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Economic drivers of the optimal productive lifespan of dairy cows in two different Swiss milk production systems

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ABSTRACT

The short lifespan of dairy cows not only raises ethical questions but is also the subject of economic debates. Determining the economically optimal productive lifespan (OPL) is a complex issue because a large share of cows is culled during the first 2 lactations. The objective of this study was to estimate the OPL, taking into account relevant influencing factors, such as milk loss risks, heifer costs, and breeding progress (BP). We developed a bioeconomic cow model for 2 production systems with different milk-yield levels (C_low = 6,194 kg/year, C_high = 9,338 kg/year) based on the net revenue approach. The model used accounting data from 189 family farms and herd-specific data from 9,858 cows with 10 completed lactations, as well as culling statistics from different breeds based on herdbook data. To estimate the impact of different risk scenarios on OPL, culled cows were assigned a milk loss of 10% to 50%. The theoretical OPL excluding milk loss risks was over 9 yr of productive lifespan, with marginal income declining significantly from the fourth year of production onwards. With an effective productive lifespan of 3.6 years (C_low) or 2.9 years (C_high), the milk loss rate expected by the farm was estimated to be around 25% if the cows remained in production for longer. Heifer costs had a significant influence on OPL: with heifer costs between 2,700 and 5,000 USD and considering 25% risk, OPL varied between 3 and 7 yr. For the baseline scenario for heifer costs (3,423 USD), the OPL was found to be between the fourth and fifth years of production. The effect of BP in milk yield on OPL was weak: Assuming 2% BP per generation reduced OPL by 6 mo, compared with the baseline assumption of identical replacement. To fully exploit income potential, it is more important to improve production reliability by reducing risk, which is particularly relevant for higher-yielding cows. This requires a stronger focus on fitness-related traits, such as fertility and health. A realistic economic potential of higher longevity was found between 10% and 15% higher income per cow, which was achieved for an average productive lifespan of 4 years and 6 years for C_high and C_low, respectively.

INTRODUCTION

In recent years, public criticism of dairy production has increased, with cow welfare being the most important concern of society, not only in Switzerland but also in other countries (Boogaard et al., 2008; Cardoso et al., 2016; García-Ruiz et al., 2016; GFS-Zürich, 2018; Ammann et al., 2024).

The longevity of a cow is commonly associated with animal welfare, based on the assumption that poor animal welfare, including increasing milk yields, will push cows to their health limits, ultimately causing an early exit from the production system (Bascom and Young, 1998; Knaus, 2009; Rushen and de Passillé, 2013; De Vries, 2020). Some years ago, death in the barn was identified as the most frequent cause of all disposals in US dairy herds (Pinedo et al., 2010).

There are numerous surveys on the average length of the productive lifespan (**LPL**) of dairy cows, which ranges from 2.5 to 4.5 years (Heikkilä et al., 2008; Wathes et al., 2008; Ahlman et al., 2011; Nor et al., 2013; Kerslake et al., 2018; Schuster et al., 2020; De Vries, 2020). In general, there is a common sense that LPL is too low, which, in addition to animal welfare, would also threaten the economic viability of milk production. This is expressed in some model calculations of the economically optimal productive lifespan (**OPL**), ranging from 4 to 9 years, which is about double the realized LPL. Calculations that excluded the risk of health disorders, fertility problems, or low milk-yield values were at the upper end of the range (Zeddies, 1972; Gantner et al., 1990). Studies that included these risks or considered the breeding progress (**BP**) of the new replacement cow

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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-25. Nonstandard abbreviations are available in the Notes.

resulted in a lower OPL (Simianer, 2003; Heikkilä et al., 2008; Kiefer et al., 2019; De Vries, 2020). After all, cows leave the farm, on average, before they are biologically fully mature and before they can produce the maximum milk yield after the fourth lactation (Horn et al., 2012; Pritchard et al., 2013; Missfeldt et al., 2015), with most cows exiting during the first 2 lactations (Pinedo et al., 2010; Dallago et al., 2021; Bieber et al., 2023).

The reasons for the gap between real LPL and perceived OPL have been addressed in different studies. Researchers have highlighted different health problems and poor fertility as the cause of involuntary or unplanned disposals (Allaire et al., 1977; Pinedo et al., 2010; De Vries and Marcondes, 2020), and even poor milk yield is identified as a reason for involuntary or unplanned disposal, given that the (theoretically calculated) OPL is considered planned (Missfeldt et al., 2015; Rödiger and Home, 2023). The extent to which health and fertility problems or the improved genetics of the replacement cow explain the difference between the actual LPL and the expected OPL has been discussed in some studies (Heikkilä et al., 2008; Missfeldt et al., 2015; Kiefer et al., 2019; Owusu-Sekyere et al., 2023). The level of milk yield and the associated risks to health and fertility cannot explain the difference alone, especially because the productive lifespan has remained stable in recent years despite increases in milk yield (De Vries, 2017; Alvåsen et al., 2018; Dallago et al., 2021; Schuster et al., 2020; Heikkilä et al., 2008; Identitas, 2023). According to Fetrow et al. (2006), a distinction between voluntary and involuntary disposals does not seem useful. It is much clearer to distinguish between forced disposals and disposals for economic reasons, whereby cows are only forced to leave due to death, obviously incurable disease, or inability to continue producing milk. All other disposal reasons, including those due to health or fertility problems, ultimately have economic motivation and are subject to the manager's decision (De Vries, 2020).

Studies on the determination of OPL are rare (De Vries and Marcondes, 2020; Adamie et al., 2023), especially those that attempt to account for varying production situations, different levels of milk yield, and different farmer attitudes. Previous studies have mostly been based on an average standard situation, with correspondingly numerous assumptions about the various cost items and without taking into account different farming situations (Zeddies, 1972; Steinwidder and Greimel, 1999; Missfeldt et al., 2015; De Vries, 2020). In general, there seems to be a lack of integration into the overall system of milk production, hindering clear conclusions about the economic relevance of productive lifespan. To our knowledge, there has been little research on the economic interactions of productive lifespan and milk yield together with secondary performance traits, such as health or fertility. It is well known that higher-yielding cows require more demanding management to ensure milk yield (Nebel and McGilliard, 1993; Wilkinson et al., 2020). On farms where there is no well-developed management for high-yielding cows, this leads to higher risks and milk losses due to fertility and health problems. However, high culling rates in early lactations do not only occur in higher-yielding cows (Bieber et al., 2023). If cows have at least one incident in their first or second lactation, they are often culled at an early stage because the cow is also expected to generate lower milk revenue in the future. The subsequent losses are therefore based on expectations and cannot be verified with data because the cows are no longer alive, mainly due to economic reasons. The inclusion of these obvious risks makes the calculation of OPL speculative because the data are censored. To avoid distortion, culled cows with hypothetical milk revenue losses must therefore be considered.

The aim of this study and its main scientific contribution is to advance the understanding of the economic implications of productive lifespan and to assess the effect of some relevant factors on the culling decision under conditions of incomplete information. The analysis is based on a bioeconomic model. Compared with previous studies, the full costs of the dairy cow and the costs of the heifer are mapped on the basis of real farms from an accounting network, which are combined with real herdbook data from breeding organizations. The model is applied to 2 different production systems with different milk-yield levels, whereby the income in each phase of a cow's productive lifespan is modeled year by year across all outputs (milk and calves) and inputs (variable operating costs and overhead costs).

The OPL is calculated by varying the following 3 factors: (a) the economic effects of fitness-related production losses (10%–50% loss in milk revenue for cows that are removed), (b) different heifer costs (2,700–5,400 USD/head), or (c) BP in milk yield (1%–2% per generation). Furthermore, the economic relevance of a cow's productive lifespan is estimated based on herds with different age structures at the level of the entire production system.

MATERIALS AND METHODS

To calculate the OPL of a cow, we used the well-established marginal net revenue approach (Zeddies, 1972; Van Arendonk, 1984, 1985). Compared with dynamic programming models, this approach achieves similar results for decision-making and is also transparent and comprehensible via a spreadsheet model (Groenendaal et al., 2004). In this study, the method was applied to real accounting data. To assess the economic relevance of a cow's productive lifespan in the overall milk production

Table 1. Glossary of relevant abbreviations used for performance indicators

Abbreviation	Explanation
CEI	Expected average annual income of replacement cow after culling in year *n*
CMI	Marginal income of the present cow, if it stays in production for another year
CInc	Cow's current income in a production year, optionally discounted
CPD	Net profit differential between CEI and CMI in year *n*
CDI	Annual "dairy herd" income per cow (modeled)
DI	Annual dairy income from accountancy (income of the production system)
LPL	Length of productive lifespan
OPL	Economically optimal productive lifespan

system, overhead costs, such as infrastructure, machines, and labor, were also considered. Therefore, overall farm accounting data from a selection of dairy farms were split into the single production years of a cow to allow the calculation of the net income per cow for each year of her productive lifespan. To achieve this objective, various technical production data (herd data) were required in addition to economic data. Table 1 lists the main abbreviations used for performance indicators.

No human or animal subjects were used, so this analysis did not require approval by an Institutional Animal Care and Use Committee or Institutional Review Board.

Economic Data

Data Origin. Two distinct farm accountancy datasets are available in Switzerland (Renner et al., 2019). The first is designed to monitor income trends, and the second, the farm management sample, provides more detailed data at the product branch level. This study used economic data from the second, more detailed dataset, which covers a total of around 1,600 farms per year. From this dataset, 189 dairy family farms were selected from 2020 to 2023 based on criteria such as region, farm size, and milk yield per cow.

Data Selection Criteria and Definition of Production Systems. Farms in the lowlands were considered because they have the most favorable natural production conditions and produce the largest proportion of milk. The average herd size in this region is around 30 cows (Agristat, 2023). There is a great diversity of milk production systems, which is primarily due to different natural site conditions but also the different preferences of the farmers. We therefore differentiated 2 production systems by milk-yield performance and their underlying feeding systems: farms with low-yielding cows (**C_low**) and primarily grass-based feed with a lot of grazing and farms with high-yielding cows (**C_high**) with a higher proportion of concentrated feed and frequent barn feeding. The upper limit for milk yield in the low-yielding group was set at 7,000 kg because up to this maximum yield level, it is possible to feed the cows almost exclusively on roughage (including maize silage, with concentrate only in early lactation). The filter criteria for the nonrandomly selected samples were defined step by step so that, on average, the farm groups were as similar as possible in terms of farm size and forage area (Table 2).

Overhead Costs. Production systems with different milk yields and feed rations result in different overhead costs. A higher share of conserved feed in the total annual feed supply increases the overhead costs compared with extensive grazing, because, for example, a larger building volume (storage), more machinery, and higher labor input per cow are required. The farm accounting data enabled a full-cost analysis, which was used to differentiate the overhead costs in the 2 production systems accordingly. Machinery, buildings, employees, capital, and general

Table 2. Selection criteria and main characteristics for farm groups with low-yielding cows ("C_low") and high-yielding cows ("C_high")

Item	Variable	C_low	C_high
Selection criteria	Region	Lowlands	Lowlands
	Agricultural area (ha)	>12	>12
	Share of cattle in total LU	>75%	>75%
	Number of cows per farm	>17–60	>17–45
	Milk yield (kg)	>4,500–7,000	>8,500
Characteristics of selected farm groups	Number of farms (sample)	110	79
	Average herd size (cows)	30.7	31.5
	Cow share of total cattle LU (average)	0.86	0.86
	Average forage area (ha)	21.5	19.5
	Average milk yield (kg/year)	6,194	9,338

structural costs associated with milk production were taken into account and summarized as overhead costs.

Heifer Cost Calculation. The heifer costs, which are particularly relevant to the research question, were calculated based on 2 different data scenarios. For the baseline situation, heifer costs were calculated based on the accounting data of the farm groups described in Table 2. Based on accounting data, the heifer costs of an additional 548 farms were also modeled for 3 different farm types as follows: (1) specialized rearing farms in mountain areas (without dairy cows; n = 31), (2) dairy farms in the hilly region with exclusively own rearing (n = 73), or (3) lowland dairy farms, which mainly outsourced rearing (n = 444).

Herd Data

For the analysis, we used a dataset of around 128,000 lactations of herdbook cows from the Swiss lowlands, containing various herd data such as dairy breed, milk yield, calving intervals, and lactation lengths differentiated by lactation number (Qualitas AG, 2022). The lactation yields were sorted by lactation number over 10 lactations. The resulting herd data from 9,858 cows on calving interval, lactation length, and age structure, as well as corresponding Wood factors for the estimation of lactation curves (Wood, 1967), were used for the conversion to a reference lactation (fourth lactation) for the average herd of each farm group. The survival rate data are based on recent surveys of culling rates in Switzerland for 5 different breeds: Brown Swiss (**BS**), Holstein-Friesian (**HF**), Original Braunvieh, Simmental, and Swiss Fleckvieh (Bieber et al., 2023). Age structure, as well as average productive lifespan, were calculated in a herd model according to the formula of Nieuwhof et al. (1989). We assumed that breed choice and production intensity were closely interrelated, with BS cows being more prevalent in low-intensity production systems and HF cows dominant in high-yielding systems. Therefore, survival rate data of BS cattle was used for the low-yielding herd, and that of HF cattle was used for the high-yielding herd. The productive lifespan corresponded quite well with the slaughter cow revenues from the respective accounting farms. The reciprocal of the productive lifespan corresponds to the replacement rate, whereby these values assume that no cows are sold alive.

Calculation Steps

The method for setting up the productive lifespan model of a cow will be outlined in several steps (Figure 1).

From the Farm Group to the Model Farm (Farm Analysis Model). The selected samples of farms also included mixed farms with activities other than dairy farming, such as crop farming in particular. Mean values of the structural data, yields, revenues, and direct costs per farm branch were used to derive a single model farm with the farm analysis model "AgriPerform" (Gazzarin and Lips, 2018). The spreadsheet tool enables automatic overhead cost allocation based on observations of more than 4,500 Swiss farm branch groups in the farm accountancy data network (Hoop and Schmid, 2015; Lips, 2017).

From the Model Farm to the Production System. The allocation of all costs and revenues to the farm branches with "AgriPerform" resulted in a full-cost accounting for a dairy branch that included replacement cattle. For the calculation of heifer costs, the overhead costs of the dairy branch were allocated by the share of own rearing cattle in livestock unit (**LU**). To replace the cows that had left the farm, the farm analysis model supplemented its own rearing with additional purchases, which were recorded in the accounting data and included in the heifer costs. The overheads for cows and heifers were then reduced by direct payments linked to the forage area and the implementation of animal welfare programs because these compensate particularly for natural production disadvantages and yield losses due to biodiversity services, as well as for the higher building costs due to animal welfare services. In addition to direct costs, this results in net overhead costs per cow.

From the Production System to a Single-Cow Model. Once the revenues and costs for the production system and the herd were determined, they were broken down across the different production years of an average cow. This was achieved by calculating allocation coefficients that reflected differences between the single production years of a cow (see Appendix, Tables A1, A2, A3, and A4 for additional cost and model assumptions). The base value to which the coefficients were applied was adjusted according to the herd's age structure. This ensured that the weighted sum of the values for each production year—calculated by multiplying each year's value by the corresponding cow "share"—matched the average value of a cow in the herd (i.e., the total accounting value divided by the number of cows).

The first step was to model the progression of milk yield over the 10 yr of productive lifespan. The correction factors for each lactation number were calculated based on the yield differences between the lactation numbers from the herd data and were related to the fourth lactation (fourth lactation factor = 1). The herd model was used to calculate the lactation yields of the respective herds of the production systems based on the age structure, calving interval (lactation rate), and the choice of Wood factors in such a way that the herd average (annual milk yield per cow) from the production system was equalized. The economic results from the modeled production

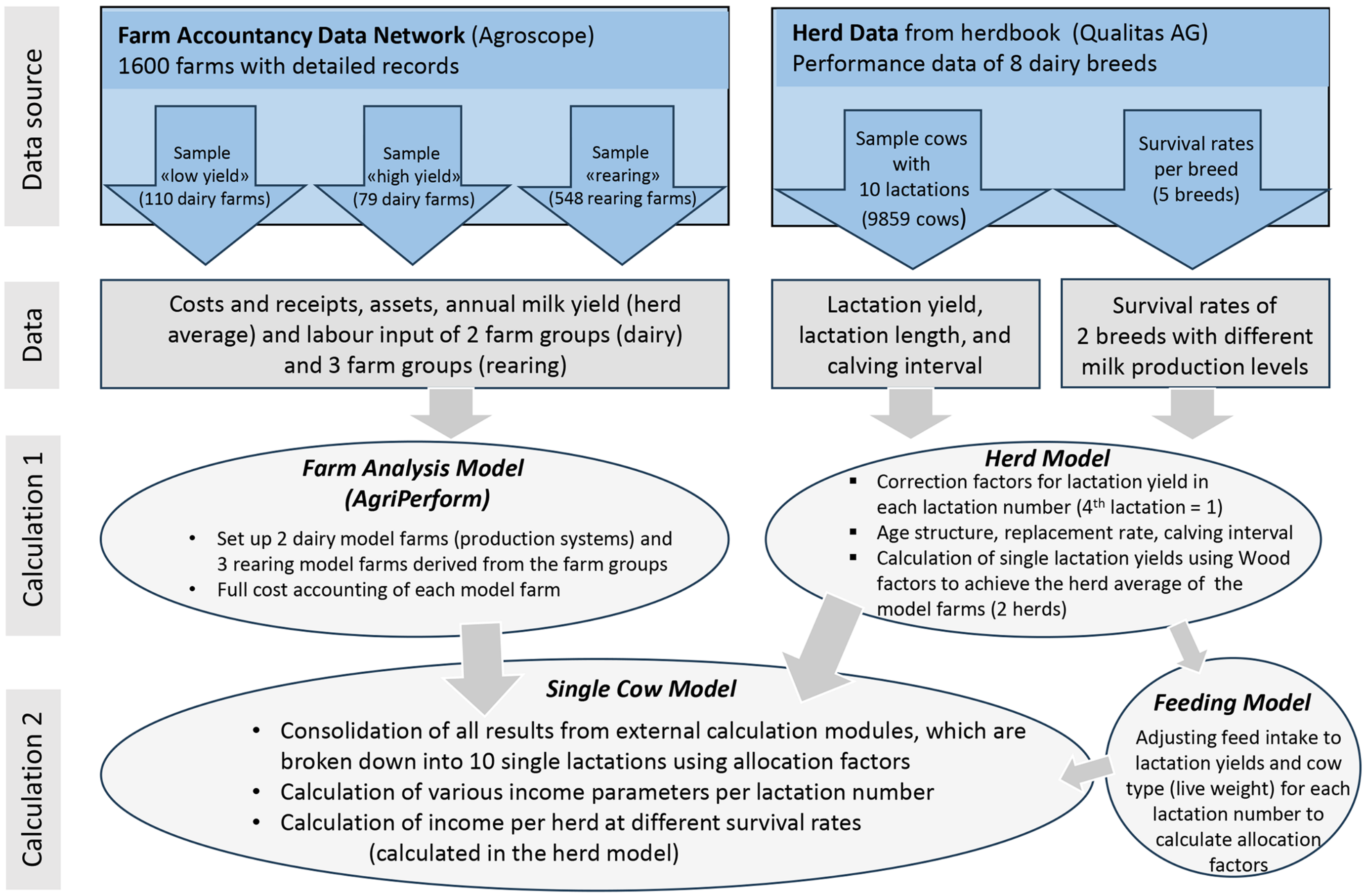


Figure 1. Simplified diagram of the model calculations.

system and biological parameters from the herd model were then merged into the single-cow model.

Next to the milk price, the share of milk sold in total production is also relevant for calculating milk revenues. The accounting data showed that 5%–10% of the milk was usually fed to calves, which resulted in higher slaughter weights and higher animal revenues.

The number of calves sold was also calculated using the herd-specific replacement rate, the average calving interval from the herd data, and the usual loss rates (1.5% stillbirths, 4% rearing losses; Agridea, 2024b). Given that the share of crossbred calves for fattening increases with a longer productive life or lower replacement rates, we increased the price by the corresponding factors, as crossbred calves are paid around twice as much as dairy breed calves (Agridea, 2024a, see Appendix). Again, the average prices were derived from the accounting data, including all animal sales generated by the farm's own cows. The use of sexed semen was included in the modeling but results are not reported or discussed.

The typical live weight (**LW**) of an adult cow for the respective average yield was also differentiated by production year using the coefficients from Burren et al. (2021; see Appendix, Table A3). These formed the basis for the calculation of slaughter revenues in the respective production year, whereby the average price was calculated based on the accounting data and the herd-specific replacement rate.

Most of the costs, such as costs for supplementary feed (concentrates) and the main overheads were allocated to single production years based on coefficients calculated by an external feeding model (Münger et al., 2021, see Appendix). Despite this simplification, the main part of the overhead costs in the respective production year was determined by the feed intake of the single cow, which, in turn, was determined by the LW, milk yield, and feeding system.

Veterinary and medicine costs were particularly differentiated. They were reduced by 10% in the first year of production because a higher share of cows was culled for several reasons at this time. With increasing age, the costs were then increased continuously by a factor of up to 1.5, based on the study of Winter et al. (2024), capturing the higher tolerance limit of the farm in the best production years and health problems that increase with age (Bigras-Poulin et al., 1990, see Appendix). The costs of insemination and various direct costs were included, but for reasons of simplicity, they were not differentiated by production year because they are less relevant.

Calculation of Optimal Economic Productive Lifespan (Single-Cow Model)

In this study, "income" refers to "labor income." Labor income compensates for the family's own labor and is the most important economic indicator for family farms. Whereas the costs for employees are included in the calculation, the family's own labor hours are recorded but not calculated as costs. All monetary values were converted using the average exchange rate between 2020 and 2023 of 0.927 Swiss francs for 1 USD.

To calculate the optimal timing for replacement, that is the OPL, the expected income of the replacement cow was compared with the marginal income of the present cow (**CMI**). The calculation steps listed above can be used to determine the expected net income per cow (**CEI**) across various production years. The CEI is the average annual income of a cow over her entire productive lifespan if she would be culled in year n. The CEI also corresponds to the opportunity costs of not replacing the older cow or postponing the replacement. This income is achieved through 3 calculation steps. Because this is a dynamic process over several years, the income is discounted and annuitized again, assuming an interest rate of 2%, which corresponds to the average rate for 10-year fixed-rate loans between 2020 and 2023 (SNB, 2025).

Equation 1 shows the current cow income ($CInc$) discounted in production year i.

$$CInc_i = \frac{Prod_i - \left(DE_i + OE_i\right)}{\left(1 + rate\right)^i}, \quad [1]$$

where $Prod_i$ is the total product revenues (milk and young stock) per cow in year i (i = 1–10), DE_i is the directly allocated expenses per cow (concentrate, veterinary service, insemination, others), OE_i is the net overhead expenses per cow (roughage production, storing and feeding, housing, others; netted with direct payments), and $rate$ is the interest rate (%/100).

Equation 2 shows the discounted slaughter value per cow in production year i (SVD_i).

$$SVD_i = \frac{SV_i}{\left(1 + rate\right)^i}, \quad [2]$$

where SV_i is the slaughter value in the year i (i =1–10) and $rate$ = interest rate (%/100).

The expected average annual net income per cow (**CEI**; equation 3) also considers discounts and annuitization. If these are not taken into account, the denominator can be replaced with n (production years).

$$CEI_i = \frac{SVD_i - HC + \sum_{i=1}^{n} CI_i}{DF\left(\frac{1 - DF^n}{1 - DF}\right)}, \quad [3]$$

where CEI_i is the expected average annual net income per cow (opportunity cost for postponed replacement) after n production years, CI_i is the discounted current cow income in year i, HC is the heifer costs based on full-cost accounting, SVD_i is the discounted slaughter value per cow in year i, DF is the discounting factor: 1/(1 + $rate$), $rate$ = interest rate (%/100), and n = number of years for which CEI is calculated.

The value of CMI corresponds to the marginal income that can be expected from a present cow if it stays in production for another year, considering the difference in slaughter value between the current year (i) and the previous year (i − 1). It is calculated according to equation 4.

$$CMI_i = P_i - \left(DE_i + OE_i\right) - \left[SV_{i-1}\left(1 + rate\right) - SV_i\right], \quad [4]$$

where CMI_i is the CMI in production year i, P_i is the total product revenues per cow (milk and young stock), DE_i is the directly allocated expenses per cow (concentrate, veterinary service, insemination, others), OE_i is the net overhead expenses per cow (roughage production, storing and feeding, housing, others; netted with direct payments), SV_i is the slaughter value in year i, and $rate$ = interest rate (%/100).

Equation 5 corresponds to the net profit differential (**CPD**) in year i (CPD_i) for the replacement cow compared with continued production of the present cow. It is the difference between the CEI after n years and the CMI in year i.

$$CPD_i = CEI_i - CMI_i. \quad [5]$$

The optimal economic time to replace the present cow is achieved as soon as CPD becomes positive or the opportunity costs of the replacement cow are lower than the CMI. Figure 2 shows the theoretical background for determining the OPL of a dairy cow.

In one case, the replacement is identical; in the other, the replacement cow is expected to have higher milk production, either through BP in milk yield or also in fitness by reducing the risk of health or fertility problems. The curve for the expected average income of the replacement cow shows an increase that is essentially due to the decrease in average heifer costs or the "amortization" of heifer costs. In contrast, the CMI is significantly higher at the beginning, after which it continuously decreases and approaches the average income of the replacement cow and then falls below it at some point (A), which is mainly due to the decline in milk yield. If the replacement cow can be expected to perform as well as the present cow, the point of crossover is where the average income of the replacement cow is highest. For the identical replacement cow, the OPL is 6 years (Point A).

If the dairy farmer expects the next cow to generate a higher annual milk revenue than the existing cow, the optimal replacement time is correspondingly earlier, that is, an OPL of 5 years (Point B).

With the CPD, OPL can also be depicted in a single curve (equation 5). The CPD is first in the negative area, crosses the zero line at the OPL of 6 years, and then comes into the positive area (Figure 3).

Simulation of Risk, Different Heifer Costs, and BP

To integrate the yield differences between individual lactations into the model, the herd data refer to cows that have completed 10 lactations and thus survived at least 10 production years. Of course, this does not apply to a herd in practice because unfiltered herd data indicated that many cows were removed from the herdbook in the first and second lactations and that fertility and udder health problems were the main culling reasons (Bieber et al., 2023). We assume that most of these cows were culled for economic reasons, that is, expected economic losses due to fertility problems, mastitis, or low milk yield (Dallago et al., 2021). Therefore, their future lactation yields or milk revenues are unknown or "censored;" however, we assumed that the potential average revenues of the subsequent production years would have dropped depending on the share of cows that did not survive. To monetarize the loss rates in the milk revenue, we calculated a milk loss factor (**MLF**) for the entire herd based on the survival rate and the potential milk revenue loss of the nonsurviving cows. If we assume that all cows in a herd, with the exception of the few forced disposals, reach the 10 lactations with the recorded milk yields, the expected milk-yield loss is 0%; thus, MLF = 1, which of course is not realistic for a herd. The expected potential milk revenue losses of the removed cows (MLF < 1) were simulated as a "risk" in the model, ranging from 10% to 50% milk-yield loss, to demonstrate the effects on the OPL (Table 3).

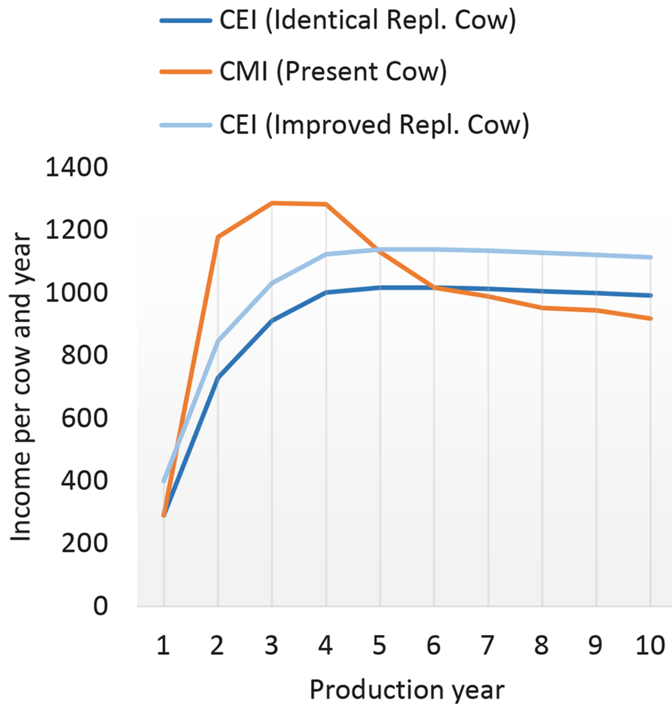


Figure 2. Example of average expected income (CEI) of replacement (Repl.) cows (blue lines) and marginal income of the present cow (CMI; red line) over their productive lifespans. A = optimal economic productive lifespan assuming an identical replacement cow (dark blue); B = optimal economic productive lifespan assuming an improved replacement cow (light blue).

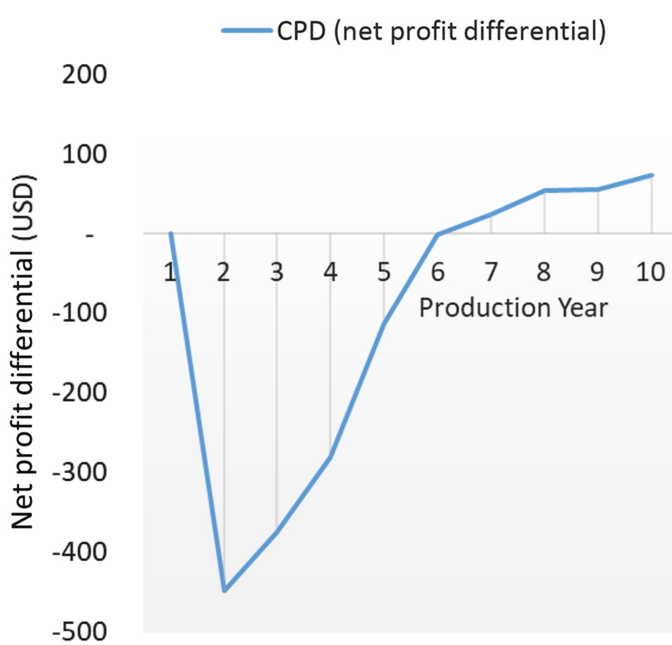


Figure 3. Development of the net profit differential (CPD). Expected income of the replacement cow minus marginal income of the present cow (CMI), which drops to 0 at 6 yr, thereby reaching the optimal economic productive lifespan (identical replacement, scenario A).

Table 3. Calculated milk loss factors (MLF) per production year[1] based on different risk scenarios (loss rates 10%–50%) and survival rates for cows in production systems C_low and C_high

Survival rate and risk scenario	Production year									
	1	2	3	4	5	6	7	8	9	10
Survival rate C_low	1.00	0.77	0.59	0.44	0.31	0.21	0.13	0.08	0.04	0.02
Survival rate C_high	1.00	0.73	0.49	0.32	0.19	0.11	0.05	0.01	0.01	0.005
C_low 10%	1.00	0.98	0.96	0.94	0.93	0.92	0.91	0.91	0.90	0.90
C_low 25%	1.00	0.94	0.90	0.86	0.83	0.80	0.78	0.77	0.76	0.76
C_low 33%	1.00	0.92	0.86	0.81	0.77	0.73	0.70	0.69	0.67	0.67
C_low 50%	1.00	0.89	0.80	0.72	0.66	0.61	0.57	0.54	0.52	0.51
C_high 10%	1.00	0.97	0.95	0.93	0.92	0.91	0.91	0.90	0.90	0.90
C_high 25%	1.00	0.93	0.87	0.83	0.80	0.78	0.76	0.76	0.75	0.75
C_high 33%	1.00	0.91	0.83	0.77	0.73	0.70	0.68	0.67	0.66	0.66
C_high 50%	1.00	0.87	0.75	0.66	0.60	0.55	0.53	0.51	0.51	0.50

[1]Calculation example for fifth production year with scenario C_low 25%: MLF = (1 − 0.31) × (1 − 0.25) + 0.31 = 0.83.

The MLF is calculated from the share of culled cows after *n* production years multiplied by the reduced milk yield (1 − loss rate), the value of which is then added to the share of surviving cows after *n* production years. In other words, the economically motivated culling rate was monetized as the potential decline in annual milk revenue after each year of production. A value of 10% loss rate means that removed cows would generate no milk revenue for 1.2 mo of the year, 25% corresponds to 3 mo of loss, 33% to 4 mo, and 50% to 6 mo of loss.

The inclusion of different heifer costs changed the difference to the slaughter revenue, with the latter kept constant. The difference is relevant for determining OPL, in that both revenue and costs occur only once in the lifespan of a cow. Based on the calculation of the heifer costs in different farm situations, a corresponding range could be defined in the simulation. This range was derived from 548 accounting farms representing 3 types of rearing farms, as described in the economic data section. Using the AgriPerform farm analysis program, 3 model farms were set up after the total costs of the rearing branch of the farm had been isolated. The farms could be specifically modeled to focus on the usual rearing period between 24 and 30 mo, whereby the rearing period corresponds to the number of heifers sold based on the herd size that can be kept in a fixed forage area. Data that could not be obtained from the accounts were supplemented with planning data used in farm extension services (Agridea, 2024b). This included the costs of milk powder and special concentrate for young cattle and calves, depending on the rearing period (see Appendix, Table A4). In addition to the usual opportunity cost rates of 31 USD per hour of own labor (Gazzarin et al., 2022), these heifer costs were also modeled using a reduced rate (16 USD) to reflect the preferences of passionate breeders who also regard dairy farming as a lifestyle.

As shown in Figure 2, BP in the area of milk yield or fitness has an influence on OPL. Based on information from breeding organizations for HF and BS (Qualitas AG, 2022), annual increases in breeding values for milk yield of between 30 and 100 kg are simulated for the replacement cow to show the effect on OPL, while 0 kg (0%, identical replacement) corresponds to the baseline. The simulation was carried out taking into account the BP resulting from the percentage increase in milk yield. Of course, a reduction in the previously mentioned MLF through breeding to more robust, less risky cows also represents BP.

Taking into account the share of milk for sale and the classic BP, the milk revenue is calculated as follows (equation 6):

$$Mr_i = Ly_i \times Ms \times p \times MLF_i \times (1 + BP), \qquad [6]$$

where Mr_i is the milk revenue in year i (i = 1, 2,…10) in USD, main part of P_i (equation 1); Ly_i is the milk yield in year i (kg), which is the lactation yield (kg) × 365/calving interval (d); Ms is the factor for share of sold milk; p is the milk price (USD/kg); MLF_i is the MLF in year I; and BP = breeding progress (%/100).

To reflect the cost effects of different milk revenues with differing MLF and BP assumptions, the concentrate feed costs were adjusted with the same factor, while other cost factors were neglected for reasons of simplicity due to their significantly lower effect. Forced disposals were not taken into account because they were 4.1%–7.8%, relatively low in Switzerland (Bieber et al., 2023).

Economic Relevance of Productive Lifespan at the Herd Level

In contrast to determining the OPL of a single cow, taking into account all costs and revenues in its life, an assessment of the economic impact of an extended

Table 4. Calculated age structures (share of cows per production year) for different productive lifespans and respective replacement rates (RR; rounded values, calculated with the formula of Nieuwhof et al. (1989)

		Production year									
Productive lifespan (yr)	RR	1	2	3	4	5	6	7	8	9	10
Baseline C_low: 3.6	0.28	0.28	0.21	0.16	0.12	0.09	0.06	0.04	0.02	0.01	0.01
Baseline C_high: 2.9	0.35	0.35	0.25	0.17	0.11	0.06	0.03	0.02	0.01	0.00	0.00
2	0.5	0.48	0.19	0.09	0.08	0.05	0.05	0.04	0.00	0.00	0.00
4	0.25	0.25	0.20	0.16	0.12	0.09	0.06	0.05	0.03	0.02	0.02
6	0.17	0.17	0.15	0.14	0.13	0.12	0.11	0.09	0.06	0.03	0.02
8	0.13	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.09	0.09	0.08

productive lifespan on annual income requires an annual consideration at herd level.

The age structure of the herd is influenced by the LPL or the replacement rate. The average income of an average "cow herd" was determined by calculating the income per cow at each production age and multiplying it by the corresponding percentage of cows, then summing these values over all production years and finally adding the difference between the average slaughter revenue and the average heifer costs at the herd level (equation 7).

$$CDI_n = Rrate \times \left(SV_n - HC_n\right) + \sum_n SC_i \times \left[P_i - \left(DE_i + OE_i\right)\right], \quad [7]$$

where CDI_n is the annual "dairy herd" income per cow per year n (modeled), $Rrate$ is the replacement rate (%/100), SV_n is the average slaughter value in a herd per cow $\left(\sum_n SC_i \times SV_i\right)$, HC_n is the average heifer costs in a herd per cow (Table 6), SC_i is the share of cows in the herd structure (%/100) in production year i (1–10; age structure), P_i is the total product revenues per cow (milk and young stock) in production year i, DE_i is the directly allocated expenses per cow (concentrate, veterinary, insemination, others) in production year i, and OE_i is the net overhead expenses per cow (roughage production, storing and feeding, housing, others; netted with direct payments) in production year i.

Table 4 shows the age structures calculated according to Nieuwhof's formula (Nieuwhof et al., 1989) on the basis of survival rates corresponding to a productive lifespan of 2, 4, 6, and 8 years in comparison to the baseline of the analyzed production systems. The Nieuwhof formula contains the variables of mean productive lifespan, survival rate to parity, (mean) calving interval (days between parities), and (mean) DIM for cows in the last lactation.

RESULTS

Economic Performance of the Production System (Baseline)

The economic comparison of the 2 production systems is shown in Table 5. The C_low group produces significantly less milk than C_high with a similar number of cows (30.7 vs. 31.5) and a similar forage area (21.5 vs. 19.5 ha), which is reflected in the productivity indicators. Nevertheless, the various income figures are only slightly lower. This can be explained by significantly higher expenses of C_high for direct inputs and overheads and, to a lesser extent, by C_low's higher milk price and higher nonmilk returns (more details in Tables 6, 9, and 10). The slightly higher milk price of the C_low group is reasonable because it includes significantly more farms that produce without silage for raw milk cheese or according to organic guidelines. For total income and income per hectare, only direct payments that can be directly allocated to the dairy branch were included. General farm-

Table 5. Economic performance indicators of two different production systems (per year)

Item	Unit	C_low	C_high
Milk sold	kg	175,243	278,441
Milk price	USD/kg	0.76	0.73
Nonmilk returns[1]	USD	90,945	89,584
Labor hours	h/LU[2]	116.1	124
Labor productivity	kg/h	46	65
Land productivity	kg/ha[3]	8,860	15,054
Dairy income (DI)[4]	USD	36,232	44,554
Income/ha	USD/ha[3]	1,685	2.285
Return to labor[5]	USD/h	16.0	17.1
Break even[6]	USD/kg	1.05	0.91

[1]Revenue from sale of calves, young cattle, cows, and allocated direct payments.

[2]Livestock units (cows and young stock).

[3]Forage area.

[4]Dairy related returns minus expenses (excluding opportunity costs), including decoupled direct payments.

[5]Total returns (including allocated farm payments) minus total costs, except labor costs, divided by labor hours.

[6]Cost price: total costs (including opportunity costs) minus total nonmilk returns, divided by sold milk (kg).

Table 6. Basic data used for modeling the production years, derived from the accounting data of the two production systems (per year)

Item	Unit	C_low	C_high
Milk yield	kg/year	6,194	9,338
Avg. slaughter revenue	USD/cow	3,008	2,902
Heifer cost	USD/heifer	3,259	3,423
Concentrate cost	USD/cow	673	1,399
Veterinary/medicine	USD/cow	214	303
Net overhead cost	USD/cow	2,641	3,499

related direct payments were only taken into account for return to labor, which hardly differs either, mainly due to the lower labor input of C_low. Nevertheless, taking into account its own labor, C_high milk production is less expensive due to the economies of scale (break even 0.84 vs. 0.97).

Table 6 provides an overview of the basic accounting data, which are differentiated over the single production years using the herd data. There are major differences in costs, with the exception of heifer costs. The average slaughter revenues were also similar.

Herd Structure Data (Baseline)

To evaluate the economic performance of a cow after *n* production years, the data from the annual accounts were extrapolated down to the single cow using herd data. Tables 7 and 8 contain the herd data, which are matched to the 2 production systems via the specified calculation steps. It is evident that 50%–60% of the cows (49.3%, C_low; 59.7%, C_high) were in the first or second year of production, in which the lowest lactation yields were achieved. The mean age and productive lifespan of the low-yielding herd was approximately 6 mo higher.

Revenues and costs up to the calculation of the different income levels are shown for the specific production years in Table 9 (C_low) and Table 10 (C_high). The incomes cannot be compared directly with the annual results in Table 5 because the results in Tables 9 and 10 relate to single cows and were averaged over the entire lifespan after the completed production year *n*. The risk had not yet been taken into account; that is, it was assumed that all cows entering their first lactation would achieve the specified performance in subsequent production years. Thus, for an identical replacement cow, the OPL was greater than 9 yr (C_low) or greater than 10 yr (C_high). This could be identified by the maximum expected income CEI (C_low: 1,167 USD; C_high: 1,652 USD) or by the positive CPD for the replacement cow, which became positive only after 10 years in C_high.

Table 11 presents the different heifer costs depending on the region, rearing period, and opportunity cost rate, which ranged from 2,495 to 5,401 USD. The prices achieved at breeding cattle auctions from 2020 to 2023 ranged between 2,535 and 3,658 USD (Agridea, 2024a); although some animals were likely to have been sold below cost price.

Table 7. Age structure[1] and modeled milk yield per production year for two production systems

	C_low		C_high	
Production year	Age structure, % of herd	Milk yield, kg/animal	Age structure, % of herd	Milk yield, kg/animal
1	27.8	5,342	34.7	7,930
2	21.5	6,040	25	9,438
3	16.5	6,560	16.8	10,091
4	12.2	6,817	10.7	10,734
5	8.7	6,843	6.3	10,810
6	5.8	6,857	3.4	10,823
7	3.6	6,846	1.7	10,840
8	2.1	6,803	0.8	10,828
9	1.2	6,733	0.4	10,813
10	0.6	6,227	0.2	10,707

[1]Calculated by the formula of Nieuwhof et al. (1989) using survival rates based on herd data (Table 3).

OPL with Risk Scenarios

The performance indicators shown in Tables 9 and 10 refer only to cows that had actually reached at least 10 lactations. Even though most cows can theoretically or biologically reach 10 lactations, we can assume that many cows would be culled earlier due to expected economic losses. To determine OPL with these considerations, these losses were therefore estimated using risk scenarios. The inclusion of risks corresponds to the theoretical loss of milk revenue that could be expected if culled cows were still used. The average income per cow drops if the expected milk revenue losses increase (Figure 4). Furthermore, the OPL for C_low under the given age structure can decrease from more than 9 to 3 production years. With an expected loss of 10%, the income remains almost stable after the fifth year of production. We observed a similar picture for C_high (Figure 5). Here, however, the theoretical OPL was greater than 10 yr. The optimum then dropped to 2 yr with increasing loss expectations. The absolute loss of income was obviously much larger with the same relative loss expectations for milk

Table 8. Modeled herd data for two production systems

Item	Unit	C_low	C_high
Mean herd age	yr	3.1	2.5
Productive lifespan	yr	3.6	2.9
Calving interval	d	370	388
Replacement rate	%	28	35
Fourth reference lactation	kg	6,910	11,410
LW (fourth lactation)*	kg	670	730
Average LW*	kg	618	661
Sold young stock	head/cow	0.65	0.54

Table 9. Economic results per cow in USD in the low-yielding production system (baseline), without BP; MLF = 1 (no expected losses)

Economic variable[1]	Production year 1	2	3	4	5	6	7	8	9	10
Milk revenue	3,733	4,222	4,585	4,764	4,783	4,793	4,785	4,755	4,706	4,352
Sale of young stock	514	514	645	711	750	776	795	809	820	828
Concentrate	581	626	737	807	807	807	815	815	769	634
Veterinary/medicine	183	203	203	223	243	264	284	304	304	304
Insemination	103	103	103	103	103	103	103	103	103	103
Diverse direct costs	190	190	190	190	190	190	190	190	190	190
Net overhead costs	2,382	2,602	2,764	2,822	2,822	2,822	2,804	2,804	2,802	2,728
Cow's income (CI)	810	1,014	1,234	1,330	1,367	1,383	1,383	1,347	1,357	1,222
Slaughter revenues (SV)	2,823	2,980	3,130	3,261	3,252	3,242	3,228	3,219	3,210	3,196
CI cumulated, discounted (including heifer costs)	−2,465	−1,491	−328	900	2,339	3,367	4,571	5,721	6,856	7,859
Expected income (CEI)	309	707	909	1,028	1,079	1,115	1,141	1,159	1,169	1,167
Marginal income (CMI)	309	1,114	1,324	1,398	1,293	1,309	1,305	1,273	1,283	1,144
Net profit differential (CPD)	0	−406	−415	−371	−214	−194	−164	−117	−114	23

[1]CI = income for each production year excluding heifer costs and slaughter revenues; CEI = expected average income for replacement cow per production year (discounted and annuitized); CMI: marginal income for present cow if it is used for one more year; CPD = net profit or loss for the replacement cow compared with the present cow.

revenue. In other words, if the removed cows were only in production for half of the year, the average income of the high-yielding cow would be even lower than that of the low-yielding cow. Here too, with an expected revenue loss of 10%, the income hardly changed from the fifth year of production onwards as the length of productive lifespan increased.

Assuming that low-yielding cows have fewer losses, a comparison of the average cow incomes showed that an expected loss of 3 mo (25%) for the cow "C_low" with 745 USD at the optimum of 4 production years (Figure 4) generated a higher income than the cow "C_high" if it loses one month longer (33%) and reaches the optimum at 3 production years (725 USD; Figure 5).

Considering the age structure (Table 7), the comparable average income per cow and year corresponds to the baseline (Tables 9 and 10) and amounted to 758 USD for C_low and 871 USD for C_high (CEI in production year *i* multiplied with percentage of cow in production year *i*, summarized over 10 production years). This corresponds roughly to a risk scenario of 25% milk revenue losses, which allowed us to assume that, on average, the farms expect an annual production loss of 3 mo from the removed cows. In reality, the expected loss is likely to be lower because cows are also culled for noneconomic reasons.

Table 10. Economic results per cow in USD in the high-yielding production system (baseline), without BP; MLF = 1 (no expected losses)

Economic variable[1]	Production year 1	2	3	4	5	6	7	8	9	10
Milk revenues	5,489	6,534	6,986	7431	7,483	7,493	7,504	7,496	7,485	7,412
Sale of young stock	503	503	655	732	777	808	829	846	858	869
Concentrate	1,106	1,343	1,541	1,775	1,813	1,813	1,820	1,820	1,820	1,782
Veterinary/medicine	270	300	300	330	360	390	420	450	450	450
Insemination	156	156	156	156	156	156	156	156	156	156
Diverse direct costs	255	255	255	255	255	255	255	255	255	255
Net overhead costs	3,176	3,603	3,677	3,752	3,753	3,753	3,731	3,731	3,731	3,730
Cow's income (CI)	1,030	1,379	1,712	1,893	1,923	1,933	1,952	1,930	1,932	1,907
Slaughter revenues (SV)	2,774	2,929	3,076	3,205	3,196	3,186	3,173	3,163	3,154	3,140
CI cumulated, discounted (including heifer costs)	−2,413	−1,087	527	2,276	4,017	5,734	7,433	9,080	10,697	12,261
Expected income (CEI)	313	890	1,188	1,375	1,466	1,529	1,575	1,608	1,634	1,652
Marginal income (CMI)	313	1,479	1,801	1,961	1,849	1,860	1,874	1,857	1,859	1,830
Net profit differential (CPD)	0	−588	−613	−585	−383	−331	−299	−249	−226	−179

[1]CI = income for each production year excluding heifer costs and slaughter revenues; CEI = expected average income for replacement cow per production year (discounted and annuitized); CMI = marginal income for present cow if it is used for one more year; CPD = net profit or loss for the replacement cow compared with the present cow.

Table 11. Calculated mean net heifer costs[1] (USD) in different regions based on accounting data of specialized rearing farms (SR) and dairy farms with own (OR) or outsourced (OSR) rearing, modeled for different rearing periods, and with different opportunity cost rates (31 USD/h; 16 USD/h); n = 548

	Rearing farm type, region, opportunity cost rates		
Rearing period (mo)	SR-mountain (31)	OR-hills (31/16)	OSR-lowlands (31/16)
	n = 31	n = 74	n = 444
24	3,985	3.066/2,515	3,131/2,495
26	4,490	3.431/2,793	3,533/2,795
28	4,892	3.686/2,958	3,941/3,099
30	5,401	4.057/3,241	4,340/3,398

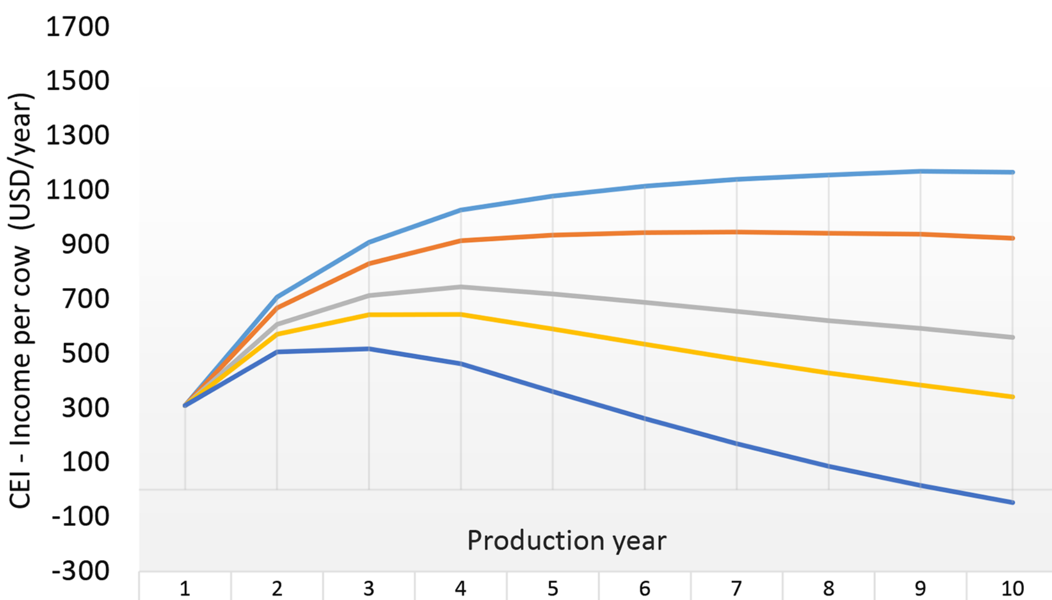
[1]Total costs including opportunity costs minus allocated direct payments.

OPL with Different Heifer Costs

Because the heifer costs—that is, ultimately the difference between the slaughter revenue and the heifer costs—have a significant influence on OPL, their effect on the net profit differential (CPD) is illustrated using the C_high production system under a risk scenario of 25% loss of milk revenue. Figure 6 shows CPD for replacement of a (identical) cow with heifer costs between 2,700 and 5,000 USD. With the most cost-effective heifer costs (2,700 USD), CPD becomes positive shortly after the third year of production, which is equal to OPL. For the baseline scenario (3,423 USD), the optimum is between the fourth and the fifth year of production. With the highest heifer costs, OPL is reached with the seventh production year.

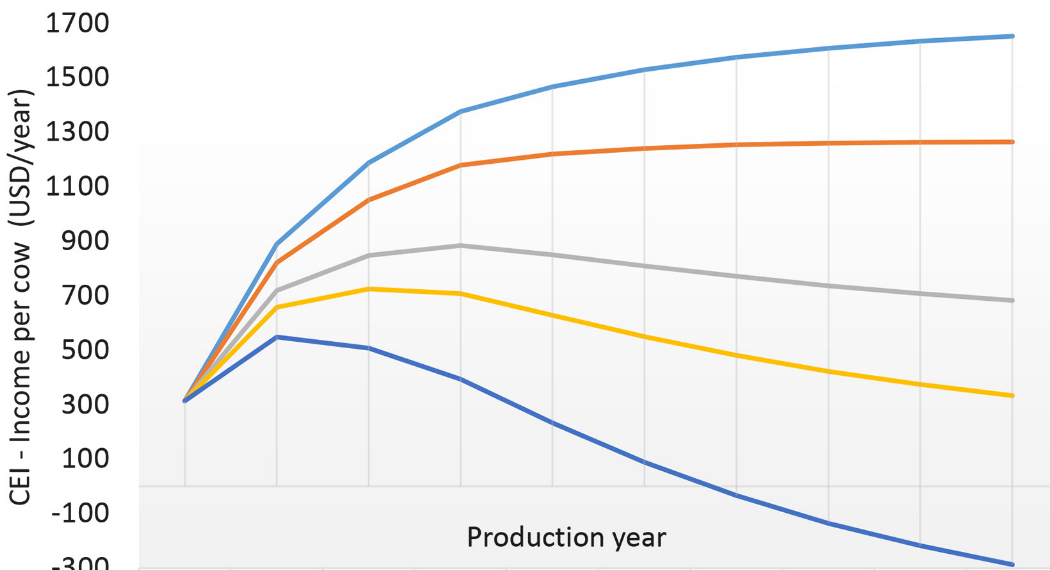
OPL with Different BP Assumptions

Previous determinations of OPL assumed an identical replacement of cows, which corresponds to a BP of 0%. To change a currently unsatisfactory situation, an improvement can be achieved through breeding selection, which introduces a dynamic dimension to the question



	1	2	3	4	5	6	7	8	9	10
0%	309	707	909	1028	1079	1115	1141	1156	1169	1167
-10%	309	667	831	915	935	944	946	942	938	924
-25%	309	607	713	745	719	688	655	621	592	560
-33%	309	571	642	644	590	534	480	429	385	341
-50%	309	506	517	463	360	261	170	86	16	-47

Figure 4. Development of expected average income (CEI) for C_low according to productive lifespan and varying degrees of milk revenue losses. The milk yield of the surviving cows (0% loss) is averaged with the potential milk-yield reduction (10%–50%) of actually culled cows in each production year.



	1	2	3	4	5	6	7	8	9	10
0%	313	890	1188	1375	1466	1529	1575	1608	1634	1652
-10%	313	822	1052	1179	1220	1241	1254	1259	1263	1264
-25%	313	719	847	884	850	809	771	736	708	682
-33%	313	657	725	708	628	549	481	422	374	333
-50%	313	548	507	394	234	89	-33	-136	-218	-287

Figure 5. Development of expected average income (CEI) for C_high according to productive life and varying degrees of milk revenue losses. The milk yield of the surviving cows (0% loss) is averaged with the potential milk-yield reduction (1%0–50%) of actually culled cows in each production year.

of OPL. For the classic BP of milk-yield increase, we used an empirically observed annual BP between 30 kg and 100 kg, which corresponds to a milk production increase of 1% and 2% considering a 2-year rearing period. This corresponded to a milk-yield improvement of the replacement cow of 53 kg and 106 kg for C_low and 79 kg and 158 kg for C_high. Because the effects for both production systems are very similar, the case of C_high is displayed in Figure 7. A maximum BP of 2% (158 kg) leads to a shortening of the OPL by approximately half a year.

The improvement of secondary performance traits, such as udder health or fertility ("fitness"), can also be achieved through breeding and ultimately leads to a reduction in risk and lower production losses. Similar to BP in milk yield, OPL is also lower during a breeding improvement in fitness; that is, when lower milk revenue losses are to be expected for the replacement cow compared with the baseline. However, the long-term effects on the average income per cow are of interest. If, for example, we reach the optimum for C_low at 9 yr of productive lifespan with all cows that have entered the first lactation, this results in an income difference of 424 USD per cow (1,169 − 745 USD; see Figure 4). In the model, this corresponded to a milk-yield increase of 683 kg in the first lactation with 25% milk loss (risk) and an OPL of 4 yr. Assuming a realistic BP of approximately 40 kg of milk/yr in this performance class, it would take approximately 17 yr until the income of a cow with significantly better fitness (0% risk) would be equalized.

Economic Potential of Herds with Increased Productive Lifespan

In a standard accounting year, a herd approach is needed to estimate the economic relevance of the productive lifespan in a production system. Therefore, we compared the annual average dairy income per cow (CDI) in the 2 production systems with 4 different age structures, each corresponding to an average productive lifespan of 2, 4, 6, and 8 years, with the baseline scenarios (2.9 and 3.6 production years, Tables 7 and 12). An increase in the productive lifespan had a substantial income increase potential of 3% to 32%, depending on the production system (Figure 8). The longer a cow lives and the higher its milk yield, the greater its potential.

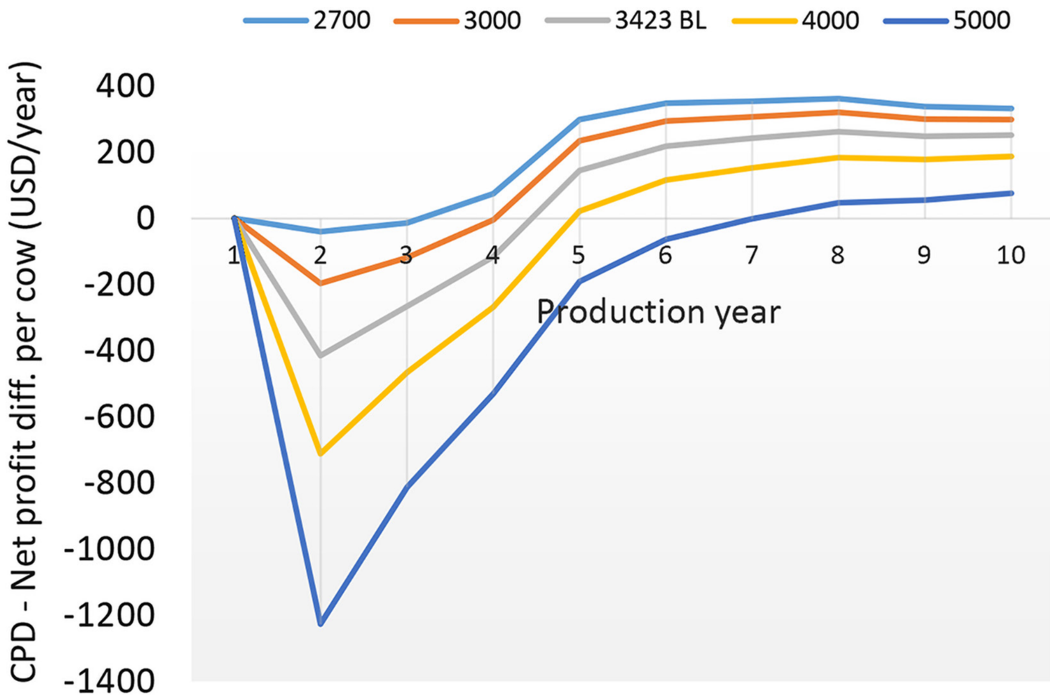


Figure 6. Net profit differential (CPD) of the replacement cow (example C_high) compared with the present cow under different heifer cost assumptions of 2,700, 3,000, 3,423 (baseline = BL), 4,000, and 5,000 USD (risk = 25% milk revenue loss). Optimal productive lifespan can vary between 3 (low heifer costs) to 7 yr (high heifer costs). diff. = differential.

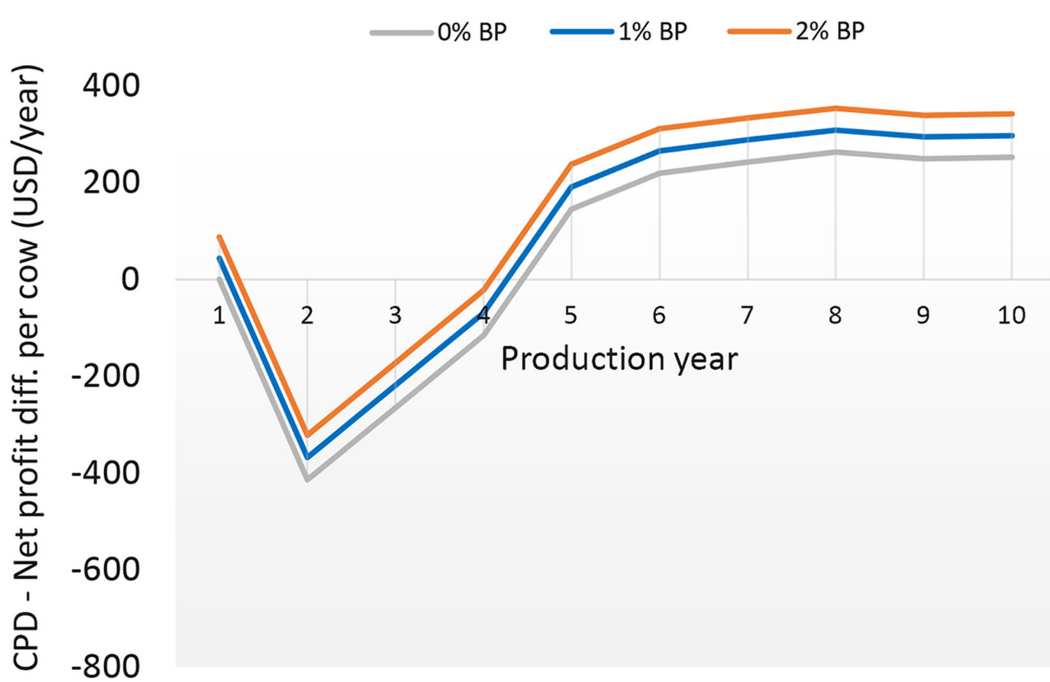


Figure 7. Net profit differential (CPD) for the replacement cow (example C_high) compared with the present cow with breeding progress (BP) in milk yield of 0% (baseline), 1%, or 2% increase (risk = 25% milk revenue loss). When assuming 2% BP OPL can be shortened by 6 mo. diff. = differential.

Table 12. Annual average dairy income (USD) per cow and year (CDI), modeled in two production systems with four different age structures of productive lifespans

Production system	Baseline[1]	Productive lifespan (yr) 2	4	6	8
C_low (USD)	1,052	882	1,079	1,181	1,216
C_high (USD)	1,278	1,131	1,452	1,613	1,688

[1]Baseline corresponds to 3.6 yr for C_low and 2.9 yr for C_high.

DISCUSSION

Based on accounting data from 189 dairy farms and various herdbook data, the study defined 2 production systems and employed a dynamic single-cow model of 10 productive years to estimate the impact of different risk scenarios, heifer costs, and BP assumptions on the OPL.

Optimal Economic Productive Lifespan

The question of OPL cannot be addressed by a single value, given its complexity, as indicated by various studies (Zeddies, 1972; Gantner et al., 1990; Simianer, 2003; Heikkilä et al., 2008; Kiefer et al., 2019; De Vries, 2020). To the best of our knowledge, there has so far been little explanation for why the effective productive lifespan on dairy farms differs so greatly from theoretical models, which consider a productive lifespan of at least 2 yr longer to be economically viable. The answers can be found in the decision-making behavior of farmers, which is influenced by both economic and psychological factors (Bergeå et al., 2016; Rilanto et al., 2022; Rödiger and Home, 2023), as well as by future perspectives or structural changes. When farms increase the size of their herds, this usually leads to a significantly longer productive lifespan as long as the herd grows (Nor et al., 2013; Owusu-Sekyere et al., 2023). Apparently, tolerance for fertility and health problems seems to be higher when the herd is growing.

The basic simulation shows that OPL is more than 9 yr, with the marginal income diminishing as the cow gets older. The average income per cow is particularly low after 1 to 2 yr of the productive life. After around the fourth year of production, income increases only slightly, as confirmed by previous calculations (Zeddies, 1972;

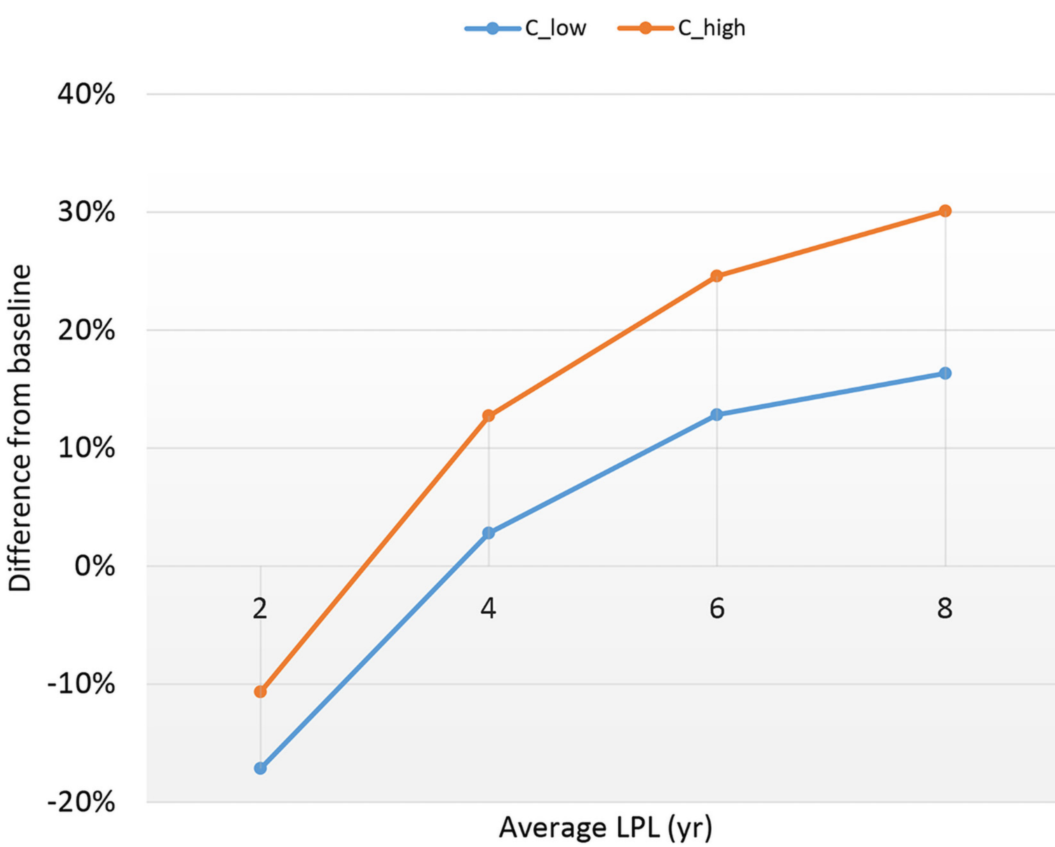


Figure 8. Potential for changes in annual “dairy herd” income per cow (CDI) with different average lengths of productive lifespan (LPL) compared with the baseline situation (C_low: 3.6 years; C_high: 2.9 years). To increase dairy income by more than 10%, LPL should be 4 years (C_high) or 6 years (C_low).

Missfeldt et al., 2015; De Vries, 2020). With continued use, noneconomic motives for earlier culling therefore become more important. Thus, small income differences could at least be compensated for by the noneconomic benefit of a particular culling decision or by higher expectations of the replacement cow, which, of course, also represents a risk if the present cow actually produces smoothly. This indicates that psychological motives can play an important role, as various studies have shown (Bigras-Poulin et al., 1985; Beaudeau, 1995; Bergeå et al., 2017).

In practice, however, farm managers remove most cows from the herd much earlier, generally resulting in dissatisfaction with the shorter lifespan of the cows (Rilanto et al., 2022). The baseline modeling assumed that a model cow produces milk continuously over 10 lactations, so that risks are initially excluded from the basic calculation. Assuming that early culling decisions are primarily economically motivated, this results primarily from the expected economic losses if these cows were used for longer. These expected milk revenue losses are mainly due to a lack of fitness, that is, fertility disorders, udder health, and other health problems (Bascom and Young, 1998; Bieber et al., 2023). The corresponding simulation of these risks showed a considerable drop in OPL and can largely explain the effective lower average productive lifespan associated with an expected loss rate of around 25%. This would mean an expected (theoretical) production loss of around 3 mo for an expiring cow so that the farmer culls the cow prematurely based on this expectation. The higher the expected losses, the lower the OPL. The inverted U-shape of the association between productive lifespan and economic performance (Figures 4 and 5) is consistent with a recent study in Sweden (Adamie et al., 2023).

Psychological motives can also be explained in economic terms, as in the example of heifer costs as a relevant factor for OPL. Assuming a realistic risk scenario of around 25% fitness-related milk loss, the range of OPL is between 3 and 7 yr, depending on the heifer costs. Passionate breeders are likely to have high expectations of the new replacement cow's performance and systematically overestimate it while also overweighting fitness-related risk and thus the expected milk loss of the older cows. In addition, such farms tend to raise more animals than would effectively be necessary to replace the old cows, which means that economically average cows can also be pushed out by replacement heifers, as mentioned in other studies (Bergeå et al., 2016; De Vries and Marcondes, 2020). In economic terms, such farms value the opportunity costs of their own labor in rearing heifers significantly lower, indicating that the heifer price decreases accordingly and that a shorter productive lifespan is therefore economically attractive.

Production Reliability

The simulations also show that production systems with higher milk yields must expect significantly higher losses in the event of production failure. This means that a longer productive lifespan is particularly important for higher-yielding cows, consistent with a recent study (Schlebusch et al., 2025). This squares the circle to a certain extent because high-yielding cows in particular have a higher average risk of health problems (Simianer, 1991; Hansen, 2000; Ingvartsen et al., 2003; Leblanc, 2010; Pritchard et al., 2013). In this respect, the calculated potential for a 30% increase in income is highly theoretical, which does not mean that this should not be the goal. Although increases in milk yield have so far been considered a means of increasing income, the economic potential of so-called production reliability seems to be underestimated. Production reliability refers to steady, sustained, and trouble-free production over several years, regardless of actual lactation performance. Accordingly, the results show that lower-yielding cows can outperform higher-yielding cows if they have better performance reliability, that is, fewer production losses due to health or fertility problems. A reduction in milk production losses of just 1 mo can be enough to compensate for the difference in income between the 2 production systems.

Overall, with production reliability and a correspondingly longer productive lifespan, there is a realistic income increase potential between 10% and 15% compared with the baseline situation if low-yielding cows achieve 6 yr of production on average and high-yielding cows achieve 4 yr (Table 12).

However, it should be noted that a higher proportion of dual-purpose cows is expected in the low-yielding group (Original Braunvieh). When slaughter prices are favorable, this reduces the gap between slaughter cow revenue and heifer replacement costs, making early slaughter economically more attractive. This partly explains the relatively small difference in productive lifespan between the 2 performance groups, despite the large differences in milk yield.

Notably, the comparison of income per cow alone is insufficient because it does not include the labor time required by family labor. The accounting data show that the low-yielding herd has an advantage in this respect because it requires less labor (Gazzarin et al., 2021). Accordingly, the return to labor in the low-yielding herd quickly increases when the income per cow approaches that of the high-yielding herd.

Breeding Progress

In principle, every dairy farm must identify which cow would enable the farm to achieve its (breeding) target. This target is subject to certain restrictions, such as the production site, society's expectations, and the dairy farmer's management skills, regardless of whether increasing milk yield is biologically possible. When setting breeding targets, increasing milk yield has always been a top priority, resulting in impressive BP. If the performance of a herd is to be continuously improved until the defined target is reached, the replacement cow should also perform better economically and thus replace the present cow earlier, resulting in a reduction of the productive lifespan. However, the effect of BP in milk yield of 2% per generation with a reduction of the OPL by about 6 mo in this study is modest, at least in the short term, which is confirmed in a study by De Vries (2017).

Nevertheless, BP does not necessarily mean improved milk yield but can also mean an improvement in performance reliability. In considering the economic impact, breeding for performance reliability appears even more relevant. To achieve production reliability, cows must be selected for longevity. However, this trait has relatively low heritability (Madgwick and Goddard, 1989; Vollema and Groen, 1996) but is increasingly being incorporated into breeding programs (Brito et al., 2021). Therefore, choosing site-adapted genetics can lead to faster success (Bieber et al., 2019). Crossbreeding could also play an important role here.

Poor heritability also shows that the provision of an optimal, health-promoting environment for dairy cows is of high economic relevance and can, in turn, be realized more easily. In this context, the management skills of farm managers often do not increase in step with milk yields, indicating that health problems are more likely to become apparent.

Given the aforementioned restrictions, the breeding target in terms of lactation yield will be achieved at some point. In Switzerland, as in other Western countries, the role of the high-yielding dairy cow as a competitor to human food sources is being questioned by both experts and society in general as resources become increasingly scarce (Schader et al., 2015). Unlike pigs and poultry, the cow's digestive system can metabolize cellulose, which does not compete with human nutrition and results in a net protein contribution (Schader et al., 2015; Wild et al., 2025). Reducing feed food competition by focusing on grass-based feeding of dairy cows results in a certain milk-yield limit. Swiss agricultural policy provides targeted incentives for grass-based feeding because the economic advantages of high-yielding cows are well recognized. This partly explains the relatively small income differences between the 2 production systems examined in this study.

Limitations

The study's approach relied on different data sources, with accounting and herd data not necessarily obtained from the same farms. The age structures calculated from the survival rates in the baseline modeling take into account cows that have left the herd book but have not necessarily been slaughtered. A small proportion may therefore have been sold alive to non-herd-book farms, which means that the effective productive life may be slightly underestimated. However, this is likely to be largely offset by the fact that forced disposals were also not taken into account.

Studies have found that in their first lactation, long-lived cows generally produce below-average milk yields (Essl, 1998). This leaves some uncertainty as to whether the yield differences in early lactation also apply to other cows that are culled earlier.

In this respect, the results generated from the available data are to be regarded as the best possible estimates, which, however, are considered to be highly stable because the relevant influencing factors have been taken into account in detail.

The methodological approach presented here can, in principle, also be applied to production systems in other countries. However, the basic economic data used in the modeling are largely specific to Switzerland, which is characterized by numerous agrarian policy interventions. This applies particularly to price conditions, while direct payments were only taken into account indirectly via reduced (net) overhead costs. It should also be noted that production systems in many other countries are less heterogeneous and, consequently, rearing costs may be less diverse.

CONCLUSIONS

The effective productive lifespan of dairy cows is currently limited by high early culling rates, primarily due to economic risks related to fertility, mastitis, and other health problems. These culling decisions are often economically justified because keeping unprofitable cows in production may lead to income losses. However, this study demonstrates that extending the productive lifespan can enhance profitability by 10% to 15% if performance reliability is improved. This corresponds to a productive lifespan of 6 yr for dairy farming with low production intensity and 4 yr for dairy farming with high production intensity. In view of the wide variety of production systems, the OPL would have to be calculated individually for each farm, especially given that beyond milk yield, heifer costs and slaughter prices also play a major role. With BP, a shorter productive lifespan is economically beneficial, although the optimum is only shifted slightly.

Thus, for long-term sustainability, it is essential that dairy farms define realistic milk-yield targets aligned with their production environment and focus breeding efforts on enhancing longevity and reliability rather than solely maximizing milk yields. From an economic perspective, cows with good performance reliability should therefore not be culled, even if the replacement cow promises higher milk yields.

NOTES

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Nonstandard abbreviations used: APD = absorbable protein; BL = baseline; BP = breeding progress; BS = Brown Swiss; CEI = expected net income per cow; C_high = farms with high-yielding cows and including a higher proportion of concentrates and frequent barn feeding; C_low = farms with low-yielding cows and primarily grass-based feeding; CMI = marginal income of the present cow; CPD = net profit differential; DI = dairy income; HF = Holstein-Friesian; LPL = length of the productive lifespan; LU = livestock unit; LW = live weight; MLF = milk loss factor; OPL = optimal productive lifespan; OR = own rearing; OSR = outsourced rearing; Repl. = replacement; RR = replacement rate; SR = specialized rearing farm.

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APPENDIX

Table A1. Supplementary production and price assumptions in the herd model and single-cow model differentiated according to production system

Assumption	Unit	C_low	C_high	Reference
Production				
Dry period	d	60	60	Agridea, 2024b
Final lactation period[1]	d	290	340	
LW calf	kg	74	74	Agridea, 2024b
Share of milk sold	%	0.92	0.947	Accounting data
Price[2]				
Dairy calf	USD/kg of LW	4.85	3.99	Agridea, 2024a
Crossbred calf	USD/kg of LW	10.16	10.16	Agridea, 2024a
Residual revenue young stock[3]	USD/cow	154.92	207.85	Accounting data
Slaughter cow (first lactation)[4]	USD/kg of LW	5.21	4.7	Agridea, 2024a
Slaughter cow (other lactations)[5]	USD/kg of LW	4.87	4.39	Accounting data
Energy concentrate	USD/kg	0.54	0.54	Agridea, 2024a
Protein concentrate	USD/kg	0.78	0.78	Agridea, 2024a

[1]Days between last calving and removal, used for calculation of age structure according to Nieuwhof et al. (1989).

[2]Used for calculation of animal sales and allocation factors (allocation of concentrate costs to the single production years).

[3]Calculated so that total revenue from young stock (including calves) matches the accounting data.

[4]Price difference between younger and older cows based on price statistics (Agridea, 2024a).

[5]Derived from accounting data using the average LW (Table 8).

Table A2. Supplementary assumptions in the feeding model (Münger et al., 2021)

Assumption	Net energy for lactation (NEL/kg of DM)	Absorbable protein (APD, g/kg of DM)	CP (g/kg of DM)
Winter forage ration (161 d)	5.5	79	137
Summer forage ration (203 d)	6.2	103	161
Energy concentrate	7.1	92	96
Protein concentrate	6.3	179	395

Table A3. Supplementary assumptions and calculations differentiated according to production year and production system (basis for calculating allocation coefficients that attribute revenues and costs to single production years)

	Production year									
Assumption	1	2	3	4	5	6	7	8	9	10
Kilograms of DMI for C_low basic forage ration[1]	4,759	5,198	5,522	5,639	5,639	5,639	5,603	5,603	5,599	5,450
Energy concentrate[2]	201	126	161	193	193	193	197	197	176	127
Protein concentrate[2]	226	233	265	279	279	279	281	281	271	236
Kilograms of DMI for C_high basic forage ration[1]	5,023	5,699	5,816	5,935	5,937	5,937	5,901	5,901	5,901	5,899
Energy concentrate[2]	867	1,060	1,263	1,502	1,540	1,546	1,546	1,546	1,546	1,508
Protein concentrate[2]	403	485	524	571	579	578	581	581	581	573
Coefficients for allocation[3]										
Concentrate costs (C_low)	0.818	0.882	1.038	1.137	1.137	1.137	1.148	1.148	1.084	0.893
Concentrate costs (C_high)	0.790	0.960	1.101	1.269	1.296	1.296	1.301	1.301	1.301	1.274
Overhead costs (C_low)	0.902	0.985	1.047	1.069	1.069	1.062	1.062	1.062	1.061	1.033
Overhead costs (C_high)	0.908	1.030	1.051	1.072	1.073	1.073	1.066	1.066	1.066	1.066
Veterinary / medication[4]	0.9	1	1	1.1	1.2	1.3	1.4	1.5	1.5	1.5
Calf revenues (C_low)	0.68	0.68	0.92	1.04	1.12	1.17	1.2	1.23	1.25	1.27
Calf revenues (C_high)	0.68	0.68	1.04	1.21	1.32	1.39	1.44	1.48	1.5	1.53
Other assumptions										
LW factors[5]	0.812	0.914	0.960	1.000	0.997	0.994	0.990	0.987	0.984	0.980
Crossbred calves (%)[6]	0	0	0.33	0.5	0.6	0.67	0.71	0.75	0.78	0.8

[1]Based on assumed calving periods of 40% in spring and 60% in fall; used to calculate allocation coefficients for overhead costs.

[2]Used to calculate coefficients that allocate concentrate costs to single production years.

[3]Coefficients in rounded values resulting from feeding model and price assumptions, used to allocate accounting values to production years.

[4]Following Winter et al. (2024) and Bigras-Poulin et al. (1990).

[5]Assumed LW in the fourth year of production: 670 kg (C_low) and 730 kg (C_high) following Burren et al. (2021); for calculating feed intake and allocating slaughter weights to single production years.

[6]Share of inseminations with beef bulls.

Table A4. Supplementary assumptions and results of cost modeling for heifers (costs per heifer in USD) on specialized rearing farms in mountain region (SR_M), on dairy farms with own rearing in hilly region (OR_H) and with outsourced rearing in the lowlands (OSR_L) for 24-, 26-, 28- and 30- mo rearing periods

	Rearing farm type and length of rearing period											
Item	SR-M24	SR-M26	S-M28	SR-M30	OR-H24	OR_H26	OR_H28	OR_H30	OSR_L24	OSR_L26	OSR_L28	OSR_L30
Sold heifers[1]	38	32.5	28.5	25.5	21.5	18.5	16.5	14.5	6.5	5.5	5	4.5
Concentrate[2]	270	274	270	279	301	306	300	313	263	274	286	297
Whole milk[3]	397	397	291	291	397	397	291	291	291	291	291	291
Insemination	113	113	113	113	92	98	103	107	99	101	103	105
Other costs[4]	114	132	151	169	145	169	192	215	118	137	156	174
Overhead[5]	1,279	1,475	1,672	1,866	990	1,140	1,291	1,440	1,042	1,202	1,363	1,521
Own labor[6]	1,810	2,099	2,394	2,682	1,141	1,323	1,509	1,691	1,314	1,527	1,742	1,952

[1]Number of reared heifers per year (derived from accounting data and modeled for 24–30 mo).

[2]At 24 mo, accounting value was increased by 33%; at 26 mo by 20%.

[3]Assumptions based on planning data (Agridea, 2024b).

[4]Other direct costs like straw, identification, and so on.

[5]Costs for machinery, buildings, employees, and land (derived from accounting data).

[6]Full opportunity costs calculated with 31 USD/h; modeled with LabourScope (Heitkämper et al., 2020).