Profit (per cow per year) from different levels of LPL increased over years, because all simulated herds benefited from genetic trend for milk production across the

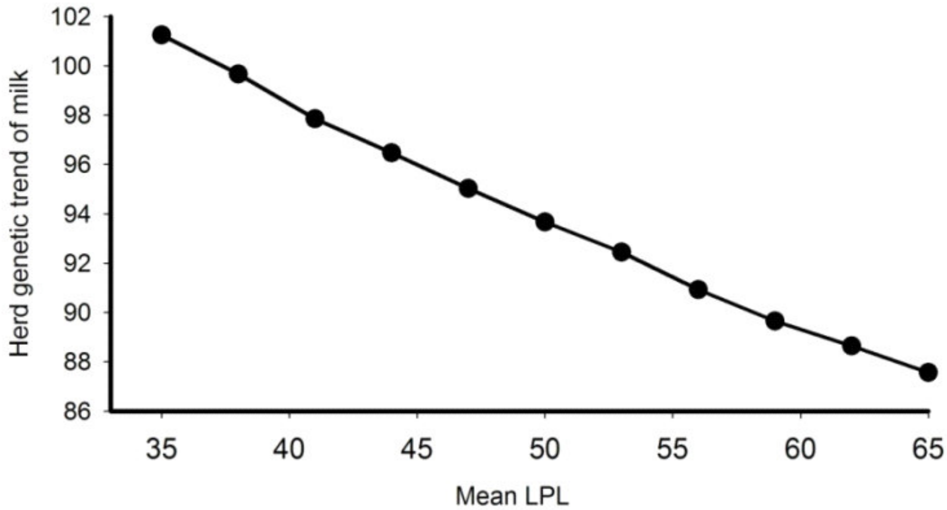

Figure 6. Mean genetic trends for milk yield in simulated herds with different levels of LPL*. *Mean of herd genetic trend per year decreased from 101.24 to 87.56 kg with increasing LPL mean form 35 to 65 months, because of increasing generation interval.

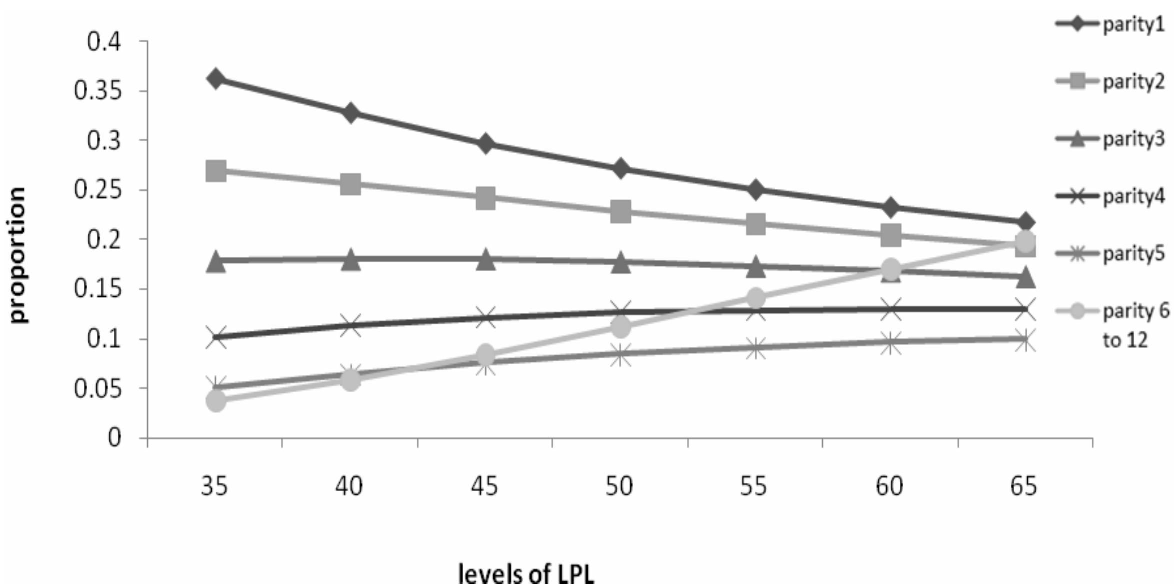

Figure 7. Proportion cows with different parities in simulated herds with different LPL levels. Herd structure varied by increase in LPL levels.

years. Figure 9 shows the cumulative discounted profit (Euro) per cow during 20 years for simulated herds with different levels of LPL. Although genetic trend for milk production decreased with increasing LPL levels, profit increased. Because proportion of female calves and heifers in the herd decreased by increasing mature cows proportion.

Therefore, increase in LPL led to decrease in culling rate (Figure 11), replacement heifer rearing costs and increase surplus sold breeding heifers (Figure 10). The number of surplus heifers is a very important part of dairy farm income in Iran. This factor was affected by several factors such as, level of LPL, average calving interval period, abortion risk and age at first calving among others.

The ratio of cumulative discounted profit (CDP) for 35, 40, 45, 50, 55, 60 and 65 months of LPL to the lowest level of LPL (35 months), were 1, 1.22, 1.43, 1.55, 1.68, 1.79 and 1.90, respectively (Figure 12). Herds with 65 months of LPL in comparison to those with 35 months of LPL had 90% higher economic efficiency.

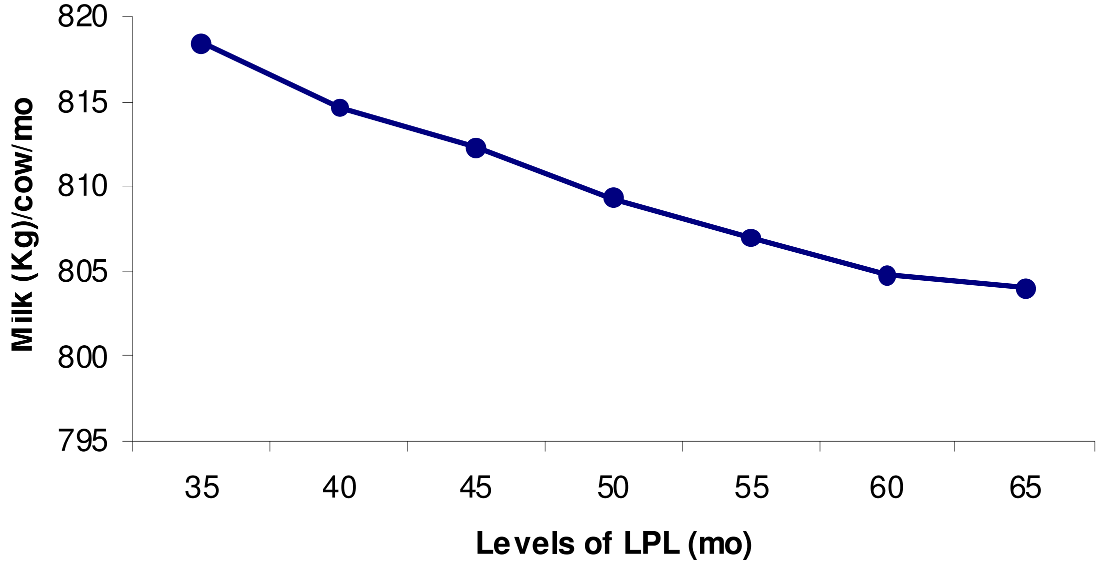

Figure 8. Milk yield per cow per month on average for simulated herds with different levels of LPL*. *Although herds with higher LPL levels have more mature cows proportion, older cows have less genetic merit in comparison to heifers. Regarding the mentioned interaction, herds with higher LPL levels had less milk production levels. This fact could be obviously revealed when genetic trend of milk increases.

Table 4. Unit prices and costs considered for calculation of profit in the model.

Average milk price	0.315	€/kg
Feed cost (cow/day) *	-	
Labor cost	26	€/cow/month
Meat price	2	€/kg
Heifer price	3077	€
Carcass weight price	1.3	€/kg
Veterinary costs (for an average first calving heifer)	120.4	€/cow/year
Insemination cost	15.38	€/breeding
Discounting rate	0.05	year

*According to NRC (2001), feed costs depends on physiological status, body weight and milk production.

The prices of milk, feed, culled cows and sold calves are the major contributors to income and costs. The result of the model sensitivity analysis showed that the profit was strongly influenced by the milk yield. Figure 13 shows cumulative discounted profit under base of evaluation and its sensitivity to changes in price of milk by ± 10% and ± 20%, respectively. Decreasing the price of milk caused a significant drop in cumulative discounted profit so that CDP became negative. However, increasing LPL level from 35 to 65 months had a tendency to reduce this effect. The sensitivity of CDP to changes in the milk price is due to the fact that milk is the most important items in farmer's return in Iran. As mentioned above, the effect of changes in prices of feed was also evaluated but the results for feed were not shown. This is because the pattern was the same as the milk. Figure 14 shows cumulative discounted profit under base of evaluation and its sensitivity to changes in price of surplus breeding heifer by ±10 and ±20%, respectively. The sensitivity of analysis revealed that CDP is more sensitive to milk price in comparison to sale of surplus breeding heifer. Increasing sale of surplus breeding heifer caused a significant rise in CDP. This effect can be manifested in herds with higher level of LPL.

Combinations of low and high prices were examined to study the impact of price fluctuations on profit. The economic advantage of increasing LPL was obviously influenced by the heifer/milk price ratio. When heifer to milk price ratio was high, more positive economic impact by increased LPL could be expected.

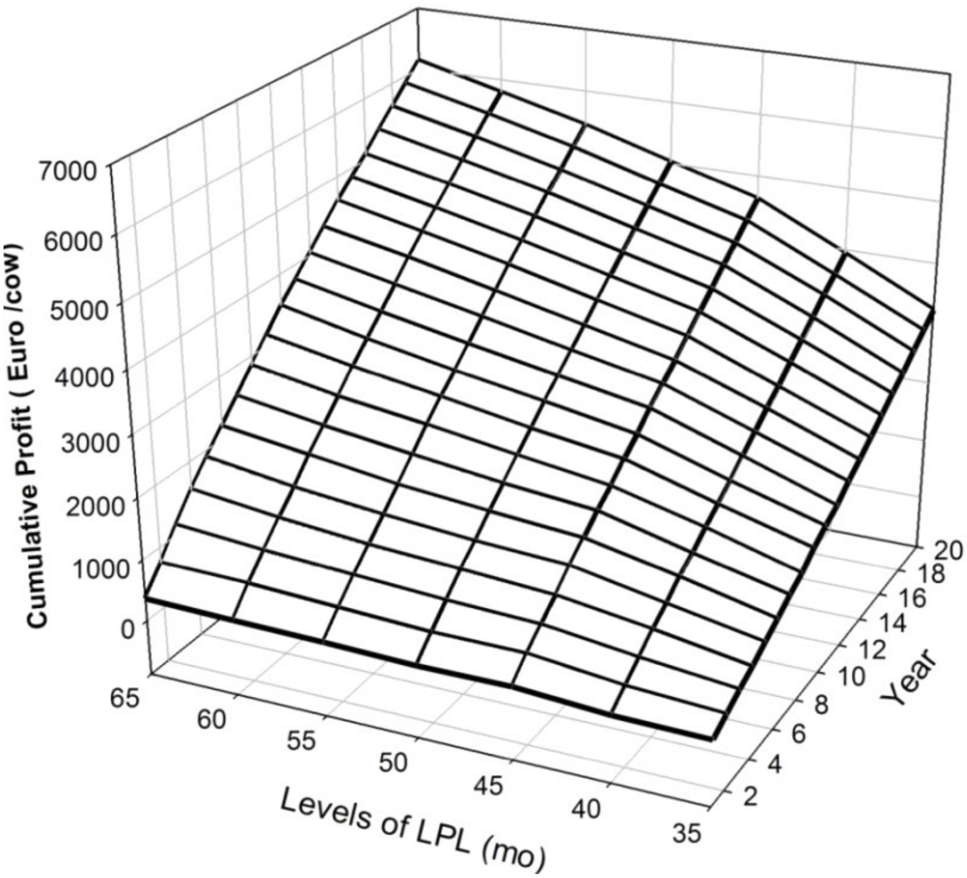

Figure 9. Cumulative discounted profit (CDP) (€)/cow across time for different levels of LPL. Although genetic trend for milk production decreased with increasing LPL levels, profit increased

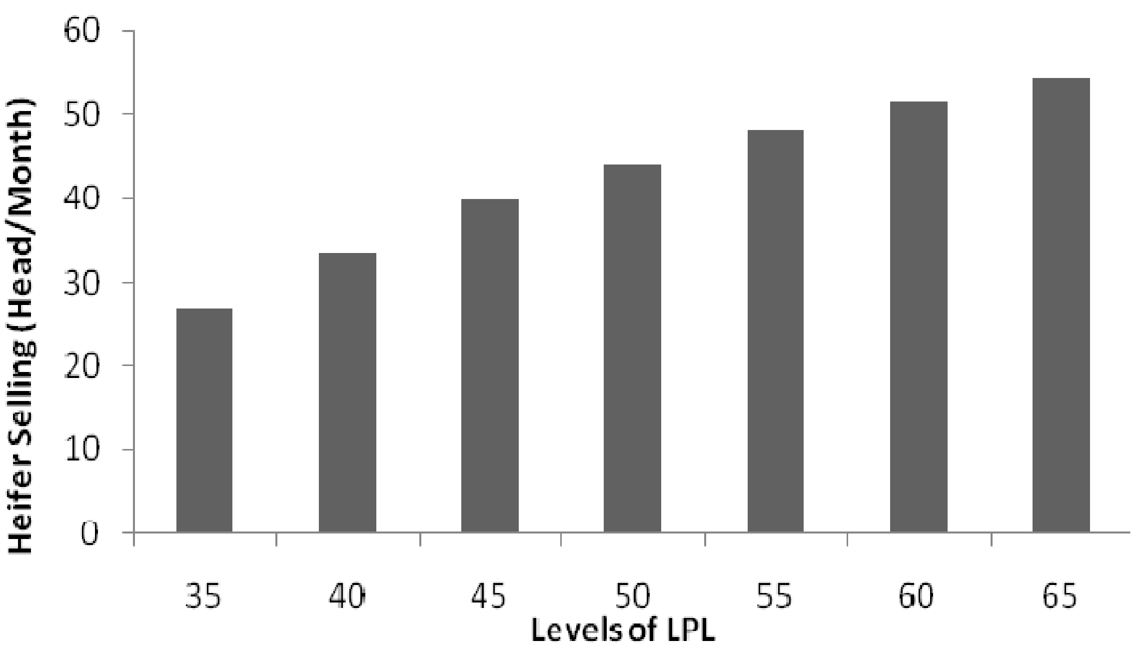

Figure 10. Heifer sale (head/month) in simulated herds with different levels of LPL.

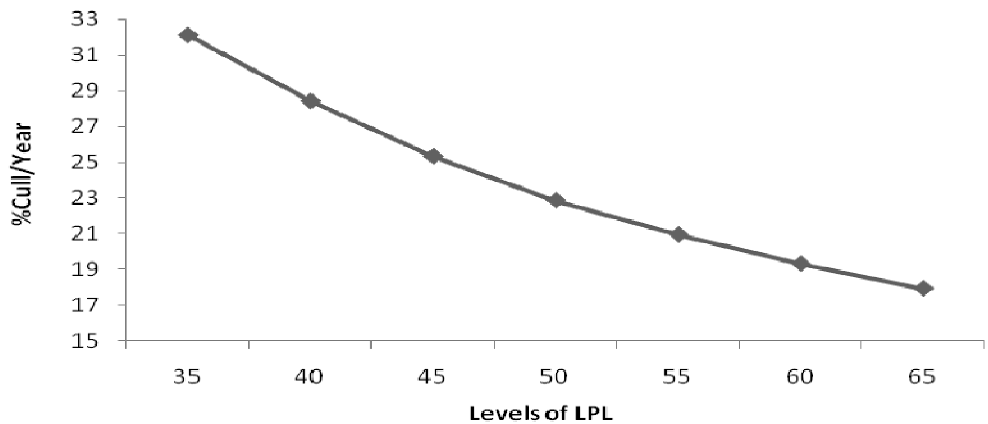

Figure 11. Culling (%) in simulated herds with different levels of LPL.

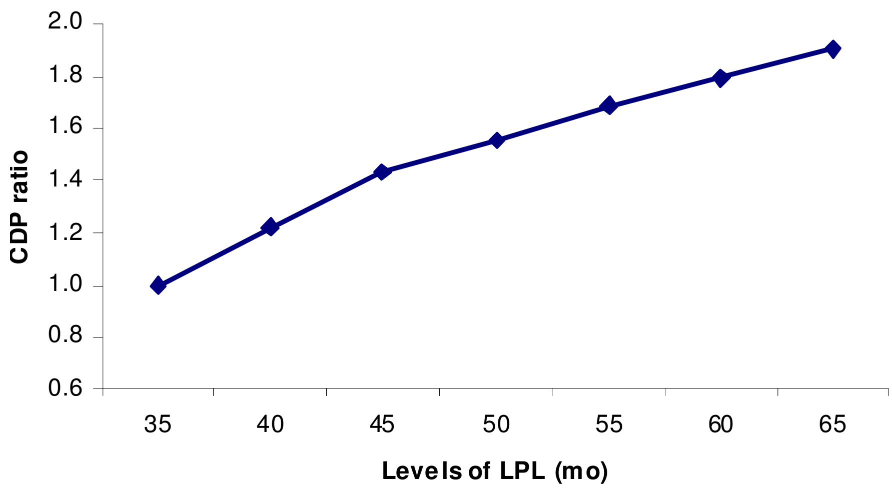

Figure 12. The ratio of cumulative discounted profit (CDP) for different levels of LPL to the lowest level of LPL (35 months).

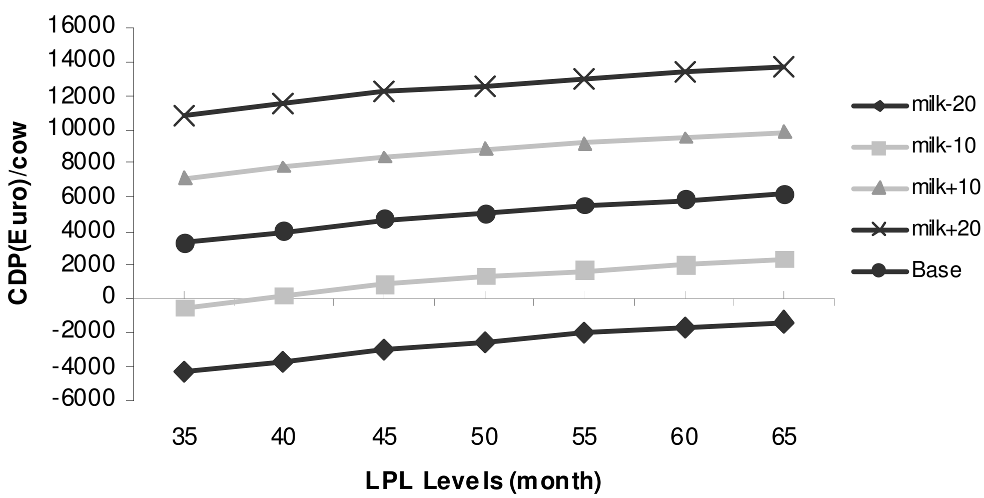

Figure 13. Cumulative discounted profit under base of evaluation and its sensitivity to changes in price of milk by ±10 and ± 20%, respectively.

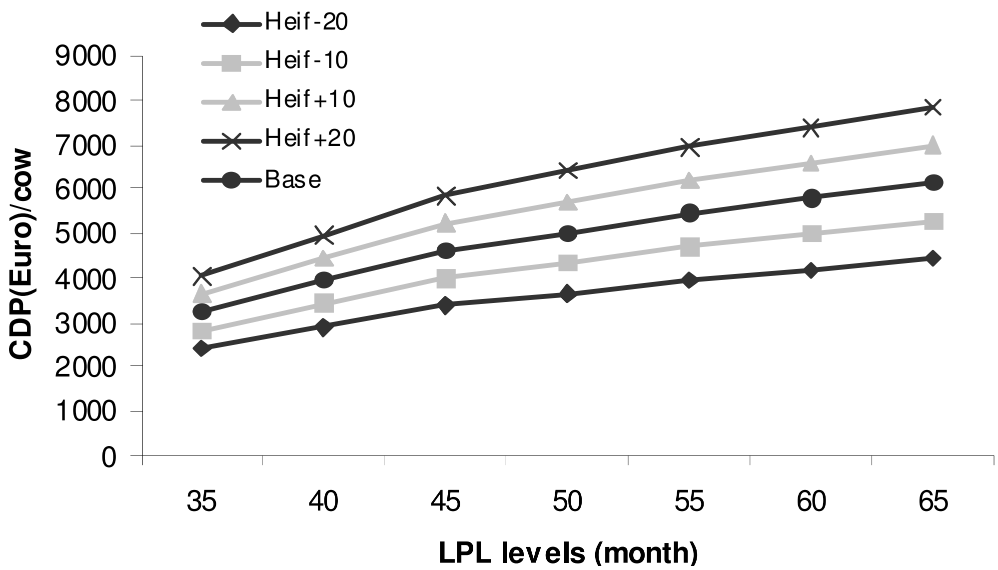

Figure 14. Cumulative discounted profit under base of evaluation and its sensitivity to changes in price of surplus breeding heifer by ±10 and ±20%, respectively.

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