MARKET ANALYSIS

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Cost Estimation for Rearing Dairy Young Stock in Sabah, Malaysia: A Stochastic Model Accounting for Calf Mortality Uncertainty

The rearing of young stock in tropical countries is considered a substantial investment for dairy farmers due to non-productivity and the higher risk of mortality in the first 2 to 3 years of youngstock life. ICalculating the rearing costs of young calves, especially on non-commercial farms, is challenging due to incomplete farm records. This study, which was conducted at Keningau, Sabah, East Malaysia, estimated the costs of rearing dairy young stock from birth to the first calving age, taking into account uncertainty regarding young stock mortality. A stochastic bioeconomic model was developed at the animal level to calculate the cost of young stock rearing. Our results revealed that the average total costs of rearing dairy young stock from birth to the first calving age for non-commercial and commercial farms were €1,689 and €1,645, with average mortality costs of €15 (0.88%) and €13 (0.79%), respectively. The first calving age of dairy young stock were 32.1 months (442.87 kg) and 24 months (585 kg) in non-commercial and commercial farms, respectively. Sensitivity analysis showed that a 2% decrease in mortality rate reduced rearing costs by €7 for non-commercial farms and €5 for commercial farms. In conclusion, non-commercial (small-scale) dairy farmers should pay more attention to the control and prevention of diseases to reduce mortality, as higher mortality rates have greater cost implications for smaller herds without proper health management.

Keywords: dairy young stock, bioeconomics, tropics, stochastic model

JEL classification: Q13

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Introduction

Malaysia is a developing country in Southeast Asia located north of the equator. It comprises two non-contiguous regions known as Peninsular Malaysia (West Malaysia) and the island of Borneo (East Malaysia), with 329,613 km^2 of land area. The country has 2,000-2,500 mm of regular rainfall per year and an average temperature of 26-28°C (Hazir *et al.,* 2020). Although Malaysia is not ideal for dairy calf rearing (Moran, 2011), dairy farming is an indispensable industry that contributes to national food security and reduces the cost of dairy imports in the agricultural sub-sector (Suntharalingam, 2019). The Malaysian dairy industry achieved 66% self-sufficiency with 40.6 million litres of milk production in 2019, and the country aims to achieve 100% self-sufficiency level (SSL) by 2025. Additional milk is imported primarily from Australia (Arumugam, 2018). The cattle population (44,761 heads) in the country is made up of crossbreed dairy cattle (98.6%) and Local Indian Dairy (LID) crossbred (1.4%) with 50% or more exotic blood levels (DVS, 2020). Previous studies have highlighted that the industry faces several substantial problems and challenges. These include lack of knowledge of farming, lack of a skilled workforce, low-quality breed, insufficient land area and the high costs of the inputs (Faghiri et al., 2019; Moran and Brouwer, 2013). Despite the challenges faced by the dairy industry, all the above factors are likely to be solved if relevant authorities (e.g., government, supporting industries) and dairy farmers work together. The Department of Veterinary Services (DVS) Malaysia has taken the initiative by introducing a crossbreeding programme with a view to improving the Sahiwal and Friesian cattle breeds since 1974. Compared to indigenous cattle, crossbred cattle are better adapted to local production conditions; moreover, purebred cattle usually mature late and have poor growth rates and low milk yields (Usman *et al.,* 2012; Galukande *et al.,* 2013).

In Malaysia, there were 826 dairy farms registered with DVS and 79 of those dairy farms (9.6%) in Sabah (unpublished data) are located in 2017. A dairy farm with less than 50 dairy cows was classified as a non-commercial farm while a dairy farm with more than 50 dairy cows was categorised as a commercial farm (Suntharalingam, 2019). Semi-intensive and intensive systems are the two main farming systems in the Malaysian dairy industry (Mohd Suhaimi *et al.,* 2017). Keningau is located in the internal division of Sabah, Malaysia (5.3289 °N, 116.1826 °E). This study was chosen to be conducted in Keningau, Sabah as all types of farm management systems (non-commercial and commercial farm) existed there, enabling the researchers to compare the total cost of rearing dairy young stock in different farms management systems. In addition, dairy farms in Keningau contribute the highest milk production in Sabah's milk production (90.6%) compared to the other districts (DFAS, unpublished data) as dairy farms in Keningau have more well-established facilities such as milking machines including in the smallholder farms.

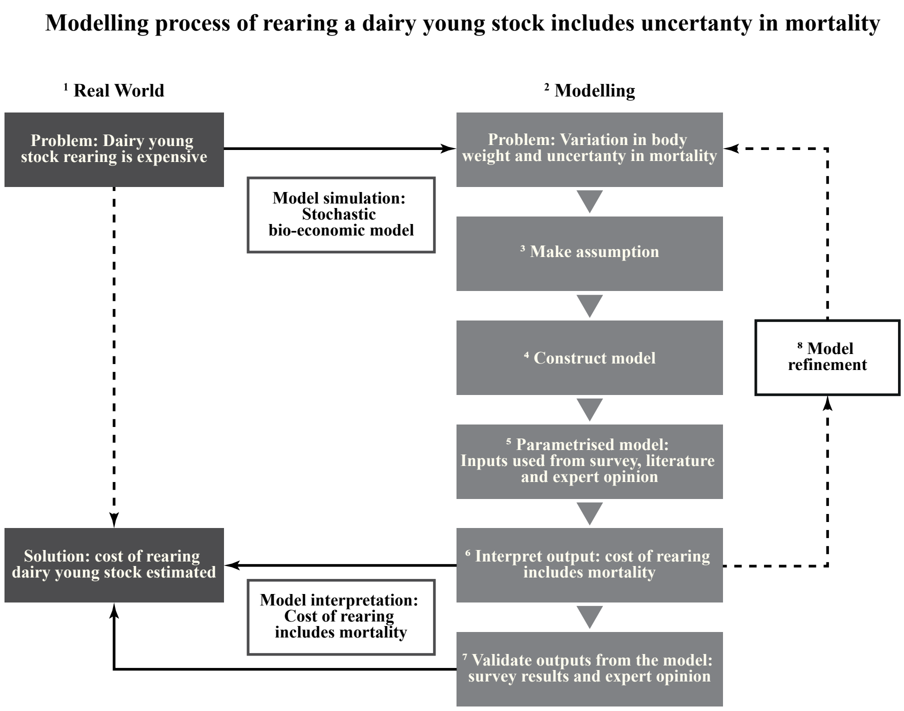
On dairy farm operations, young stock needs to be reared in order to replace dairy culled cows (van Eetvelde and Opsomer, 2017). However, this aspect of cattle husbandry does not get optimal attention from dairy farmers because it is considered laborious and risky. Any heifer that does not reach first calving successfully could result in economic losses, which must be covered by income generated elsewhere (Boulton *et al.,* 2017). In the tropical country, young stock rearing has a high mortality rate and 15-40% of young stock is non-productive for at least 2 to 3 years (Moran, 2011; Ang *et al.,* 2021). The cost of rearing the young stock includes the costs of feed, housing, breeding and health care (Mohd Nor *et al.,* 2012). Various studies on the cost of rearing dairy young stock have been published over the past 20 years (Boulton *et al.,* 2017; Heinrichs *et al.,* 2013; Gabler *et al.,* 2000) and these have revealed that successfully rearing a heifer is a large investment, as the cost of rearing a dairy young stock from birth to first calving age can vary between €1,015 to €1,950 (Currency exchange as €1=RM4.64, on March 22, 2022). These studies provide good insights into the total cost of rearing based on temperate conditions that differ from those tropical countries. Most farms do not calculate the cost of rearing as it is hard to separate the inputs from other enterprises on the farm operations, and estimating it is assumed to be an unnecessary chore that correlates with both biological process and uncertainty. Hawkins *et al.* (2019) stated that failure to identify the on-farm cost to rear a young stock might lead to the cost of feed, labour, housing, or health going unnoticed.

This study aims to fill the gap by estimating the costs of rearing dairy young stock from birth to first calving age that includes uncertainty in mortality. Most of the studies in Malaysia focused on the dairy cows and lack of detailed investigation of dairy young stock. So far as the authors are aware, there are no prior studies on dairy young stock that employ stochastic modelling. The findings of this study can provide valuable guidelines and insight, particularly in the context of tropical dairy farming and the economics of rearing dairy young stock for different stakeholders, and have the potential to enable better decision making, which may in turn improve the profitability and sustainability of dairy farms.

Materials and Methods

Model Building

A stochastic bioeconomic model was developed at the animal level in Microsoft Excel using @Risk add-in software. Figure 1 shows the framework for estimating the costs of rearing dairy young stock. The model was simulated by 2,000 iterations based on the number of dairy young stock on commercial farms in Malaysia (unpublished). The young stock was characterised by different farm management systems (non-commercial and commercial farms) in the model. This model's economic and biological inputs were obtained from the survey, existing literature, and expert opinion.



[1] In Malaysia, dairy young stock rearing is expensive and difficult to estimate on account of its complexity due to variation and uncertainty.
[2] Modelling was built to estimate the cost of rearing from birth to first calving age. Firstly, by making the assumptions, secondly by constructing the model in Microsoft Excel using @Risk, thirdly by parameterising the model using biological and economics inputs from survey, literature, and expert opinion, fourthly by interpreting outputs, and finally by validating outputs of the model and refining the model where necessary.
[3] The stochastic bioeconomic model developed assumptions such as milk was restricted to 10% of the preweaning calf live weight (Palczynski *et al.,* 2020), solid feed was based on 3% of dry matter intake for postweaning heifer (Saadiah *et al.,* 2019), the animal was assumed to have been bred through artificial insemination (AI; unsexed semen) and successfully bred after the first insemination with 270 days of gestation (Sguizzato *et al.,* 2020). The oestrus detection sand conception rates were not included in the model, the record of disease outbreak was not included, but the uncertainty of mortality was included from birth to first calving age.
[4] The stochastic bioeconomic model was built by including the cost of feed, labour, breeding, and mortality.
[5] The biological and economic inputs used in the stochastic bioeconomic model were taken from literature, and expert opinion.
[6] The model output was interpreted as the total cost of rearing include uncertainty of mortality.
[7] Survey results in a previous study and expert opinion were used to validate the model output.
[8] The model was refined to reflect the situation of dairy young stock enterprise on dairy farms in Keningau, Sabah.

Figure 1: A framework for the estimation of the total cost of rearing dairy young stock from birth until first calving age using a stochastic bioeconomic model.
Source: own composition

This model consists of 52 stages representing the rearing period of a dairy young stock from birth to first calving age. The first thirteen stages correspond to intervals of 7 days to reflect the period from birth to 3 months of age. The following stages from fourteen to fifty-two comprised intervals of 21 days. The need for different intervals was due to the biological process (oestrus cycle) which varies across different age (pre-weaning and post-weaning). Supplementary Figure 1 in the Supplementary materials section presents the stochastic model that simulated dairy young stock mortality costs. As shown in Figure 2, a transition matrix was used to determine the health status of dairy young stock at each stage, referred to as a state. “Healthy” was defined as a dairy young stock that stays alive. Young stocks that reached first calving were considered as successfully reared young stocks, while unsuccessfully reared young stocks were animals that did not reach first calving age due to death.

Stage=n+1

Stage=n	Stage	Healthy	Dead
	Healthy	1–(A2)	Mortality rate (A2)
	Dead		1

Figure 2: The transition matrix that comprises 2 states of the dairy young stock (healthy and dead).

The state of dairy young stock at a stage (n+1) was dependent on the state of dairy young stock at the previous stage (n). We can see that at stage=n, healthy state dairy young stock (cell A) was determined by the mortality rate in the stage. The dairy young stock now can remain healthy (cell 1) or dead (cell 3) in the next stage. If the dairy young stock was dead in the previous stage (n), the dairy young stock state will remain dead in the following stage (B2).

Source: own composition

Development of growth curve

In this model, the individual animal body weight data were collected from seventy-six animals (n=76; 76 observations) in non-commercial farms and one-hundred fifty animals (n=150; 1,022 observations) from commercial farms at Keningau, Sabah. In the commercial farm data set contained variables such as identification number, dam identification number, birth date and date of weighing. Data was edited by segregating according to management system (non-commercial and commercial).

The predicted body weight measurement in non-commercial and commercial farms at different rearing periods for dairy young stock at birth is 23.37kg and 31.33kg, respectively. At weaning age, the body weight was increased to 46.21kg (non-commercial farm) and 86.37kg (commercial farm). The breeding weight of dairy young stock in the non-commercial farm is 329.61kg, while in the commercial farm at 424.60kg. The first calving weight is 434.90kg (non-commercial farm) and 584.65kg (commercial farm).

In this model, there are few assumptions: 1. milk was restricted to 10% of the pre-weaning calf live weight (Sung *et al.,* 2016); 2. solid feed (e.g. concentrate and forage) was based on 3% of dry matter intake (DMI) for post-weaning heifer (Hutchison *et al.,* 2017); 3. the animal was assumed to have been bred through AI (unsexed semen) and successfully bred after the first insemination with 270 days of gestation (López-Paredes *et al.,* 2018) and 4. there were no disease outbreaks. The results of previous studies (Ang *et al.,* 2021), and veterinary experts’ opinions from the Faculty of Veterinary Medicine, Universiti Putra Malaysia were used to validate the output of the stochastic bio-economic model.

The biological inputs of the model include the rearing period, mortality rate and body weight of the dairy young stock. The biological inputs used in this study were summarised in Table 1. Dairy farm background and farm management practices can be referred to (Ang *et al.,* 2021). The economic input includes milk price (€0.60 per litre), calf milk replacer price (€0.40 per litre), calf starter price (€0.33 per kg), forage price (€0.03 per kg), dairy cattle pellet price (€0.30 per kg), total mixed ration price (€0.25 per kg), wages (€0.02 per minutes), and semen price (€1.94 per straw) (Table 2).

Table 1: Biological input used in the stochastic bio-economic model of rearing a dairy young stock.

Variable	Data	Sources
[1] Mortality rate in non-commercial farm (%)		survey
0-3 months	5.0	
4-6 months	5.0	
7-9 months	5.0	
10-12 months	5.0	
13-14 months	1.0	
15-16 months	2.0	
17-24 months	1.0	
25-32 months	1.0	
[1] Mortality rate in commercial farm (%)		survey
0-3 months	4.0	
4-6 months	0.0	
7-9 months	6.0	
10-12 months	2.0	
13-14 months	1.0	
15-16 months	2.0	
17-24 months	1.0	
[2] Body weight measurement (kg)	-	farm data
Feeding amount		
Pre-weaning	10% of body weight	Heinrichs and Swartz (1990)
Post-weaning	3% of DMI	Saadiah *et al.,* 2019
Dry Matter (%)		
Dairy cattle pellet	91.6	Farm data
Total mixed ration	92.8	Farm data
Forage (Napier)	27.6	Farm data
Gestation length (days)	270	López-Paredes *et al.,* 2018
Average time taken to do activity (minutes/young stock)		
Feeding		
Pre-weaning	9	survey
Post-weaning	7.5	survey
Cleaning	3	survey
Artificial insemination	21.5	expert opinion
Calving assistance	67.5	expert opinion

[1] Refer to Supplementary Equations 10 in the Supplementary materials.
[2] Body weight measurement from birth until first calving age was predicted using Gompertz function.
Source: own calculations

Table 2: Input prices used in the stochastic bio-economic model to estimate the cost of rearing dairy young stock.

Input Variable	[1]Average cost (min-max) (€)	Sources
Feed		
[2] Whole milk (litre)	0.60 (0.58-0.62)	Milk collecting centre
Calf milk replacer (litre)	0.40 (0.36-0.44)	survey
Total mixed ration (kg)	0.25 (0.24-0.26)	survey
Dairy cattle pellet (kg)	0.30 (0.29-0.31)	survey
Calf stater (kg)	0.33 (0.27-0.39)	survey
[3] Forage (kg)	0.03 (0.026-0.034)	survey
Labour		
Wages (minutes)	0.02 (0.018-0.022)	survey
Breeding		
[4] Semen (straw)	1.94 (1.72-2.16)	survey

[1] The specific commands RiskTriang (average, min, max) was used in the stochastic model.
[2] The price of whole milk (litres) is the opportunity cost of saleable milk.
[3] Purchased price of forage (kg).
[4] The price of unsexed semen per straw was used in the model.
Source: own composition

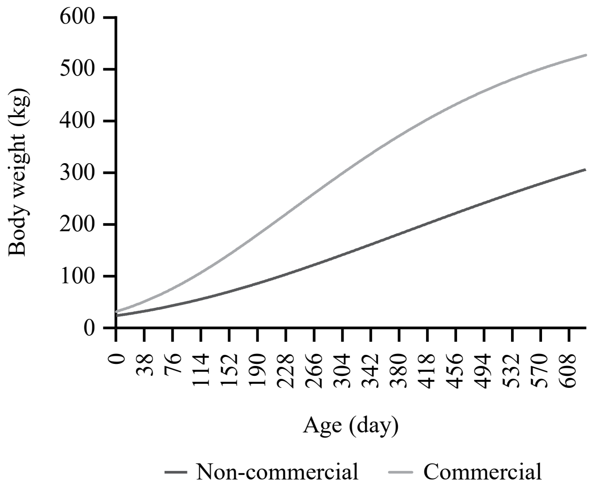
Table 3: Sensitivity analyses were performed by changing the biological and economic input one at a time to evaluate the impact of the changes to the total cost of rearing dairy young stock.

Variables	Input Change	Source
Growth rate		
Non-commercial farm	–25% and +25%	Veterinary expertise
Commercial farm	–24%	Veterinary expertise
Mortality rate (%)	–15% and +40%	Moran (2011)
Feed price (€)		
Milk /litre	–0.02 and +0.02	survey
Calf milk replacer/litre	–0.04 and +0.04	survey
Calf starter /kg	–0.06 and +0.06	survey
Total mixed ration/kg	–0.01 and +0.01	survey
Dairy cattle pellet/kg	–0.01 and +0.01	survey
Forage /kg	–0.004 and +0.004	survey
Labor wages (€)	-0.002 and +0.002	survey
Semen /straw (€)	-0.22 and +0.22	survey

Source: own composition

Sensitivity analysis was performed on important biological inputs and economic inputs by changing default input value to lower or higher value, one at a time to find the impact of the input change on the change in total costs of rearing dairy young stock from birth until the first calving age (Table 3). The biological changes were: 1. predicted body weight based on Gompertz function at default was changed one at a time by 25% for dairy young stock on non-commercial farm and 24% for dairy young stock on commercial farm; 2. the mortality rate in non-commercial farm and commercial farm was decreased by 2% and increased 40% one at a time. The economic inputs changed were: 1. raw milk/litre with default value at €0.60 was changed one at a time to become €0.58 (-€0.02 from default value) then changed to €0.62 (+€0.02 from default value); 2. calf milk replacer/litres default value at €0.40 (-€0.04; +€0.04); 3. calf starter/kg default value at €0.33 (-€0.06; +€0.06); 4. dairy cattle pellet/kg default value at €0.29 (-€0.01,+€0.01); 5. total mixed ration/kg default value at €0.25 (-€0.01, +€0.01); 6. forage/kg default value at €0.03 (-€0.004,+€0.004); 7. semen/straw default value at €1.94 (-€0.22,+€0.22); 8. wages/min default value at €0.02 (-€0.002,+€0.002).

The output from the stochastic bio-economic model was analysed descriptively using Stat Tools add-on in Microsoft Excel. Gompertz function (Supplementary Equation 1 in the Supplementary materials section) is used to predict the body weight. The mature body weight for dairy young stock on non-commercial farm was 367kg according to literature by Panda and Samanta (2018), while the mature body weight for dairy young stock on commercial farm was 650kg based on survey. The model was determined by A, K and B parameters representing the mature live weight, growth turning point and growth rate, respectively (Hawkins, 2019). Predicted body weight were fitted into a Gompertz function to plot the growth curve (Figure 3). Data from survey was analysed and published in a previous study (Ang *et al.,* 2021).



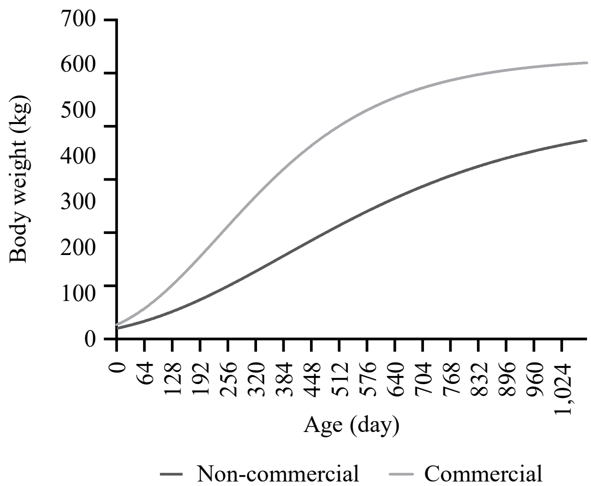


Figure 3: The growth curve of the dairy young stock in non-commercial farm and commercial farm at Keningau, Sabah using Gompertz function.

Note. A: The growth curve until breeding age. B: The extrapolation after breeding age growth curve showed an increasing growth curve at decreasing rate.
Source: own composition

Results

The total cost of rearing comprises of feed cost, labour cost, breeding cost (fixed cost) and mortality cost (provision cost). Feed cost (Supplementary Equation 5 in the supplementary materials section) was the major contributor to rearing cost that cost €1,267 (75%) and €1,327 (80%), respectively in non-commercial and commercial farms. The average cost to rear a dairy young stock from birth until the first calving age for non-commercial and commercial farms was €1,689 and €1,645, respectively. The average mortality costs (Supplementary Equation 11 in the supplementary materials section) from birth to the first calving age for the non-commercial and commercial farms are €15.30 and €13.80, respectively (Table 4).

The predicted body weight measurement in non-commercial farm and commercial farm at different rearing periods for dairy young stock at birth are 23.37kg and 31.33kg, respectively. At weaning age, the body weight was increased to 46.21kg at 2.9 months of age (non-commercial farm) and 86.37kg at 3 months of age (commercial farm). The breeding weight of dairy young stock in non-commercial farm is 329.61kg (23.1 months) while in commercial farm, breeding starts at 15 months at 424.60kg. The first calving weight are 442.87kg at 32.1 months of age (non-commercial farm) and 584.65kg at 24 months of age (commercial farm), respectively (Table 5).

Based on the sensitivity analysis conducted on the biological inputs (Figure 4), when bodyweight for the non-

Table 4: The cost of rearing dairy young stock per heifer from birth to first calving age using the stochastic model.

Costs (RM)	Non-commercial farm	Commercial farm
	Average cost (5-95%) (€)	
[a] Feed		
Whole milk	172.21 (168.04-176.34)	-
Calf milk replacer	-	192.79 (179.31-206.23)
Calf starter	9.31 (8.14-10.48)	12.81 (11.23-14.39)
Dairy cattle pellet	646.18 (628.20-663.99)	-
Total mixed ration	-	688.78 (662.46-715.06)
Forage (Napier)	439.00 (377.46-499.39)	432.22 (373.05-491.24)
Total Feed	1,266.69 (1,181.83-1,350.21)	1,326.61 (1,226.06-1,426.92)
[a] Labour		
Feeding	337.02 (323.67-350.65)	251.65 (241.52-261.75)
Cleaning	66.20 (63.58-68.87)	49.09 (47.12-51.06)
AI setup	0.50 (0.47-0.51)	0.50 (0.47-0.51)
Calving assistance	1.54 (1.48-1.61)	1.54 (1.48-1.61)
Total Labour	401.90 (386.00-418.16)	302.76 (290.58-314.91)
[a] Breeding	1.94 (1.79-2.09)	1.94 (1.79-2.09)
Subtotal	1,673.9 (1,572.83-1,773.93)	1,631.32 (1,518.43-1,743.94)
[a] Mortality	15.30	13.80
[a] Total cost of rearing	1,689.22	1,645.12

[a] Refer to Supplementary Equations 4-11 in the Supplementary materials.
Source: own composition

Table 5: The biological output of the dairy young stock rearing model based on commercial and non-commerical farms at Keningau, Sabah.

Output	Non-commercial farm	Commercial farm
Age (months)		
Weaning	2.9	3
Breeding	23.1	15
First Calving	32.1	24
Body weight (kg)		
Birth	23.37	31.33
Weaning	46.21	86.37
Breeding	329.61	424.49
First Calving	442.87	584.65
[1]Amount of feed		
Milk (L)	299.33	-
Calf milk replacer (L)	-	511.49
Calf starter (kg)	29.60	39.00
Dairy cattle pellet (kg)	2,230.80	-
Total mixed ration (kg)	-	2,745.00
Forage (kg)	16,282.98	16,053.90

[1] Amount of feed provided to the dairy young stock from birth to first calving age not until the dead age.
Source: own composition

commercial farm increased (+25%), the costs of rearing dairy young stock decreased by €295.95 less/young stock. When growth performance for the non-commercial farm (-25%) and commercial farm (-24%) decreased, the costs of rearing dairy young stock increased by €542.63 and €468.70 more/young stock, respectively. Dairy young stock in non-commercial and commercial farms were simulated 79% and 84% survived as the model's output. When the mortality rate in non-commercial and commercial farm decreased by 2%, the costs decreased by €7 and €5 less/young stock, respectively. When the mortality rate in non-commercial and commercial farm increased 40%, the costs increased by €44.15 and €31.42 more/young stock, respectively.

Based on the sensitivity analysis conducted on the economic inputs, the cost of rearing dairy young stock was most sensitive to the change in the price of forage. When raw milk price/litre increased by €0.02 more from the default price, the average costs of rearing increased by €12.60 more/young stock. When raw milk price/kg decreased by €0.02 less from default price, the costs of rearing decreased by €18.70 less/young stock. When the calf milk replacer/litre increased by €0.04 more than the default price, the rearing costs increased by €23.05 more/young stock. When the calf milk replacer/litre decreased by €0.04 less than the default price, the rearing costs decreased by €17.29 more/young stock When dairy cattle pellet price/kg increased by €0.01 more, the costs increased by €27.30 more/young stock. When dairy cattle pellet price/kg decreased by €0.01 less, the costs decreased by €24.10 less/young stock. When the total mixed ration price/kg increased by €0.01 more, the costs increased by €45.63 more/young stock. When the total mixed ration price/kg decreased by €0.01 less, the costs decreased by €35.71 less/young stock. When forage price/kg increased by €0.004 more, the costs increased by €87.38 more/young stock. When forage price/kg decreased by €0.004 less, the costs decreased by €82.64 less/young stock (Figure 5).

Discussion

The total cost of rearing in the current study was higher than the previous study conducted in Keningau, Sabah, because the previous study only estimated the cost of concentrate and cost of milk (Ang *et al.,* 2021). Further, comparison of the total cost of rearing is difficult with previous studies in temperate countries such as in the Netherlands (Mohd Nor *et al.,* 2012), the United States (Heinrichs *et al.,* 2013) and the United Kingdom (Boulton *et al.,* 2017) due to different years

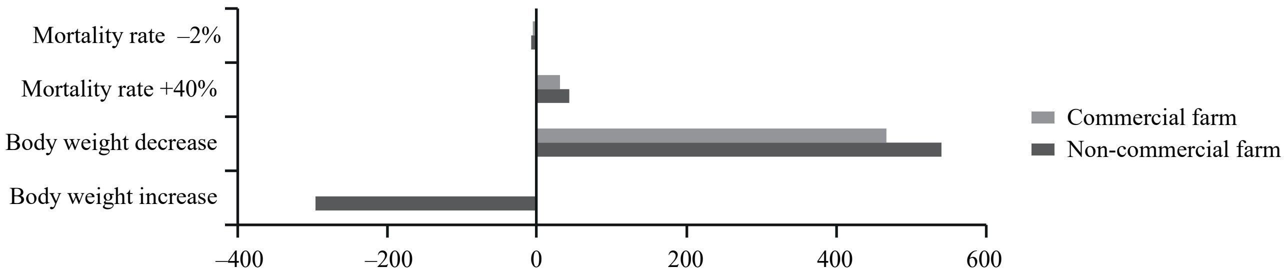


Figure 4: The impact of change in biological inputs to the total cost of rearing dairy young stock from birth until first calving age based on commercial and non-commercial farms at Keningau, Sabah.

Source: own composition

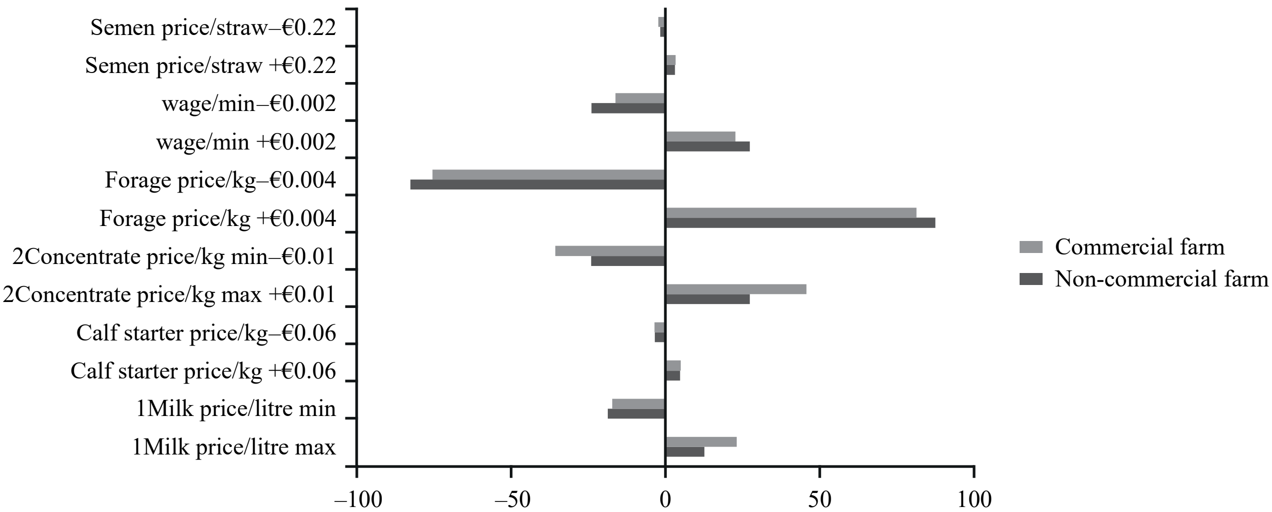


Figure 5: The impact of change in economic inputs to the total cost of rearing dairy young stock from birth until first calving age based on commercial and non-commercial farm at Keningau, Sabah.

Source: own composition

of research conducted, currency and management. The total cost of rearing in this study was reported based on individual animals because reported averages do not allow for statistical comparison of the observed data (Boulton *et al.*, 2017). The input costs commonly used by researchers include variable costs (feed, labour, health, reproduction, bedding, mortality and interest cost) and fixed costs (housing, facilities, equipment) (Mohd Nor *et al.,* 2012; Heinrichs *et al.,* 2013; Gabler *et al.,* 2000) This study only comprises the variable cost not the fixed costs as it is hard to separate them from other enterprises (e.g. land enterprise) and may cause overestimation. For example, the cost of building is shared between a young stock enterprise and a dairy cows' enterprise, but a previous study said that farmers could only recover the expenses of rearing dairy young stock when the revenue from milk sales covers both the fixed and variable costs incurred during the rearing period, and only if revenue from milk is greater than the variable costs (Boulton *et al.,* 2017).

The results showed that the total cost of rearing in non-commercial farm is higher than commercial farm because of late FCA and high mortality rate. The first calving age in non-commercial farms is 8 months later than commercial farms. This may be caused by higher feed cost and labour cost. Detailed mortality cost will be discussed further in the next paragraph. However, it is not much different (€44) because the growth performance in the non-commercial farms is lower than dairy young stock in commercial farm. The effects of early FCA (early than 24 months) such as high culling rate (Sung *et al.,* 2016), less likely to deliver a live calf (Hutchison *et al.,* 2017) and greater daily energy requirements (López-Paredes *et al.,* 2018), while the impacts of delayed FCA are increased cost of rearing, decreased milk production and lower fertility (Sung *et al.,* 2016). The results showed that the first calving age of dairy young stock in the commercial farm was optimal within the suggested average FCA of 24-28 months (Sung *et al.,* 2016); this could be due to proper management.

Feed cost contributes on average 78% to the total cost of rearing followed by labour cost (21%). Even though there are differences among previous studies, there is general agreement that feed cost is the major contributor to the total cost of rearing. Feed costs contribute one-half of the total variable costs of production (Gabler *et al.,* 2000; Panda and Samanta, 2018). In other words, feed cost makes a major contribution (60-73%) to the cost of rearing young stock (Heinrichs *et al.,* 2013; Gabler *et al.,* 2000; Hawkins, 2019). As feed cost is the major contributor, dairy farmers need to focus on nutrition because the daily feeding cost of heifers increases with age, in part due to greater bodyweight maintenance requirements. However, the feed cost will vary according to the type and price of feed, nutrition and expected growth of the animal. Dairy farmers have suffered cost pressures where imported raw materials have the risk of exchange rate depreciation, resulting in an increase in prices (Haryo *et al.,* 2017), which is similar to our findings with the farmer who purchased imported dairy cattle pellets instead of preparing their own total mixed ration.

From the sensitivity analysis results, the cost of rearing dairy young stock was most sensitive to the change in the price of forage as forage is the main feed of a herbivore. The price of forage included in this study was the opportunity cost of purchase directly from others instead of homegrown price because it is a complex factor correlated with land management. If the cost of forage was excluded, the cost of rearing could save up to 26% (€432). However, the cost of homegrown forage should be studied in the future. The government or universities can hold knowledge transfer programme with a "local recipe" in preparing nutritious and cost-effective total mixed ration to assist the dairy farmer in reducing the cost of rearing practically. Dairy farmers should keep the optimal number of dairy young stock on the farm to avoid unnecessary costs.

In this study, labour cost is the second largest contributor (21%) after feed cost, a finding which aligns with the results of a previous study which reported that the labour cost represented 33% of the total cost of rearing ranged between 20% to 45% (Akins *et al.,* 2017). Undoubtedly, dairy farming is a labour-intensive industry. The daily labour cost for pre-weaning dairy calf in this study is higher (€0.07) than post-weaning as the pre-weaning dairy calf needs an average of 2 more minutes (e.g. bottle feeding) in feeding. Recent studies reported that switching from manual to automated labour can reduce pre-weaning total costs by 6% because the total number of workers is reduced while at the same time increasing the efficiency of both labour and management (Akins *et al.,* 2017). In non-commercial farms, it is basically operated by family members or the owner themselves. According to the early work of van Biert (2018), regardless of whether labourers were family members or hired employees, family labour is paid as hired labour.

In this study, the mortality cost of dairy young stock was €15 and €13, respectively in non-commercial farm and commercial farm. Mortality can be considered a great economic loss to the dairy farm that brings negative economic effects, which is unexpected and unwanted (Fentie *et al.,* 2020). The animal welfare status of a herd is reflected in its mortality rate (Boersema *et al.,* 2010). The calf mortality rates on tropical dairy farms ranged between 15% to 25% (Moran, 2011) and is relatively higher than in temperate regions such as Sweden (2.1%) (Svensson *et al.,* 2006). As shown in Table 1, the mortality rate in the non-commercial farm is only available in the first year of dairy young stock's life due to insufficient farm records which are not well-documented and validated. Data from commercial farms started from the second year was used to simulate the model. The most common causes of mortality of dairy young stock are described by Boersema *et al.* (2010) according to different age categories such as navel joint illness (from birth to first month of age), abomasa ulceration (from 1 to 3 months of age), and respiratory infections (from 3 months to first calving). According to Moran (2012), scours and pneumonia are the two major calf diseases that cause 80% of calf deaths. In Malaysia, the common diseases of dairy young stock are diarrhoea, pneumonia, navel illness, bloat, joint illness, foot-and-mouth disease (FMD) and pink eye (Azhar *et al.,* 2016; DVS, 2010). Previous studies reported that the mean cost of mortality per surviving heifer ranged from €124 to €280.23 (Boulton *et al.,* 2017; Mohd Nor *et al.,* 2012), which is higher than the results in this study.

The mortality cost in this study was lower compared to the previous study because it happened in early life (pre-weaning) of dairy young stock. This observation is in line with the findings of a previous study and reflects reality as there is high mortality during pre-weaning period (Zucali *et* *al.,* 2013). An interesting finding (Heinrichs *et al.,* 2013) is that the cost of mortality will increase €77 to €445 when animals die after the infection. Farmers will benefit more by targeting low mortality rates instead of just feeding lower quality feed to reduce costs and increase income (Moran, 2012). A previous study showed that dairy farmers could benefit from reducing the overall cost of rearing from €35 to €33 per calf by reducing the mortality rate 15% to 2% in the pre-weaning period (Hawkins, 2019). The model did not include any disease outbreaks in this research and death did not occur due to special conditions like a calf falling in the drain happening on the farm. It includes the cost of resources used up to the point of death assigned to the remaining number of surviving heifers, an approach which may serve to underestimate the mortality cost. Reducing calf mortality by better management positively affects gross margins (Razzaque *et al.,* 2009). Dairy farmers, especially smallholders, should pay more attention to control and prevent disease as mortality had a greater cost implication on smaller herds the cost was spread over a smaller number of the surviving heifer (Boulton *et al.,* 2017). To reduce the mortality rate, dairy farmers were advised to improve the management practices of calf rearing, adopting suitable biosecurity measures at farms such as introducing a footbath, quarantining sick dairy young stock, regular veterinarian visits to check the health status of young stock, and the implementation of vaccinations (e.g. Salmonella Double Ad-juvant Vaccine, Haemorrhagic Septicemia Alum Precipitated Vaccine) as preventive measures to prevent further economic losses.

As far as we are concerned, this is the first study conducted in the tropics (Malaysia) that calculated the cost of rearing according to different management systems, including the uncertainty of mortality using a stochastic bioeconomic model. There are previous studies that developed a stochastic (dynamic) model in the Netherlands (Mohd Nor *et al.,* 2012; Mourits *et al.,* 1999) and the United States (Hawkins, 2019) with a view to optimising management decisions and quantifying the cost of rearing. The advantages of using this method to estimate the cost of rearing were numerous. First, it was able to include variation such as mortality rate and market conditions (i.e. the price of feed). It enables us to estimate the losses due to mortality in different age categories. Moreover, as the price depended on market feed price that changing on a daily, weekly and monthly basis, as it is unreasonable for farmers to be changing the feed mix that frequently (Alqaisi *et al.,* 2019). Second, we were able to observe the consequences of various management practices, such as different types of feed that can be adopted by farmers as a better alternative. Third, the output (e.g., cost of rearing, first calving age) in this study can be explained by the inputs and assumptions. Fourth, the Gompertz function was used to model the body weight of dairy young stock at the different management systems to estimate the amount of feed. To the best of the authors' knowledge, no previous studies have measured the actual growth curve of crossbreed cattle in our country in a way that reflects the actual dairy young stock's biological growth. These gave a more accurate estimation of the total cost of rearing. Fifth, the sensitivity analysis results enable the dairy farmers to understand better the impact of the input change on the cost of rearing dairy young stock from birth until the first calving age. We can therefore regard it as proven that a stochastic model is a useful tool in estimating the cost of rearing dairy young stock.

There are limitations of this model, which might underestimate the total cost where future studies are suggested to improve necessary aspects of the model that might be useful for economic evaluation as no simulation model includes all elements perfectly. The model assumes there is no disease outbreak, we simulated heifer calves under good rearing conditions, but the uncertainty of mortality was included from birth to first calving age that discussed in the previous section. Besides, all dairy young stock was assumed to be successfully bred with 270 days of gestation because there was no oestrus detection rate and conception rate included due to incomplete records. In a future study, this part may be improved. The cost of subsequent AI is also not included in this model. The authors calculated that if the heifer received three times of AI, it would cost €5.8/heifer additionally. Such consequences showed no obvious effects on the cost of rearing at the animal level, but it can be modelled in a herd-level model. Non-commercial dairy farmers in this research did not weigh the young stock, which could be because weighing was perceived as an unnecessary chore and could be laborious, especially for smallholder farms. The difficulty of our study lies in the growth performance of dairy young stock, in the absence of a proper record of body weight data. The heart girth of dairy young stock was measured by measuring tape during a farm visit. The measuring tape is practical due to the unavailability of weighing facilities on the farm. Previous studies reported that the advantages of using measuring tape are that body measurement (e.g. heart girth) was highly correlated with body weight and can be used to estimate the body weight with a high degree of accuracy (Mohamad Hafiz *et al.,* 2016). Nevertheless, the limitation of measuring tape is that it is unlikely to be more precise than a weighing scale or weigh-bridge when the animal alters its posture, which could be less reliable (Sawanon *et al.,* 2011; Wangchuk *et al.,* 2018) (39,40)the need for weighing equipment in the market place causes substantial difficulties for developing countries, especially where cattle production involves rural households.

Conclusions

This study reveals the total cost of rearing and the economic impact of mortality from birth to the first calving age. The average costs of rearing dairy young stock from birth until the first calving age for non-commercial and commercial farms were €1,689 and €1,645, respectively. The average mortality cost from birth to the first calving age for non-commercial and commercial farms were €15.30 and €13.80, respectively. The current findings fill the knowledge gap from previous works conducted in the which tropics focused on mortality rates and the growth performance of Mafriwal cattle in Malaysia (Moran, 2011). In practice, dairy young stock will become cows in the future. Therefore, understanding the costs associated with dairy young stock rearing could help in reducing the average first calving age and increase the enterprise's profitability. This study provides new insights and valuable guidelines for tropical dairy farming and the economics of rearing dairy young stock, enabling better decision-making by practitioners, dairy farmers, and government officials towards improving the profitability and sustainability of dairy farms.

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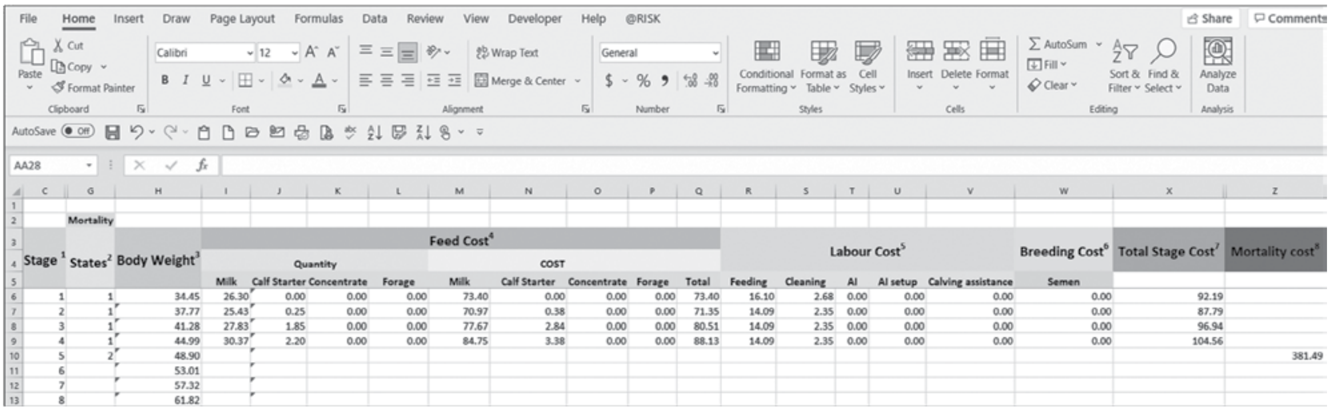
Supplementary Material



Stage [1]	States [2] (Mortality)	Body Weight [3]	Feed Cost [4] Quantity: Milk	Calf Starter	Concentrate	Forage	COST: Milk	Calf Starter	Concentrate	Forage	Total	Labour Cost [5]: Feeding	Cleaning	AI	AI setup	Calving assistance	Breeding Cost [6]: Semen	Total Stage Cost [7]	Mortality cost [8]
1	1	34.45	26.30	0.00	0.00	0.00	73.40	0.00	0.00	0.00	73.40	16.10	2.68	0.00	0.00	0.00	0.00	92.19	
2	1	37.77	25.43	0.25	0.00	0.00	70.97	0.38	0.00	0.00	71.35	14.09	2.35	0.00	0.00	0.00	0.00	87.79	
3	1	41.28	27.83	1.85	0.00	0.00	77.67	2.84	0.00	0.00	80.51	14.09	2.35	0.00	0.00	0.00	0.00	96.94	
4	1	44.99	30.37	2.20	0.00	0.00	84.75	3.38	0.00	0.00	88.13	14.09	2.35	0.00	0.00	0.00	0.00	104.56	
5	2	48.90																	381.49
6		53.01																	
7		57.32																	
8		61.82																	

Supplementary Figure 1: The example of one iteration of the stochastic bioeconomic model in excel that simulated the costs of rearing dairy young stock from birth until first calving age.

[1] Column 1 showed stage (1 to 52), column 2 showed states (1=healthy or 2=dead), column 3 showed the body weight of dairy heifer (kg), column 4 onwards are the variable costs. Stage 1 until stage 52 reflect the development of a dairy young stock from birth until first calving age.
[2] Two states were defined (healthy and dead) to reflect the status of the dairy young stock in the model.
[3] The body weight was predicted using Gompertz function (**Supplementary Equation 1**) to estimate the amount of feed based on dry matter intake (DMI).
[4] Feed costs (milk (**Supplementary Equation 2**), calf starter (**Supplementary Equation 3**), concentrate (**Supplementary Equation 4, 6**) and forage (**Supplementary Equation 5, 7**) were estimated by the product of feed price/kg and amount of feed eaten based on DMI. Total feed cost (**Supplementary Equation 8**) was estimated by the sum of feed cost for milk, calf starter, concentrate and forage.
[5] Labour costs (feeding, cleaning, artificial insemination, and calving assistance) was estimated by the product of time spent on each activity and wages per minutes (**Supplementary Equation 9, 10**).
[6] Breeding cost include only the cost of semen with the assumption of successful conception.
[7] Total stage cost include the total feed costs, total labour costs, total breeding costs at each stage.
[8] In the figure, the mortality cost is the sum of variable costs until it dead (feed cost, labour cost, and breeding cost) (**Supplementary Equation 10, 11**).

Source: own composition

Supplementary Equations

$$W(t) = A * Exp(-B * Exp(-K * t)) \tag{1}$$

where:
A=Mature live weight
B=Growth turning point
K=Growth rate
T= Age (day)

$$\text{Cost of Milk Fed}_{day} = 10\%\ BWT\ (kg) \times P_{milk} \tag{2}$$

where:
Cost of Milk Fed_{day} is the cost of milk fed per day during the pre-weaning period, 10% BWT (kg) is the amount of milk was given based on 10 percent of body weight, and P_{milk} is the price of milk

$$\text{Cost of calf starter}_{day} = Q_{CS} \times P_{CS} \tag{3}$$

where:
Cost of calf starter_{day} is the cost of calf starter per day during the pre-weaning period, Q_{CS} is the amount of calf starter fed to calf during pre-weaning period and P_{CS} is the price of calf starter

$$\text{Concentrate}_{Q=} \text{Fresh weight of concentrate(kg)} \times \text{Dry matter of concentrate (\%)} \tag{4}$$

where:
Concentrate_Q is the amount of concentrate based on dry matter, Fresh weight of concentrate(kg) is the amount of fresh weight of concentrate, and Dry matter of concentrate (%) is the percentage of dry matter for concentrate

$$\text{Forage}_Q = \text{DMI 3\% BWT (kg)-ConcentrateQ} \tag{5}$$

where:
Forage_Q is the quantity of forage, DMI 3% BWT (kg) is dry matter intake based on 3 percent of body weight and Concentrate_Q is the quantity of concentrate provided by the farm.

$$\text{Cost of concentrate}_{day} = (\text{Concentrate}_Q / \text{dry matter of}_{concentrate}\ (\%)) \times \text{Price}_{concentrate} \tag{6}$$

where:
Cost of concentrate_{day} is the cost of concentrate that consumed by the dairy young stock per day, Concentrate_Q is the amount of concentrate based on dry matter, dry matter of $_{concentrate}$ (%) is the percentage of dry matter for concentrate and Price $_{concentrate}$ is the dry matter price of the concentrate

$$\text{Cost of forage}_{day} = (\text{Forage}_Q/\text{dry matter of forage (\%)}) \times \text{Price}_{forage} \tag{7}$$

where:
Cost of forage is the cost of forage that consumed by the dairy young stock per day, Forage_Q is the quantity of forage in dry matter, dry matter of forage (%) is the percentage of dry matter for forage

$$\text{Total Feed cost} = \Sigma \text{ of Cost of Milk Fed, Cost of calf starter, cost of concentrate, cost of forage} \tag{8}$$

where:
Total feed cost is the sum of cost of milk, cost of calf starter, cost of concentrate and cost of forage

$$\text{Cost of labour} = \text{Avg time spent (min)} \times \text{wages (min)} \times \text{Freg}_{day} \tag{9}$$

where:
Cost of labour is the cost of labour that include feeding, cleaning, AI setup, AI and calving assistance, Avg time spent (min) is the average time spent on the heifer, wages (min) is the wages paid to the labour per minutes and Freg_{day} is the number of frequency spent on each activity per day (times)

$$\text{Total cost of labour} = \Sigma \text{ Cost of feeding+ cost of cleaning+ cost of AI+ cost of calving assistance} \tag{10}$$

where:
Total cost of labour is the sum of all the activites (feeding, cleaning, breeding, and calving assistance)

$$\text{Daily mortality rate (\%)} = \frac{\text{Mortality rate}^{period}}{\text{Rearing period (days)}} \tag{11}$$

where:
Mortality rate period is the mortality rate in specific rearing described in this study and rearing period (days) is the number of days in each of those periods

$$\text{Daily mortality rate (\%)} = \frac{\text{Mortality rate}^{period}}{\text{Rearing period (days)}} \tag{12}$$

where:
TC^{dead} is the average total cost of dead dairy young stock, and $n^{success}$ is the number of successfully reared dairy young stock.