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Evaluating the economic profit of reproductive performance through the integration of a dynamic programming model on a specific dairy farm

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Abstract: The overall objective of this study was to improve the reproductive efficiency of lactating dairy cows and to improve the resulting total farm profit. The hypothesis is that a dairy farm can substantially improve its economic and environmental performance through increasing pregnancy rate, i.e. increasing the number of eligible cows that become pregnant for a given breeding period. This paper presents a tool which was designed with a view to comparing the reproductive efficiency. The tool was developed using *dynamic programming* in R (Shiny) and shows the changes in costs, revenues and net return projected for a given change in pregnancy rate. The model calculates from the first *day in milk* and stops when the last calf was born after successful insemination of each cow. Sensitivity analyses demonstrated that the economic return associated with reproductive performance is greatly affected by the input parameters and therefore real farm and market values are crucial. The average economic gain per percentage point of 21-d (21-day) pregnancy rate (PR) was 14.6 EUR per cow/year. The milk price showed the largest impact on the overall net return. A 10% increase in milk price increased the net return on average by 268 EUR (10% 21-d PR), 292 EUR (20% 21-d PR) and 299 EUR per cow/year (30% 21-d PR). Our study had the same set values of milk yield during lactations for all four evaluated farms and it was found that the milk income over feed cost increased with the reproductive performance in all evaluated farms on an individual cow level. Poor fertility means that cows spend longer producing lower amounts of less efficiently produced milk.

Keywords: cost; fertility; pregnancy rate; profit; sensitivity analysis

Poor fertility has both direct and indirect effects throughout the farm system. The management when fertility is poor is much more complex than getting cows pregnant when we want them to. Poor fertility reduces genetic gain, increases veterinary costs, decreases milk production, dis-

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rupts the pattern of milk production (the number of cows at the peak of lactation is reduced), cuts calf sales, increases the number of heifers that need to be reared, and increases the cost of AI (or the number of bulls needed). Although it has a multitude of effects, the costs of poor fertility can be calculated from its impact on two factors: (1) involuntary culling and (2) increased calving interval (Giordano et al. 2012; Galvao et al. 2013). Highly productive farms tend to have good fertility; farms with poor fertility tend to be less productive, and at the herd level high productivity is no excuse for poor fertility (Meadows et al. 2005). However, the higher the milk production, the better the fertility management has to be due to the antagonistic effect of milk production and fertility (LeBlanc 2010). The main economic impact of an increased calving interval on milk production is due to two effects. Firstly, an increased calving interval means that the average production per cow per day will decrease as cows spend proportionally more time in late lactation when yields are lower; and, secondly, during late lactation the margin between milk income and feed costs is lower and thus the profit margin per litre is smaller (Nemeckova et al. 2015). Whatever system a farm uses, whether it is a seasonal spring-calving farm or a completely non-seasonal permanently housed farm, poorer fertility means that cows take longer to get pregnant. They are therefore at an increased risk of not being pregnant at the end of the breeding season (for the seasonal herd) or when they calved too late (in the non-seasonal system) (De Vries 2004). The number of days open and conception rate may be among the best indicators of current reproductive efficiency. They can be influenced by factors such as length of the voluntary waiting period, heat detection accuracy, semen quality and breeding technique, nutrition, cow fertility, disease, or weather (Krpalkova et al. 2016). The number of services per conception is directly related to the conception rate in a herd. Conception rate influences days open because if a cow does not conceive, she will be open for an additional oestrous cycle (21 days) (Valergakis et al. 2007). The cost of dairy AI straws is fairly consistent between AI companies, ranging between 15 and 25 EUR depending on the bull used (Valergakis et al. 2007). It means that cows with additional 5 services per conception with an approximate cost of AI straw of 20 EUR per cow will cost 100 EUR more (Valergakis et al. 2007). However, it is also possible that cows are not serviced at each oestrous cycle of extended days open, due to poor heat detection, in which case the loss may be calculated based on the cost per extra day open (Kalantari and Cabrera 2015). An economic value of 3.2 USD to 5.1 USD per cow per day was calculated in US dairy farms, when average days open increased from 112 to 166, heifer replacement being the main determinant of the total value (De Vries 2006). Finally, it should be mentioned that AI straws and days open will continue to rise if problem cows remain in the herd (De Vries 2004). Nowadays wearable, behaviour-monitoring, precision dairy technologies (PDT) are available. PDT autonomously monitor cow behaviour, while minimizing human interference or human error. PDT provide precise identification of heat and good timing of artificial insemination resulting in improved heat detection rate, conception rate, 21-d pregnancy rate (PR) and finally a lower proportion of culled cows due to low fertility. The heat detection rate can reach on average approximately 95% with this technology (Grinter et al. 2019).

Dairy farm profitability depends on a herd's reproductive performance, but this relationship is complex. Farmers and consultants can easily assess reproductive performance by benchmarking 21-d PR or other reproductive metrics, but they find it difficult to measure the economic impact (i.e. profitability) of changes in reproductive outcomes (Cabrera 2012). Many studies (Olynk and Wolf 2009; Giordano et al. 2012; Galvao et al. 2013; Kalantari and Cabrera 2015; Bekara and Bareille 2019) have attempted to quantify the economic impact of reproductive programs on specific dairy farms. However, reproductive performance might affect farm profitability differently. Farms with similar reproductive performance could expect different profits from similar reproductive programs (Kalantari and Cabrera 2015). Many important stochastic factors should be considered simultaneously to analyze the effect of reproductive performance among different farms (Olynk and Wolf 2009).

In this context, the objective of this study was to create a simple tool that was designed to compare different reproduction levels of farms based on real data in the same period regarding the economics of reproductive management. Finally, a sensitivity analysis was carried out to find important relations between model inputs, predictions and observations.

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MATERIAL AND METHODS

Farms and data

The dataset consisted of four farms during the years 2016 to 2018 and all evaluated farms used an all-year-round calving system. The initial structure of data includes the date of events such as calving, breeding, heat (not all herds), pregnancy check, pregnancy, sign do-not-breed, dead and sold cows, and abortion of cows. Basic parameters were calculated based on the date of events in the created tools and are provided in Table 1. The dataset did not include milk yield and economic values. Only the last or previous calving with the subsequent information on cow was selected. Cows were removed from the calculation if they remained open for the entire evaluated period and their DIM was lower than 250. The evaluated economic impact of current management in the farm and subsequent possible changes due to different management (different 21-d PR) were calculated based on variables shown in Table 2. All averages (Table 2) come from Eurostat (https://ec.europa.eu/eurostat), Teagasc (https://www.teagasc.ie/), MilkBot Model (Ehrlich 2011) or monitoring of farms in Ireland and were used as a baseline for the final economic evaluation and can be changed according to conditions and records of evaluated farms and current averages of the farm. These data were used for the calculation of economic output [i.e. Income Over Feed Cost (IOFC), Cull Cost, Reproductive Cost, Replacement Cost, Total Calves, Net Return] with current and changed management (different 21-d PR).

The degree of improvement in 21-d PR and the time it takes to realise these improvements depend on several different factors. The overall condition of the farm, as well as components such as culling policy, labour, age at first calving, body condition score, calving difficulties, management of negative energy balance, overall health status of cows and heifers, management of infertile and non-cycling cows, environmental conditions, facilities, new technology and so on, can all have a short- or long-term impact. The objective of the created tool is to show only the economic changes due to improved 21-d PR.

Table 1. Calculated parameters based on the date of events

Indicator	Farm 1	Farm 2	Farm 3	Farm 4
Total number of cows (*n*)	357	3 122	1 239	3 623
Total number of days (*n*)	364	364	365	364
Last calf born (month)	26	23	28	29
Remained open cows at 100 DIM[1,2]	38	39	36	72
Remained open cows at 300 DIM[1,2]	22	30	27	51
Cows first bred until 70 DIM[2]	48	34	36	17
Cows with DOPN until 100 DIM[2]	63	74	77	46
Indicator	mean/median			
DIM at 1st breeding (d)	97.3/71.5	89.6/78.0	83.6/75.0	147.3/132.0
DOPN (d)[4]	99.3/72.0	87.9/77.0	84.7/76.0	125.5/107.0
Conception rate (%)	77.6/78.0	50.6/57.0	53.5/81.0	51.3/72.0
Pregnancy rate (%)	25.9/25.0	19.6/25.5	16.7/22	6.9/9.0
Indicator	reproductive costs: 27/45 EUR/cow/month		reproductive costs: 27 EUR/cow/month	
Net return[3]	2 908/2 844	2 309/2 253	2 814	2 271
IOFC[3]	3 022/3 022	2 441/2 441	2 941	2 520
Reproductive cost[3]	96/161	85/141	86	143
Replacement cost[3]	109/109	119/119	119	161
Calf sales[3]	92/92	72/72	78	56

[1]The remaining open cows were culled during simulation based on real data or in 22 months of the simulation of management; [2]In percentage (%); [3]EUR/cow/year; [4]Mean of days open (days) was calculated only for pregnant cows

DIM = days in milk; DOPN = days open; IOFC = income over feed cost

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Table 2. Average input variables of the model

Variables name	Average value
MilkBot[1] model (lactation curve)	
Average milk yield (kg/cow/d)[1]	33
Average milk yield 305 d (kg/cow)[1]	10 311
Peak milk (kg)[1]	39
Peak day (d)[1]	67
Other set variables[2]	
Voluntary waiting period (d)[2]	42
Body weight of lactating cows (kg/cow)[2]	560
Milk fat content (%)[2]	4
Feed price (EUR/kg feed) for lactating cows[2]	0.23
Feed price (EUR/kg feed) for dry cows[2]	0.20
Average reproduction cost (EUR/cow/mo) < 20% PR[2]	27
Average reproduction cost (EUR/cow/mo) > 20% PR[2]	45
Milk price (EUR/kg milk)[2]	0.35
Heifer replacement value (EUR/heifer)[2]	1 000
Cull cow value (EUR/cow)[2]	600
Calf value (EUR/calf)[2]	200

[1]The MilkBot function (Ehrlich 2011) was used to fit milk production curves; [2]Source: Eurostat, Teagasc or monitoring of farms in Ireland

All values may be adjusted in the model

PR = pregnancy rate

Model and parameters

The model, developed in R (Shiny package), was designed with a view to comparing reproduction levels within farms and to showing the changes in Costs, Revenues and Net Return. The tool was developed using *dynamic programming.*

The model used the average reproductive cycle of dairy cows of 21 days as the length of stage for better evaluation of reproductive management. Therefore, all events, such as ageing, involuntary culling, abortion, getting pregnant, calving, starting a new lactation, milk production etc. were adjusted to 21-d cycles. Cows were ordered in 21-d cycles according to days in milk and days in pregnancy. The calculation started by placing a group of cows from the first DIM and continued by moving it forward through all the defined stages until the last calf was born in the first reproduction period.

The model calculated costs and revenues in 2 steps in order to compare current and different managements.Step 1 – all open cows from first calving in the calculation are moved through all 21-d stages from their first DIM (based on real data) to the end of the period over which the comparison is based upon. Step 2 – all open cows from second calving in the calculation are moved through all 21-d stages from their first DIM (in a simulation of the relevant management). Only calved cows from the first step were included in the simulation calculations. The average 21-d PR from step 1 was used in the calculation, or in the case of comparison with other management, the selected 21-d PR was used.

The net return (EUR/cow/day) was calculated as follows in Equation 1:

$$NR = \sum_{d=1}^{n} \sum_{p=0}^{13} IOFC_{d,p} + CV_{d,p} - CC_{d,p} - RC_{d,p} \quad (1)$$

where:

d – DIM with 21-d steps;

n – number of 21-d steps (differs based on evaluated farm);

p – pregnancy/lactation number;

NR – net return;

$IOFC$ – milk income over feed cost;

CV – income from calves;

CC – culling cost, which is a difference between the salvage value of the culled cow and the replacement heifer price;

RC – average reproductive cost based on the relevant management (Table 1, 2 and 3).

Results of current management on the farms and sensitivity analysis of different 21-d PR and input variables are shown in Table 1, 3 and 4 and are discussed in the Results section of this paper.

Level of milk production. The MilkBot function (Ehrlich 2011) was used to fit milk production curves. The MilkBot predicts *milk yields* (Y) as a function of the time after parturition. Four parameters: a (*scale*), b (*ramp*), c (*offset*), and d (*decay*), control the shape of the lactation curves. *Euler's number*, e is the base of the natural logarithm, approximately: 2.718 and m is the length of DIM in 21-d stage increments (Ehrlich 2011). Details of the MilkBot model can be found here: http://dairysight.com/milkbot/model. Average values for the Holstein breed during all evaluated lactations were used as initial values.

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Table 3. Calculated economic parameters based on different levels of pregnancy rate and reproductive cost (simulation of the model)

Pregnancy rate (%)[1]	10	15	20		25		30		35	
Reproductive cost[2] (EO)[2]	27	27	27	45	27	45	27	45	27	45
Farm 1										
Net return[3]	2 509	2 691	2 816	2 743	2 893	2 825	2 941	2 878	2 969	2 910
IOFC[3]	2 670	2 826	2 931	2 931	2 993	2 993	3 030	3 030	3 050	3 050
Reproductive cost[3]	131	120	110	184	102	170	95	158	88	147
Replacement cost[3]	108	110	106	106	103	103	102	102	101	101
Calf sales[3]	79	94	102	102	106	106	108	108	108	108
Farm 2										
Net return[3]	2 203	2 341	2 430	2 366	2 477	2 419	2 502	2 449	2 516	2 467
IOFC[3]	2 375	2 495	2 568	2 568	2 604	2 604	2 622	2 622	2 630	2 630
Reproductive cost[3]	115	104	95	158	87	144	80	133	74	124
Replacement cost[3]	126	129	129	129	128	128	127	127	127	127
Calf sales[3]	69	80	85	85	87	87	88	88	88	88
Farm 3										
Net return[3]	2 682	2 899	3 029	2 955	3 094	3 027	3 112	3 050	3 108	3 051
IOFC[3]	2 827	3 013	3 121	3 121	3 171	3 171	3 178	3 178	3 166	3 166
Reproductive cost[3]	136	122	111	185	101	168	92	154	86	143
Replacement cost[3]	93	86	80	80	77	77	76	76	76	76
Calf sales[3]	83	94	99	99	101	101	102	102	103	103
Farm 4										
Net return[3]	2 290	2 427	2 508	2 443	2 539	2 480	2 551	2 497	2 555	2 505
IOFC[3]	2 461	2 579	2 643	2 643	2 663	2 663	2 668	2 668	2 667	2 667
Reproductive cost[3]	120	107	97	161	88	146	81	135	75	126
Replacement cost[3]	122	124	123	123	122	122	123	123	125	125
Calf sales[3]	70	80	84	84	85	85	87	87	88	88

[1]Set values of 21-d pregnancy rate in the model; [2]Set values of reproductive cost in the model (EUR/cow/month); [3]Calculated results of the model (EUR/cow/year)
IOFC = income over feed cost

$$Y(m) = a\left(1 - \frac{e^{\frac{c-m}{b}}}{2}\right)e^{-d\times m} \qquad (2)$$

Equation 2 was used to describe milk production curves for an average of all lactations according to the breed. In the model, it is possible to change all the milk parameters according to the current milk yield level in the evaluated farm. Milk production was also adjusted to decrease by a fixed factor of 5, 10 and 15% by month of pregnancy 5, 6 and 7, respectively, based on the methodology of De Vries (2004). Daily milk production was then calculated by summing up average milk production from Equation 2 and possible pregnancy milk depression (i.e. depression in milk yields from the 5th, 6th, and 7th month of pregnancy) based on fixed factors.

Involuntary culling. Cows in every stage were culled according to the respective events (i.e. sold or dead cows) in the dataset. All remaining open cows in the calculation were culled when their average milk production dropped below 21 kg (culling due to reproductive failure). The number of cows culled in step 2 was dependent on the culling rate recorded in step 1 and on the number of open cows remaining in the second step. Open cows were culled in the simulation in the 6th cycle of the 21-d period, i.e. after 126 DIM. After this period, fertility prob-

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Table 4. Effect of changes in input parameters on net return (EUR/cow/year) (simulation of the model)

Indicators		**Farm 1**			**Farm 2**		
Pregnancy rate (%)		10	20	30	10	20	30
Milk price (EUR/kg milk)	+10	279	308	318	245	265	272
	−10	−279	−307	−318	−245	−266	−271
Heifer replacement value (EUR/heifer)	+10	−27	−26	−25	−31	−33	−32
	−10	27	27	26	32	32	32
Cull cow value (EUR/cow)	+10	16	16	15	19	19	19
	−10	−16	−15	−15	−19	−20	−19
Feed price (EUR/kg feed) for lactating cows	+10	−12	−14	−15	−7	−10	−9
	−10	13	15	15	8	9	10
Calf value (EUR/calf)	+10	8	11	11	7	8	9
	−10	−8	−10	−11	−7	−9	−8
Body weight of lactating cows (kg/cow)	+10	−6	−7	−8	−5	−7	−6
	−10	7	8	8	6	6	7
Milk fat content (%)	+10	−2	−2	−2	0	−1	0
	−10	2	3	3	1	0	1
Indicators		**Farm 3**			**Farm 4**		
Pregnancy rate (%)		10	20	30	10	20	30
Milk price (EUR/kg milk)	+10	292	323	330	254	273	277
	−10	−293	−323	−330	−254	−274	−276
Heifer replacement value (EUR/heifer)	+10	−24	−20	−19	−31	−31	−31
	−10	23	20	19	30	30	31
Cull cow value (EUR/cow)	+10	13	12	11	18	18	19
	−10	−14	−12	−12	−19	−19	−18
Feed price (EUR/kg feed) for lactating cows	+10	−10	−11	−12	−8	−9	−10
	−10	9	11	12	8	9	10
Calf value (EUR/calf)	+10	8	10	10	7	8	9
	−10	−9	−10	−10	−7	−9	−9
Body weight of lactating cows (kg/cow)	+10	−7	−7	−8	−6	−7	−7
	−10	6	8	8	5	6	7
Milk fat content (%)	+10	−6	−6	−7	−1	−1	0
	−10	4	5	5	0	0	0

lems begin to manifest in the herd and the number of culled cows increases with DIM without positive pregnancy check (Pinedo et al. 2010). In this period, cows are after peak lactation and milk production starts to decrease as well as the reason to keep open cows in the herd. The culling rate for different reproductive management (different level of 21-d PR) did not change in the default model settings. However, the distribution of culling during both steps of calculation can be changed.

Reproduction. The voluntary waiting period was assumed to be 42 d to align with the 21-d stage length of the model and can be changed. Cows were eligible for insemination from 42 d in different management (i.e. different management with different 21-d PR was compared with current management on the farm) from the day when the last calf was born in the simulation process. According to Kalantari and Cabrera's (2015) study it was assumed that herds with poor reproductive performance invested less in management and facilities, which resulted in worse detection of oestrus and/or worse overall conception rates. Thus, based on the estimated average 21-d PR, different reproductive cost (EUR/21-d) was assigned to each herd. Reproductive cost for farms with < 20% 21-d

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PR used 0.90 EUR/d and farms with > 20% 21-d PR used 1.50 EUR/d. These reproductive costs are included in Table 1, 2 and 3.

Live body weight. Average body weights were used to calculate the carcass value of the replaced cow and to estimate dry matter intake for each cow stage (Table 2).

Dry matter intake. Daily dry matter intake was calculated using Spartan 2 (VandeHaar et al. 1992) Equations 3, which is a function of maintenance and milk production. This function used metabolic body weight and 4% fat corrected milk yields as inputs.

$$DMI_m = (0.02 \times BW.met_m) + \\ + (0.3 \times 4\%FCM_m) \quad (3)$$

$$4\%FCM_m = PM_m \times [0.4 + (0.15 \times Fat)] \quad (4)$$

$$BW.met = BW^{0.75} \quad (5)$$

where:

DMI – dry matter intake;
BW – live body weight;
BW.met – metabolic live body weight;
4% FCM – 4% fat corrected milk;
Fat – percentage of fat in milk (Table 2);
PM – daily milk yield according to the MilkBot model;
m – 21-d stage length of DIM.

Different fixed costs (EUR/kg; Table 2) were used for lactating and dry cows. Cost of 1 kg feed per dry cows was calculated as 15% less than the cost of 1 kg feed for lactating cows.

Calf value. It was assumed that all calves were sold one week after they were born and the value was assumed to be the average of the value for males and females (Table 2).

RESULTS AND DISCUSSION

Several authors have developed methodologies to estimate the financial cost of delayed pregnancy in dairy systems, based on computer simulation models (Groenendaal et al. 2004; Meadows et al. 2005; De Vries 2006; Kalantari and Cabrera 2015; Bekara and Bareille 2019). Although the use of those models made it possible to obtain quite realistic results, the real data from farms was not used in these studies, which could make it difficult to comprehend them by users. Thus, the methodology presented in this study was focused on developing a simpler tool to calculate the economic values based on real data. It is possible to change the average input variables in the tool listed in Table 2, making it useful to analyse different scenarios on the farm.

Associations between reproductive performance and profit

The factor that had the greatest effect on economic performance was the 21-d conception rate: a 10-percentage-point increase between the low and average levels and between the average and high levels increased the gross margin by 62.2 and 22.3 EUR/per cow/year, respectively. The three levels of 21-d conception rate of the herd indicate the proportion of cows pregnant 21 d after insemination; low: 25%, average: 45%, high: 70% (Bekara and Bareille 2019). Conception rate influences days open because if a cow does not conceive, she will be open for an additional oestrous cycle (21 days) (Valergakis et al. 2007). Our study showed that Farm 1 (Table 1) with the highest conception rate (78%) achieved the highest net return of 2 908 EUR per cow/year. As pointed out by LeBlanc (2010), it is important to separate the biology of the reproductive function from the effects of the economics-based management decisions on culling and continued breeding. According to Lee and Kim (2007) and Leroy and De Kruif (2006), improved oestrus detection could reduce the number of cows that are removed from the herd for reproductive reasons. The consequences of greater involuntary culling include increased replacement costs and, ultimately, lower net returns (Krpalkova et al. 2016). Farm 4 (Table 1) with the highest number of remaining open cows at 300 DIM (51%) had the highest replacement and reproductive cost followed by the lowest net return of 2 271 EUR per cow/year. The most common reasons for culling cows were low fertility (accounting for 25% of all culls) followed by movement disorders, low production, and mammary gland diseases. However, the cows are in fact often culled due to multiple reasons (Krpalkova et al. 2016). The longest recorded calving interval was associated with the highest recorded loss of calves and the lowest recorded number

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of total weaned calves per 100 cows (Krpalkova et al. 2016). The lowest calf sales were also observed in Farm 4 (Table 1) where the lowest 21-d PR (7%) and longest number of days open (125 days) were also detected. Nemeckova et al. (2015) reported similar findings that shorter calving intervals (less than 400 days) increased average daily milk yield and numbers of calves in dairy herd and they added that the milk yield is higher because the cows reach the peak of lactations more often. Cabrera (2012) argued that an increase in profitability can occur from having a higher proportion of cows in early lactation, when they are more efficient, and thus have a higher yield. Our study had the same set values of milk yield during lactations for all four evaluated farms (Table 2), and it was found that Farm 1 with the highest conception rate of 78% had the highest number of inseminated cows until 70 DIM (48%), lowest median of days open (72 days) and highest milk income over feed cost 3 022 EUR per cow/year. The success of the reproductive management of all evaluated farms may be compared in more detail in Figure 1. Bekara and Bareille (2019) concluded that not every farm achieves a 365-day calving interval or a 5% culling rate for not-in-calf cows, but a significant amount of money can be gained by reducing the calving interval by as few as 10 days.

Comparison of different level of 21-d PR and economic output

Higher reproductive performance determines faster 21-d PR establishment and, therefore, higher production of calves, which is translated into a higher net return. Previous research consistently agreed that greater calf sales or greater value of offspring are a consequence of improved reproductive efficiency (Cabrera 2012; Giordano et al. 2012; Kalantari and Cabrera 2012; Galvao et al. 2013; Bekara and Bareille 2019). Our study compared different 21-d PR for all evaluated farms and showed similar results. Higher calf sales were observed for a higher 21-d PR (Table 3). A decrease in the number of days between calving and conception (increased 21-d PR), also known as days open, is typically associated with increased profitability in dairy cows (De Vries

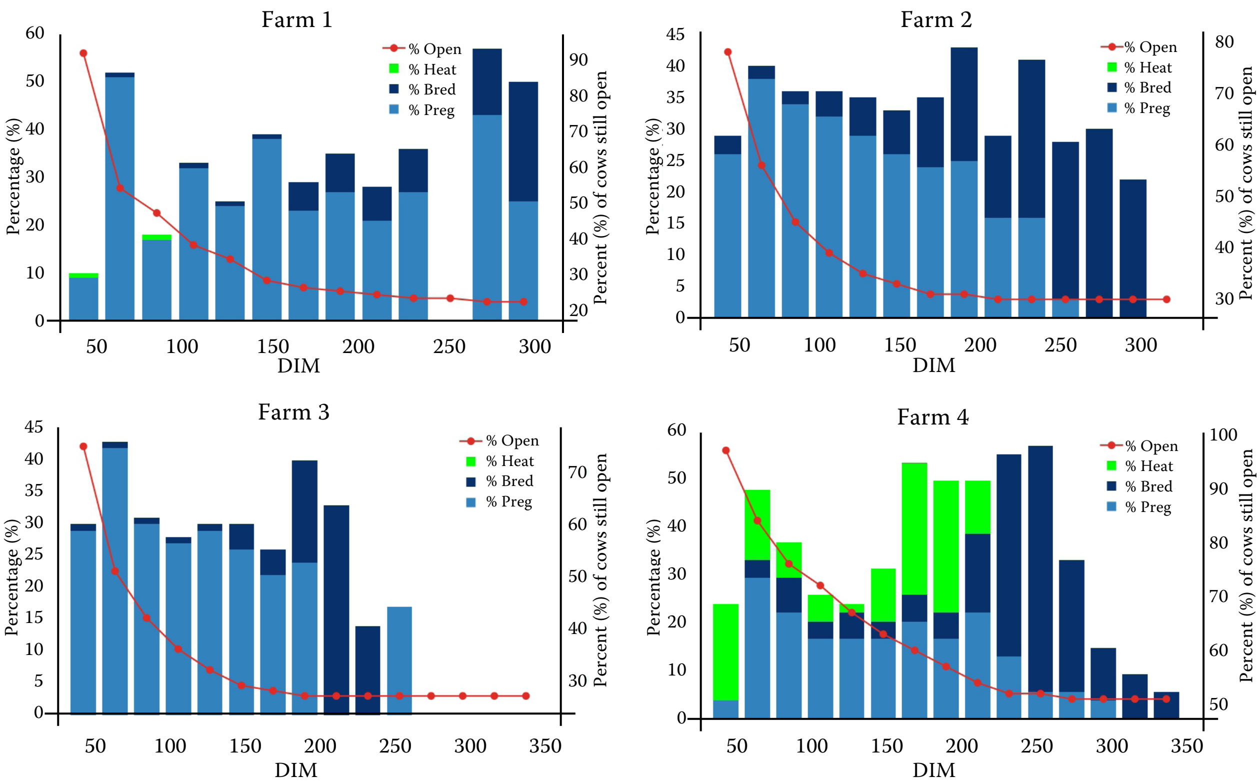

Figure 1. Calculated reproductive parameters based on the date of events (output from the tool)
% Bred = percent of inseminated cows; DIM = days in milk; % Heat = % or cows in heat (not inseminated); % Open = percent of the remaining open cows; % Preg = percent of pregnant cows

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2006). We found the same rule in our study depending on the average of reproductive cost per day used (0.90 EUR/day or 1.50 EUR/day, respectively; Table 3). The calculation showed the differences in reproductive management within the same period of the same cows, i.e. without data of new replacement due to culling. The average culling rate remained the same (based on the calculation on real data) in each calculation for different levels of 21-d PR (Table 3). However, in the case of higher 21-d PR in the real situations on farm, the culling rate is lower due to lower culling for reproductive failure and thus even higher net return can be expected. According to Cattaneo et al. (2015), the infertility culling cost is the main cause of the involuntary days open after 120 days, whereas milk yield losses became the main determinant from 180 days. De Vries (2006) reported that the cow replacement cost due to infertility represented the highest proportion of the total cost. For example, Giordano et al. (2012) aimed at the very detailed construction of reproductive programs including all the specifics related to evaluation of reproductive costs (such as the cost of labour for oestrus detection and injection, hormones for synchronization and pregnancy diagnosis) and daily reproductive dynamics of the herd. Kalantari and Cabrera (2015) included reproductive costs in the model as a random parameter and the assumption was that the herd with good reproductive performance invested more. In the present study, reproductive costs were calculated as the sum of the average costs per day open with the same assumption. Reproductive costs at a 15% 21-d PR level were approximated 40 USD per cow/year (Giordano et al. 2012), 114 USD per cow/year (Kalantari and Cabrera 2015) and in the present study the average of 15% 21-d PR (Table 3) was 113 EUR per cow/year. Different tables (Table 3 and 4) have been reported for the economic gain per percentage point of 21-d PR. The driving factors of the economic gain are the input parameters used (Cabrera 2014). Thus, there is a considerable variation among different studies per one percentage point of 21-d PR: 9 USD per cow/year (De Vries 2006), 9 USD per cow/year (Giordano et al. 2012), 18 USD per cow/year (Galvao et al. 2013), 5.2 USD per cow/year (Kalantari and Cabrera 2015) and 14.6 EUR per cow/year in the present study. De Vries (2006) showed the figure where the changes of net return by one percentage point of 21-d PR showed a different shape among the levels of 21-d PR. The changes by 10% to 15% 21-d PR were 24 USD per cow/year and by 30% to 35% 21-d PR it was 5 USD per cow/year and in our study it was 33 and 2.2 EUR per cow/year, respectively. However, these values are highly dependent on the farm and herd simulated situations including input parameters, which are discussed in the sensitivity analysis below.

Sensitivity analysis of input parameters

Among the input parameters (Table 1), milk price was shown to have the largest impact on the overall net return. The higher the 21-d PR, the higher was the change in the net return. A 10% increase in milk price increased the net return on average to 268 EUR (10% 21-d PR), 292 EUR (20% 21-d PR) and 299 EUR per cow/year (30% 21-d PR) (Table 4). The sensitivity analysis identified milk prices, milk yields, and feed costs as the main factors influencing profitability (Syrucek et al. 2019). As milk productivity increases, feed costs also increase and although some studies found that the milk income over feed cost increased with reproductive performance (Giordano et al. 2012; Kalantari and Cabrera 2012), other studies reported that the milk income over feed cost could, at times, decrease slightly as reproductive performance increases (Cabrera 2012; Galvao et al. 2013). This could be explained by pregnancy milk depression and cows being dried off sooner meaning a lower proportion of lactating cows across the lactation period and reduced yield in the short term, which results in lower milk production. Other factors can be the shape and level of milk lactation curves (Kalantari and Cabrera 2015). Our study had the same set values of milk yield during lactations for all four evaluated farms (Table 2) and it was found that the milk income over feed cost increased with reproductive performance (Table 3) in all evaluated farms. Cabrera (2012) and Galvao et al. (2013) reported a combined synergistic and antagonistic effect of reproductive performance and milk income over feed cost at varying levels of 21-d PR. The relationship between milk production and feed consumption is complex and interacts with many factors such as the herd structure, feed price and the shape and persistence of lactation curves (Cabrera 2012). Our study showed that the productivity of an individual cow might increase with better reproductive performance, but the way it interacts with herd structure

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(percentage of dry cows and lactating cows) and thereby influences the overall herd's milk production was not evaluated in our study. The next highest variables to impact the overall net return were heifer replacement value, cull cow value and feed price, the range was between 8 and 33 EUR per cow/year (Table 4). De Vries (2004) found that the major cost determinant was heifer purchase cost, ranging from an increase of 2.11 USD to 7.46 USD per cow per year for each extra day open while the impact of individual determinants and their relative contribution were greatly dependent on average days open. The lowest variables to impact on the overall net return were calf value, body weight of cows and milk fat content (used only for feed calculation), the range was between 0 and 10 EUR per cow/year. This shows that the economic return is greatly affected by the input parameters, and the gain would be considerably different across herds and regions (Table 4).

Limitations

Simulation and modelling research has always some limitations. Some diseases (such as mastitis, laminitis) play an important role in determining the profitability of farms and also affect both milk production and reproductive performance (Kalantari and Cabrera 2012; Krpalkova et al. 2019). Therefore, for better economic evaluation, diseases and their interaction with reproductive performance and milk production would be useful to consider. Different level of milk production at different parity of cows was not included in the current model either.

Another limitation is that culling decisions remained the same for all evaluated levels of 21-d PR. The culling decisions vary greatly within and across countries and are influenced mainly by cow characteristics such as age, previous reproductive or health disorders, and milk production level (Bekara and Bareille 2019). Unfortunately, the real milk yield, feeding plan and energy balance were not available in the dataset but they can significantly affect the economic output. Finally, it should be mentioned that results in modelling studies, like the one presented here, are highly dependent on the input parameters and the underlying assumptions of the model; thus, the economic gain and values presented herein are applicable to the situation of the present study only. Nonetheless, the modelling framework developed in this study could be useful in assisting research and still help with the reproductive management on-farm decision making.

CONCLUSION

The proposed methodology has demonstrated to be a simple tool for monitoring the financial impact of different reproductive scenarios in a dairy herd. Our study revealed the economic impact at the individual cow level. Poor fertility means that cows spend longer producing lower amounts of less efficiently produced milk with increased culling risk and this will negatively affect the net return of those cows. An overall increase in net return across 21-d PR was mainly due to lower reproductive and culling cost, higher calf sales and higher milk income over feed cost.

Sensitivity analyses demonstrated that the economic return associated with reproductive performance is greatly affected by the input parameters and therefore real farm and market values are crucial. The resulting cumulative net return across different 21-d PR could be informative to farmers to overview the current situation on the farm and to guide them towards better-informed decisions in the future.

Conflict of interest

The authors declare no conflict of interest.

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