J. Dairy Sci. 105:4171–4188
https://doi.org/10.3168/jds.2021-20707

Revenues and costs of dairy cows with different voluntary waiting periods based on data of a randomized control trial

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ABSTRACT

Based on modeling studies, a 1-yr calving interval for dairy cows is generally considered optimal from an economic point of view. Recently some dairy farmers are deliberately extending the voluntary waiting period for insemination (VWP) to extend the calving interval. Reasons to extend the VWP are to reduce the frequency of transitions such as dry-off and calving to improve health, to reduce labor associated with these transitions, and to reduce the number of surplus calves. This study aimed to evaluate yearly revenues, yearly costs, and yearly net partial cash flow (NPCF) for individual cows with a VWP of 50, 125, or 200 d based on data from a randomized control trial. The NPCF included revenues and costs for milk yield, calves born, inseminations, concentrate supply, partial mixed ration (PMR) supply, veterinary treatments, discarded milk due to veterinary treatments, culling, and labor (for milking, calving cows, inseminations, and veterinary treatments). Holstein-Friesian dairy cows (n = 153) within one herd were blocked for parity, calving season, and expected (primiparous cows) or previous (multiparous cows) 305-d milk yield. Cows were randomly assigned within the blocks to 1 of 3 VWP (VWP50, VWP125, or VWP200) in wk 6 after calving, and monitored from wk 6 after calving until wk 6 after the next calving or until culling. Revenues and costs were calculated per individual cow and expressed per cow per year. Revenues from milk and costs for PMR and concentrate contributed most to the yearly NPCF. Total yearly revenues were greater in VWP50 compared with VWP200 (€3,169 vs. €2,832), mainly because of €334 greater milk revenues. Total yearly costs were also greater in VWP50 compared with VWP200 (€1,964 vs. €1,729), mainly because of €102 greater concentrate costs. The VWP was not significantly associated with the NPCF per cow per year. A change in milk, feed, or calf price, or a change in labor costs for calving cows or for inseminations had a greater effect on the yearly NPCF of cows in VWP50 compared with cows in VWP200. To investigate variation in NPCF, cows were grouped for yearly NPCF and categorized into 3 economic classes (EC): EC1 (<€1,100/yr), EC2 (€1,100–€1,400/yr), and EC3 (>€1,400/yr). Cows in EC3 had greatest lactation production per day in the experiment (i.e., kg of milk, protein, fat, lactose), and lowest number of veterinary treatments during the experiment.
Key words: extended calving interval, extended lactation, economic result, individual cow variation

INTRODUCTION

Based on results of recent modeling studies, a 1-yr calving interval (**CInt**) is generally considered optimal for dairy cows from an economic point of view (Inchaisri et al., 2011; Steeneveld and Hogeveen, 2012; Kok et al., 2019). A longer CInt was associated with a lower milk production per cow per year (Kok et al., 2019). This lower milk production was attributed to the difference in milk yield in early lactation (peak milk yield) and in late lactation (Strandberg and Oltenacu, 1989) and a proportionally longer late-lactation period for cows with an extended lactation. Although a 1-yr CInt seemed optimal from an economic point of view, recently some dairy farmers have been deliberately extending the voluntary waiting period for insemination (**VWP**; Lehmann et al., 2014; Burgers et al., 2021a). Their motivation is to reduce the frequency of transition periods around dry-off and calving, to reduce the labor associated with these transitions, to reduce the number of surplus calves, and to improve cow health (Lehmann et al., 2014; Burgers et al., 2021a).

Most of the studies on economics of CInt consist of normative simulation modeling, where input is based on retrospective analyses of data from commercial farms (e.g., Strandberg and Oltenacu, 1989; Inchaisri et al.,

Received May 7, 2021.
Accepted January 12, 2022.
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2011; Kok et al., 2019). In these retrospective analyses, however, a delayed insemination or an extended CInt might be associated with poor fertility and might not necessarily have been the result of a deliberate extension of the VWP in combination with associated management (Mellado et al., 2016). When cows were assigned to a VWP of 60 or 83 d based on their calving dates, total cash flow over a 6-yr period was the same (Gobikrushanth et al., 2014). Moreover, recent experimental studies have assigned cows randomly to a certain VWP, in contrast to the earlier normative modeling studies. When cows were randomly assigned to a VWP of 40 d, 120 d, or 180 d, daily milk yield for the entire lactation was not different (Niozas et al., 2019a), and number of inseminations per pregnant cow was reduced from 1.77 to 1.56 or 1.51 (Niozas et al., 2019b). The BCS at dry-off was increased from 3.25 after a VWP of 40 d to 3.5 after a VWP of 180 d (Niozas et al., 2019a), which could result in an increased risk for diseases after the next calving (Roche et al., 2009). In recent observational studies, where cows were selected and managed for extended CInt, daily milk yield was similar (parity 2 and 3) or greater (parity 1) in a CInt of more than 19 mo compared with shorter CInt (Lehmann et al., 2016). In these farms probably more persistent or more productive cows were selected for increased CInt. Other potential effects on the net cash flow of individual cows after an extended VWP, compared with a shorter VWP, could be lower feed costs for cows in longer lactations (Lehmann et al., 2014); fewer calvings per unit of time per cow, resulting in less risk for calving-related diseases and culling (Fetrow et al., 2006; Pinedo et al., 2014); and fewer calves born. Fewer calves born might reduce revenues from calves, but, due to costs around calving and low revenues from calves, these reductions might not be severe (Mohd Nor et al., 2012).

Therefore, the economic result in a situation with a deliberately extended CInt could differ from the economic result of extended CInt in the retrospective studies. In a randomized control trial, where cows are randomly assigned to a certain VWP, the partial cash flow of individual cows can be calculated for a deliberately extended VWP. Moreover, individual cow characteristics, such as lactation persistency and parity, may influence cow performance in terms of milk yield in an extended CInt (Lehmann et al., 2017; Kok et al., 2019). Calculating cash flows for individual cows could indicate which cow characteristics contribute to individual cow performance after different VWP.

This study aimed to evaluate revenues, costs, and the net partial cash flow for cows that were randomly assigned to a VWP of 50, 125, or 200 d. We investigated complete lactations from wk 6 after calving until wk 6 after the next calving or until culling. The net partial cash flow included revenues and costs for milk yield, calves born, inseminations, concentrate supply, partial mixed ration (**PMR**) supply, veterinary treatments, discarded milk due to veterinary treatments, and labor (for milking, calving cows, inseminations, and veterinary treatments).

MATERIALS AND METHODS

Animals and Housing

The experimental protocol was approved by the Institutional Animal Care and Use Committee of Wageningen University & Research (Wageningen, the Netherlands) and complies with the Dutch law on Animal Experimentation (protocol number 2016.D-0038.005). The experiment was conducted at Dairy Campus Research Farm (Leeuwarden, the Netherlands) between December 2017 and January 2020.

The animals, experimental design, and treatments have been described earlier (Burgers et al., 2021b). In short, 154 cows were selected from a research herd of 500 lactating Holstein-Friesian cows based on the following criteria: no twin pregnancy, no clinical mastitis or SCC >250,000 at the final 2 milk test days before dry-off, and expected to finish a complete lactation based on being in good general health. For the current study, cows were followed from wk 6 after calving until wk 6 after the next calving or until culling (experimental days, **ED**). Cows were milked twice daily around 0600 h and 1800 h in a 40-cow rotary milking parlor (GEA). Partial mixed ration (grass silage, corn silage, soybean meal, wheat meal) supported 22 kg of milk. Concentrate supply started at 1 kg/d on the day of calving and increased stepwise until 21 DIM to 9 kg/d for primiparous cows or 10 kg/d for multiparous cows. After 100 DIM, individual concentrate supply was decreased based on the last 5 d of milk yield. In the milking parlor, 1 kg of additional concentrate was supplied daily. Ration during the dry period consisted of grass silage and corn silage, supplemented with wheat straw and concentrate. In the last 10 d before the expected calving date, cows received 1 kg of concentrate daily. Once per week, cows between 42 and 49 d before the expected calving date were dried off. In the 7 d before dry-off, cows were given the dry cow ration. During the last 3 d before dry-off, cows were milked once daily. When cows had SCC >150,000 cells/mL at the final milk test day, cows were treated with antibiotics at dry-off (Orbenin Dry Cow Extra, Zoetis). All cows were treated with teat sealant at dry-off (Orbeseal, Zoetis).

Experimental Design

The selected 154 animals were blocked for parity, calving date, milk yield in the previous lactation (multiparous cows) or expected milk yield (primiparous cows), and breeding value for persistency (CRV, Arnhem, Netherlands) wk 6 after calving. Each block consisted of 3 cows. First, 50 blocks of 3 cows were formed. After removal of 2 cows before the end of the VWP due to culling as a result of health issues, 2 more blocks of 3 cows were added. Per block, the cows were randomly divided over 3 treatment groups: a VWP of 50 d (**VWP50**), 125 d (**VWP125**), or 200 d (**VWP200**). Cows in the 3 treatment groups were inseminated after their VWP when estrus was detected. Estrus detection was carried out by using neck-mounted 3-dimensional accelerometers (Nedap Smarttag Neck) in combination with visual observations by the animal caretaker. Cows were inseminated until 300 DIM. Cows that did not conceive within 300 DIM stayed in the experiment until 530 DIM as long as they produced at least 10 L of milk per day.

Measurements

Milk yield (**MY**) was recorded at every milking, from wk 6 after calving until dry-off, and the first 6 wk of the next lactation. Milk samples for the analysis of fat, protein, and lactose were collected for each individual cow from the container 4 times per week (Tuesday afternoon, Wednesday morning, Wednesday afternoon, Thursday morning) in 10-mL tubes containing Bronopol as a preservative and analyzed for the percentage of fat, protein, and lactose as a pooled sample (ISO, 2013; Qlip, Zutphen, the Netherlands). Body weight was recorded twice daily after milking, using a scale that the cows walked over when returning from the milking rotary to the pen (GEA). Body condition score was visually evaluated every 4 wk by the same person, using a 1-to-5 scale (Ferguson et al., 1994). Concentrate supply was recorded for all individual cows in individual feeding boxes. Inseminations were recorded for all individual cows, including cows that did not conceive (in 300 DIM). Veterinary treatments were recorded for all individual cows, and included all preventive and curative treatments that cows received (Appendix Table A1).

Economic Calculations

For this study, we defined the net partial cash flow (**NPCF**) as the result of cash inflows and outflows associated with the calving interval and insemination decisions. More specifically, the NPCF of an individual cow k included revenues from milk (R^{MILK}) and calves (R^{CALVES}), and costs for inseminations (C^{INS}), concentrate (C^{CON}), PMR (C^{PMR}), veterinary treatments (C^{VET}), and culling ($C^{CULLING}$) during the experiment:

$$\mathrm{NPCF}_k = \left(\mathrm{R}_k^{\mathrm{MILK}} + \mathrm{R}_k^{\mathrm{CALVES}}\right) - \left(\mathrm{C}_k^{\mathrm{INS}} + \mathrm{C}_k^{\mathrm{CON}} + \mathrm{C}_k^{\mathrm{PMR}} + \mathrm{C}_k^{\mathrm{vet}} + \mathrm{C}_k^{\mathrm{CULLING}}\right).$$

Next, the NPCF_k was expressed per year, by dividing over the experimental days (ED):

$$\mathrm{NPCF}_k^{\mathrm{YEAR}} = \frac{\mathrm{NPCF}_k}{\mathrm{ED}_k} \times 365.$$

Finally, the NPCF_k was aggregated per VWP × parity class and expressed per year, as follows:

$$\mathrm{NPCF}_{ij}^{\mathrm{VWP,ParityClass}} = \frac{\sum_{k=1}^{n}\left(\mathrm{NPCF}_k\right)}{\sum_{k=1}^{n}\left(\mathrm{ED}_k\right)} \times 365,$$

where i represents the VWP (i = 50, 125, or 200 d), and j represents the parity class (j = primiparous or multiparous). This weighted mean was calculated to account for the number of ED of each individual cow. Consequently, cows that spent less time in the experiment had a smaller contribution to the weighted NPCF per cow per year.

Milk, Protein, Fat, and Lactose. Milk yield was averaged per week and summed for the complete experiment per cow. From the weekly milk samples, content was determined, and thus protein yield (**PY**), fat yield (**FY**), and lactose yield (**LY**) in kg/d were calculated per week and summed for the complete experiment per cow. With this, total milk revenues (R^{MILK}) were calculated per individual cow k, as follows:

$$\mathrm{R}_k^{\mathrm{MILK}} = \left(\mathrm{P}^{\mathrm{MILK\ VOL}} \times \mathrm{MY}_k\right) + \left(\mathrm{P}^{\mathrm{PROT}} \times \mathrm{PY}_k\right) + \left(\mathrm{P}^{\mathrm{FAT}} \times \mathrm{FY}_k\right) + \left(\mathrm{P}^{\mathrm{LACT}} \times \mathrm{LY}_k\right) - \mathrm{P}_k^{\mathrm{LABOR}},$$

where $P^{MILK\ VOL}$ is the price for the milk volume, P^{PROT} is the price per kilogram of protein, P^{FAT} is the price per kilogram of fat, P^{LACT} is the price per kilogram of lactose, and P^{LABOR} is the price for milking labor of cow k.

Calves. For cows that had a second calf within the experiment, revenues from calves (R^{CALVES}) were calculated per individual cow k, as follows:

$$R_k^{\text{CALVES}} = P^{\text{CALF}} - \left(P^{\text{MILK REPLACER}} + P^{\text{LABOR}}\right),$$

where P^{CALF} is the price for a calf, $P^{\text{MILK REPLACER}}$ is the price for milk replacer consumption of the calf, and P^{LABOR} is the labor price for a calving cow.

Inseminations. Costs for insemination (C^{INS}) were calculated per individual cow k, as follows:

$$C_k^{\text{INS}} = \left(P^{\text{INS}} + P^{\text{LABOR}}\right) \times \text{INS}_k,$$

where P^{INS} is the semen price, P^{LABOR} is the labor price per insemination, and INS is the number of inseminations per cow k.

Feed. Costs for feed were calculated both in the dry period and in the lactating periods. Costs for concentrate supply (C^{CON}) were calculated per individual cow k, as follows:

$$C_k^{\text{CON}} = P^{\text{CON}} \times \text{CONSUP}_k,$$

where P^{CON} is the price per kilogram of concentrate, and CONSUP is the total amount of concentrate (kg) supplied to cow k in the complete experiment. The concentrate supply consists of both concentrate in feeders with individual concentrate supply and concentrate in the milking parlor.

Costs for PMR supply (C^{PMR}) were calculated per individual cow k, as follows:

$$C_k^{\text{PMR}} = P^{\text{PMR}} \times \text{PMRSUP}_k,$$

where P^{PMR} is the price per kilogram of PMR, and PMRSUP is the total amount of PMR (kg) supplied to cow k in the complete experiment. To estimate PMR supply, energy requirements for maintenance, milk production, growth, and gestation were calculated per individual cow, using the Dutch VEM system (Feed Unit Milk; 1,000 VEM = 6.9 MJ of NE) with requirements for maintenance and fat- and protein-corrected milk (**FPCM**). For this calculation, milk production was converted to FPCM using the following formula (CVB, 2016):

$$\text{FPCM}_k\ (\text{kg}) = \text{MY}_k\ (\text{kg}) \times [0.337 + 0.116 \times \text{fat}_k\ (\%) + 0.06 \times \text{protein}_k\ (\%)],$$

after which the energy requirements were calculated per cow k (Dutch net energy system for lactation; CVB, 2016):

$$\text{VEM}_k = \left[42.2 \times \text{BW}_k^{0.75} + \left(442 \times \text{FPCM}_k\right)\right] \times \left[1 + \left(\text{FPCM}_k - 15\right) \times 0.00165\right] + \text{VEM}_k^{\text{GROWTH}} + \text{VEM}_k^{\text{GEST}},$$

where $\text{BW}^{0.75}$ is the metabolic BW of cow k, $\text{VEM}^{\text{GROWTH}}$ are the energy requirements for growth, and VEM^{GEST} are the energy requirements for gestation. After calculating the total energy requirements of each cow, energy from concentrate supply was subtracted to estimate energy from PMR supply. Using the mean VEM of the PMR in the experiment (437 VEM per kg of product), PMR supply in kilograms was estimated.

Veterinary Treatments. Costs for veterinary treatments (C^{VET}) were calculated per individual cow k for the complete experiment, as follows:

$$C_k^{\text{VET}} = \sum_{l=1}^{n} \left[\begin{array}{l}\left(P_l^{\text{MEDICINE}} + P_l^{\text{LABOR}}\right) \\ + \left(\text{WP}_l \times \text{MY}_k^{\text{WP}} \times P^{\text{DISC MILK}}\right)\end{array}\right],$$

where n is the number of veterinary treatments for cow k, P^{MEDICINE} is the price for medicine l (Appendix Table A1), P^{LABOR} is the labor price for medicine l, WP_l is the waiting period in days for medicine l, MY^{WP} is the milk yield (kg/d) of cow k during the waiting period, and $P^{\text{DISC MILK}}$ is the price for the discarded milk per kilogram.

Culling. Costs for culling (C^{CULLING}) were calculated per individual cow that was culled due to health issues, or that did not become pregnant within 300 DIM in the first lactation in the experiment, as follows:

$$C_k^{\text{culling}} = \frac{C^{\text{REARING}} - \left[P^{\text{SLAUGHTER}} \times \left(0.6 \times \text{BW}_k\right)\right]}{\text{Aimed productive days}} \times \left[\text{aimed productive days} - \left(\text{culling age}_k - \text{rearing days}\right)\right],$$

where C^{REARING} are the rearing costs, $P^{\text{SLAUGHTER}}$ is the slaughter price per kilogram, BW_k is the body weight of a cow k at the time of culling, 0.6 is the dressing percentage of a cow (60%; Rutten et al., 2014), and culling age is the age at culling of cow k in days.

For analysis, revenues (R) and costs (C) for all different variables were expressed per cow k per year, as follows:

$$R_k^{\text{YEAR}} \text{ or } C_k^{\text{YEAR}} = \frac{R_k \text{ or } C_k}{\text{ED}_k} \times 365.$$

Input

For the calculations, some input was assumed based on the Dutch dairy farming system between 2015 and 2020 (Table 1). Moreover, information from the network of dairy farmers (Burgers et al., 2021a) was used for input on labor costs for milking and for calving cows. Prices for milk were calculated as the average price for protein, fat, and lactose from FrieslandCampina (2020) between 2015 and 2020. Costs for milking were calculated assuming 100 cows per hour were milked in the 40-cow rotary milking parlor (GEA), and 1 h of own labor was worth €26 (mean from network dairy farmers). The price for calves was calculated assuming that the chance for a bull or a heifer is 50%, rearing costs for calves were calculated assuming a total milk replacer consumption of 6 L/d (9 kg of milk replacer) in the first 14 d except for the first 2 d (KWIN-V, 2020), and labor costs for a calving cow were assumed to be €36 (mean from network dairy farmers). The costs for 1 insemination were based on labor costs for insemination (KWIN-V, 2020) and the semen price (KWIN-V, 2020). To calculate feed costs, energy requirements for growth (VEM^{GROWTH}) were assumed to be 660 VEM/d for cows that were between 2 and 3 yr of age, and 330 VEM/d for cows that were between 3 and 4 yr of age (Kok et al., 2019). Energy requirements for gestation (VEM^{GEST}) started from 5 mo of pregnancy and were assumed to be in total 167,750 VEM (CVB, 2016). This was added for cows that had a second calf within the experiment. Costs for veterinary treatments were based on information from the veterinarian of University Livestock Practice (Harmelen, the Netherlands). Losses for discarded milk were calculated for the waiting period per treatment with the MY of the cow at that moment. For each cow that was culled due to health issues, revenues from slaughter were calculated with the slaughter value per kilogram of slaughter weight. For this calculation, individual body weight at the time of culling was used. Culling costs were calculated assuming a depreciation method with an aimed lifespan of 8 yr (2,920 d) and lactation starting at 2 yr of age (730 d), resulting in 6 productive years (2,190 d). Moreover, costs for rearing were assumed to be €1,567 per cow (Mohd Nor et al., 2012). Non-pregnant cows left the experiment at approximately 530 DIM and were assumed to be culled at that moment for the calculation of culling costs.

Table 1. Monetary value (€) used to calculate the economic result of cows that had a voluntary waiting period of 50, 125, or 200 d

Variable	Value	Reference
Milk		
Milk (€/100 kg)	−0.67	FrieslandCampina (2020)
Protein (€/100 kg)	550.84	FrieslandCampina (2020)
Fat (€/100 kg)	275.42	FrieslandCampina (2020)
Lactose (€/100 kg)	55.08	FrieslandCampina (2020)
Milking labor costs (€/cow per day)	0.52	GEA, Dusseldorf, Germany Mean of dairy farmers network
Calves		
Milk replacer, first 14 d[1] (€/calf)	18	KWIN-V (2020)
Labor around a calving cow (€/calf)	36	Mean of dairy farmers network
Heifer sold (€/calf)	25	KWIN-V (2020)
Bull sold (€/calf)	105	KWIN-V (2020)
Inseminations		
Labor (€/insemination)	13.75	KWIN-V (2020)
Semen (€/straw)	18	KWIN-V (2020)
Feed		
Concentrate (€/100 kg)[2]	26	Dairy Campus (2018–2019)
Partial mixed ration[3] (PMR; €/100 kg)	9.39	Dairy Campus (2018–2019)
Veterinary treatments		
Veterinary treatments (€/treatment)	See Appendix Table A1	Veterinarian Dairy Campus
Labor preventive treatment (€)	5	Veterinarian Dairy Campus
Labor simple treatment (€)	15	Veterinarian Dairy Campus
Labor multiple treatments (€)	30	Veterinarian Dairy Campus
Discarded milk (€/100 kg)	33.7	Mean price FrieslandCampina (2020)
Culling		
Rearing costs	1,567	Mohd Nor et al. (2012)
Slaughter value (€/kg slaughter weight)	2.01	Rutten et al. (2014)

[1]6 L/d except for first 2 d; in total 72 L (9 kg of milk replacer).

[2]Mean price for concentrate: Dairy Campus, 2018–2019.

[3]Mean price for PMR (grass silage, corn silage, soy, wheat): Dairy Campus, 2018–2019.

Statistical Analysis

One cow was culled on d 43 after calving; therefore 153 cows were included in the analyses (41 primiparous and 112 multiparous cows). Parity class (primiparous or multiparous cows) refers to the parity of the cow during the first lactation within the experiment. Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc.). Values are presented as least squares means (LSM) ± standard error of the mean. All P-values of pairwise comparisons of LSM were corrected with a Bonferroni adjustment. Two data sets were used for the analyses. Data set 1 included all cows and was used to investigate mean output per cow for their time in the total experiment. Data set 2 included only cows of which the yearly culling costs did not exceed twice the standard deviation of yearly culling costs. As a result, 1 cow from VWP50 and 2 cows from VWP200 were excluded from this data set, as they were culled relatively early in lactation (at respectively 56, 69, and 69 DIM), leading to very high costs of culling expressed per year. The high yearly culling costs were caused by the short time of these cows in the experiment.

Data Set 1 (n = 153). Data set 1 was used to investigate mean output per cow for the total ED. A general linear mixed model (PROC MIXED) was used to test the effects of VWP, parity class, and the interaction between VWP and parity class on the dependent variables: days to pregnancy, days to pregnancy after end of VWP, calving to first service interval (**CFSI**, d), CInt (d), ED (d), dry period length (d), total MY (kg), total PY (kg), total FY (kg), total LY (kg), total concentrate supply (kg), or total PMR supply (kg). Non-significant interactions ($P > 0.05$) were removed from the models. A logistic regression model with a binary distribution (PROC LOGISTIC) was used to model the probability that a calf was born, that a cow had a veterinary treatment, that milk of a cow was discarded due to veterinary treatment, that a cow was culled due to health issues, or that a cow did not become pregnant within 300 DIM, with fixed effects of VWP and parity class. For cows that had at least 1 veterinary treatment, a generalized linear mixed model with a negative binomial distribution (PROC GLIMMIX) was used to test the effects of VWP, parity class, and the interaction between VWP and parity class on the number of veterinary treatments. For cows of which milk was discarded, a general linear mixed model (PROC MIXED) was used to test the effects of VWP, parity class, and the interaction between VWP and parity class on the discarded milk, where a square root transformation of the discarded milk was used to approximate a normal distribution. A generalized linear mixed model with a Poisson distribution (PROC GLIMMIX) was used to test the effects of VWP, parity class, and the interaction between VWP and parity class on the total number of inseminations. A general linear mixed model (PROC MIXED) was used to test the effects of VWP, parity class, and the interaction between VWP and parity class on total NPCF per cow. Moreover, data set 1 was used to calculate the weighted NPCF per cow per year.

Data Set 2 (n = 150). Data set 2 was used to investigate revenues, costs, and NPCF per cow per year. In this data set, cows with yearly culling costs that exceeded twice the standard deviation of yearly culling costs were excluded. A general linear mixed model (PROC MIXED) was used to test the effects of VWP, parity class, and the interaction between VWP and parity class on the revenues and costs for milk, calves, PMR supply, concentrate supply, inseminations, veterinary treatments, culling due to health issues, not becoming pregnant, and NPCF per cow per year. Non-significant interactions were removed from all models. A log-transformation of the costs for veterinary treatments was used to approximate a normal distribution. For the analysis of calf revenues, only cows that had a second calf in the experiment were included (n = 127). For the analysis of costs for culling due to health issues, only cows that were culled due to health issues were included (n = 15). Similarly, for the analysis of costs for not becoming pregnant, only cows that did not become pregnant were included (n = 14). Statistical analyses were not performed on culling costs or costs for not becoming pregnant for all cows, as these data were zero inflated. However, to provide complete information, we did calculate the mean culling costs and mean costs for not becoming pregnant for all cows, including cows that had no costs for culling or not becoming pregnant. Data set 2 was also used to calculate the weighted NPCF per cow per year.

Moreover, data set 2 was used to investigate individual variation in NPCF per cow per year. Cows were grouped for yearly NPCF and categorized into 3 economic classes (**EC**), based on similar numbers of cows per class: EC1 (<€1,100/yr; n = 50), EC2 (€1,100–€1,400/yr; n = 51), and EC3 (>€1,400/yr; n = 49). First, a chi-squared test was used to assess whether VWP determined in which EC a cow was categorized (PROC FREQ). Second, a general linear mixed model (PROC MIXED) was used to test the effect of EC, VWP, parity class, and all 2-way interactions on several dependent variables within the experimental period from wk 6 after calving until wk 6 after the next calving: CFSI, CInt, lactation persistency between d 100 and start of dry-off, MY, PY, FY, and LY per ED, mean content of protein, fat, and lactose, veterinary treatments (log-transformed to approximate a normal distribution), mean BW, mean BCS, and NPCF. Nonsignificant interactions ($P > 0.05$) were removed from all models.

Finally, cow characteristics from the first 6 wk after the first calving within the experiment (as described in Burgers et al., 2021b) were added to data set 2. These cow characteristics were used to evaluate which characteristics in early lactation could be used to predict yearly NPCF of cows after different VWP. The following cow characteristics in early lactation (first 6 wk) were tested: maximum yield, day of maximum yield, slope to maximum yield, mean MY, mean FPCM yield, fat, protein, and lactose contents, fat-to-protein ratio, BCS, and BW. Next to these early-lactation characteristics, expected (primiparous cows) or previous (multiparous cows) 305-d MY and breeding value for persistency were tested. First, the effect of each cow characteristic on yearly NPCF was tested with a univariate analysis, using a general linear mixed model in SAS (PROC MIXED). Second, when P-value was <0.2, the characteristic was included in the multivariate model. The multivariate model always included VWP and parity class as fixed effects. The cow characteristics in early lactation and their interaction with VWP and parity class stayed in the model if $P < 0.05$, using backward selection.

Sensitivity Analysis

A sensitivity analysis was performed to assess the effect of changes in revenues and costs on the NPCF per cow per year of primiparous and multiparous cows (data set 2, n = 150). First, revenues for milk were based on either the lowest monthly price for protein, fat, and lactose (€408, 204, and 41 per 100 kg) or the highest monthly price for protein, fat, and lactose (€682, 341, and 68 per 100 kg) between 2015 and 2020 (FrieslandCampina, 2020). Second, costs for concentrate and basal ration were based on either the lowest price (concentrate: 20.6; basal ration: €8.25/100 kg) or the highest price for these (concentrate: 26.4; basal ration: €9.5/100 kg) between 2015 and 2020 (Agrimatie; KWIN-V, 2020). Third, calf prices were either €0 or €130 per calf (double value). Fourth, labor costs for calving cows were either €1.25 or €100 per calf (minimum and maximum from network dairy farmers). Fifth, labor costs for inseminating cows were either €0 or €27.5 per insemination. Sixth, labor costs for veterinary treatments were either €0 or the maximum labor costs (€30) per veterinary treatment.

A general linear mixed model (PROC MIXED) was used to test the effects of VWP, parity class, and the interaction between VWP and parity class on the change in yearly NPCF as a result of minimum and maximum milk prices, minimum and maximum feed prices, minimum and maximum calf prices, minimum and maximum labor costs for calving cows (log-transformed to approximate a normal distribution), minimum and maximum labor costs for inseminations, and minimum and maximum labor costs for veterinary treatments (log-transformed to approximate a normal distribution). Nonsignificant interactions ($P > 0.05$) were removed from the models.

RESULTS

Of the 153 cows that entered the experiment, 127 cows had a second calf, and 121 cows finished the complete experiment from wk 6 after calving until wk 6 after the next calving. In total, 14 cows did not become pregnant within 300 DIM during the first lactation (2 from VWP50, 3 from VWP125, 9 from VWP200), and 18 cows were culled during the study due to health issues (4 from VWP50, 7 from VWP125, 7 from VWP200). One cow from VWP50 was successfully inseminated at 48 DIM, and remained in the study. Increasing the VWP resulted in a greater CFSI [67 (48–113) vs. 140 (125–174) vs. 210 (200–225) d for VWP50, VWP125, and VWP200, $P < 0.01$] and greater calving interval (382 vs. 450 vs. 498 d for VWP50, VWP125, and VWP200, $P < 0.01$). Consequently, cows in VWP200 and VWP125 had more ED compared with cows in VWP50 (470 and 437 vs. 365 d, $P < 0.01$). Increasing the VWP resulted in more days to pregnancy after calving (104 vs. 172 vs. 221 for VWP50, VWP125, and VWP200, $P < 0.01$). Cows in VWP200 had fewer days to pregnancy after end of the VWP (21 d) compared with cows in VWP50 (54 d, $P < 0.01$) or compared with cows in VWP125 (47 d, $P = 0.04$). Dry period length did not differ among the 3 VWP.

Total Output Per Cow in the Complete Experiment

The VWP affected total kilograms of milk, fat, protein, and lactose, and total PMR supply in the complete experiment (Table 2). Cows in VWP200 had on average 54 kg greater PY ($P = 0.03$) and 88 kg greater FY ($P < 0.01$), and tended to have 1,305 kg greater MY ($P = 0.07$) in the complete experiment compared with cows in VWP50. Cows in VWP125 had on average 79 kg greater FY ($P < 0.01$) and tended to have 1,367 kg greater MY ($P = 0.06$), 49 kg greater PY ($P = 0.06$), and 59 kg greater LY ($P = 0.08$) in the complete experiment compared with cows in VWP50. In the complete experiment, on average 2,968 kg more PMR was supplied to cows in VWP200 ($P < 0.01$), and on average 2,194 kg more PMR was supplied to cows in VWP125 ($P < 0.04$), compared with cows in VWP50

(Table 2). The VWP tended to affect the probability that a cow did not become pregnant, but no statistically significant differences existed among the 3 VWP groups. In the complete experiment, the VWP did not affect total number of inseminations, concentrate supply, probability and number of veterinary treatments, probability and amount of discarded milk, or probability of culling due to health issues. The net partial cash flow in the complete experiment was first assessed for primiparous cows and multiparous cows separately (Figure 1). The VWP or parity class did not affect the NPCF in the complete experiment.

Yearly Revenues and Costs Per Cow

Mean yearly revenues and costs were first assessed for primiparous cows and multiparous cows separately (Figure 2). Yearly revenues from milk and yearly costs for PMR were the greatest contributors to the yearly NPCF in the 3 VWP. Yearly revenues from calves and yearly costs for inseminations were relatively small and therefore not visible in the figure.

In the analysis of yearly revenues and costs per cow, the interaction between VWP and parity class was never significant and was therefore taken out of the models. The VWP affected both total yearly revenues and total yearly costs (Table 3). Cows in VWP50 had on average €337 greater yearly revenues compared with cows in VWP200 ($P < 0.01$), mainly because of €334 greater yearly milk revenues ($P < 0.01$). Moreover, yearly calf revenues were greatest for cows in VWP50, intermediate for cows in VWP125, and lowest for cows in VWP200 ($P < 0.01$). Cows in VWP50 had on average €235 greater total yearly costs compared with cows in VWP200 ($P = 0.02$), mainly because of €102 greater yearly concentrate costs ($P < 0.01$). Moreover, cows in VWP200 had on average €28 lower yearly inseminations costs compared with VWP50 ($P < 0.01$), and on average €22 lower yearly insemination costs compared with VWP125 ($P = 0.03$). The costs of not becoming pregnant did not differ among VWP, and the VWP did not affect yearly costs per cow for PMR, veterinary treatments, or culling due to health issues. Moreover, the VWP was not significantly associated with the NPCF per cow per year, but numerically the NPCF per cow per year was €55/cow per year greater for cows in VWP50 compared with cows in VWP125 and €102/cow per year greater for cows in VWP50 compared with cows in VWP200. The weighted NPCF per cow per year was numerically €71/cow per year greater for cows in VWP50 compared with cows in VWP125 and €168/cow per year greater for cows in VWP50 compared with cows in VWP200.

Cow Factors Associated With Yearly Net Partial Cashflow

Yearly net partial cash flow was first assessed for primiparous cows and multiparous cows separately. For primiparous cows, the first quartile of NPCF per cow per year was €1,037/yr and the third quartile of NPCF per cow per year was €1,364/yr (Figure 3a). For multiparous cows, the first quartile of NPCF per cow per year was €960/yr and the third quartile of NPCF per cow per year was €1,291/yr (Figure 3b).

Based on the yearly NPCF in the study, cows were divided in 3 EC. The VWP did not affect the chance to be in 1 of 3 EC (Table 4). The effects of EC, VWP, parity class, and all 2-way interactions on several cow characteristics were tested. The effect of EC on lactation persistency depended on VWP: cows in VWP125 tended to have greater lactation persistency in EC2 (−0.051 kg/d) compared with EC3 (−0.077 kg/d, $P = 0.09$). Within EC1, cows in VWP200 had greater lactation persistency compared with cows in VWP125 (−0.042 vs. −0.075 kg/d, $P = 0.02$). Within EC3, cows in VWP200 had greater lactation persistency (−0.048 kg/d) compared with cows in VWP50 (−0.076, $P = 0.04$) and tended to have greater lactation persistency compared with cows in VWP125 (−0.077, $P = 0.07$). Cows in EC3 (>€1,400/yr) had greater lactation yield (milk, protein, fat, or lactose) per ED (kg/d) and fewer veterinary treatments in the experiment compared with cows in EC1 (<€1,100/yr; Table 5). Moreover, the effect of EC on lactose content depended on parity class: primiparous cows had greater lactose content in EC1 (4.4%) compared with EC2 (4.1%, $P = 0.02$) or compared with EC3 (4.1%, $P = 0.03$), whereas for multiparous cows lactose content did not differ among EC. Both CFSI and CInt were not different among the 3 EC.

When the effect of cow characteristics in the first 6 wk after the first calving within the experiment on yearly NPCF was evaluated, the final multivariate model included VWP class and parity class as class variables, and MY, FPCM yield, BW, the interaction BW × VWP, maximum yield, the interaction maximum yield × VWP, and the breeding value for persistency as continuous variables (Table 6). In this model, mean MY in the first 6 wk was negatively associated with yearly NPCF, whereas mean FPCM yield in the first 6 wk was positively associated with yearly NPCF. Mean BW in the first 6 wk was positively associated with yearly NPCF, mostly in VWP200, and mostly for primiparous cows. Maximum yield in the first 6 wk was positively associated with yearly NPCF, mostly in VWP50. Moreover, the breeding value for persistency was positively associated with yearly NPCF.

Table 2. Cow performance for the complete experiment from wk 6 after calving until wk 6 after the next calving or until culling for primiparous and multiparous cows with a voluntary waiting period (VWP) of 50, 125, or 200 d (VWP50, VWP125, VWP200); values shown are LSM ± SEM (n = 153)

	Voluntary waiting period						Parity class				P-value[1]	
	VWP50		VWP125		VWP200		Primiparous cows		Multiparous cows			
Item	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	VWP	Par
N cows	53		49		51		41		112			
CFSI[2] (d)	67[c]	2	140[b]	2	210[a]	2	139	2	139	1	<0.01	0.97
Calving interval[3] (d)	382[c]	7	450[b]	7	498[a]	8	438	8	449	5	<0.01	0.25
Experimental days[4] (d)	365[c]	13	437[b]	14	470[a]	14	426	15	423	9	<0.01	0.86
Dry period (d)	40	1	41	2	42	2	40	2	42	1	0.73	0.15
Milk (kg)	9,820†‡	422	11,187†	431	11,125‡	434	10,107	458	11,315	277	0.03	0.03
Protein (kg)	359[b]†	15	408[ab]†	16	413[a]	16	375	17	412	10	0.02	0.06
Fat (kg)	421[b]	18	500[a]	19	509[a]	19	462	20	492	12	<0.01	0.19
Lactose (kg)	446†	19	505†	19	500	20	462	21	505	13	0.047	0.08
Calves (n)	0.9	0.0	0.9	0.0	0.8	0.1	0.9	0.1	0.8	0.0	0.15	0.38
Inseminations (n)	2.1	0.2	2.4	0.2	1.8	0.2	2.0	0.2	2.2	0.1	0.17	0.46
Concentrate (kg)	1,837	78	2,015	80	1,920	81	1,783	85	2,065	52	0.26	<0.01
Partial mixed ration (kg)	11,990[b]	484	14,184[a]	495	14,958[a]	498	13,440	525	13,981	318	<0.01	0.38
Veterinary treatments[5] (%)	100	0	96	3	93	4	100	11	100	6	0.90	0.48
Veterinary treatments[6] (number)	6.1	0.8	7.3	1.0	6.4	0.9	4.3	0.6	10.2	0.8	0.57	<0.01
Discarded milk[7] (%)	47	8	38	7	38	7	27	7	57	5	0.58	<0.01
Discarded milk[8] (kg)	246	(146–371)	286	(167–436)	257	(150–392)	234	(108–408)	293	(227–367)	0.87	0.49
Culling due to health issues[9] (%)	5.3	3.0	10.7	4.7	9.6	4.5	4.7	3.2	14.0	3.3	0.49	0.12
Not becoming pregnant[10] (%)	3.5	2.5	5.8	3.4	16.7	5.8	6.3	3.7	8.0	2.7	0.05	0.71
Net partial cash flow (€)	1,268	91	1,437	93	1,416	94	1,360	99	1,388	60	0.34	0.81

[a–c]Different superscripts indicate a difference among LSM from VWP or parity class ($P < 0.05$).

[1]Par = parity class. Interaction VWP × parity class was never significant and therefore was not included in the models.

[2]CFSI = calving to first service interval: interval from the first calving within the experiment until first insemination.

[3]Calving interval is presented for cows that had a second calf within the experiment (n = 127).

[4]Experimental days: number of days from wk 6 after calving until wk 6 after the next calving, so including the dry period, or until culling (n = 153).

[5]Probability of at least one veterinary treatment per cow.

[6]If veterinary treatment occurred (n = 148): number of veterinary treatments.

[7]Probability of milk discarded at least once as a consequence of a veterinary treatment.

[8]If milk was discarded (n = 75): amount of discarded milk. *P*-values based on square root transformation; data are back-transformed, and CI is shown.

[9]Probability that a cow was culled due to health issues.

[10]Probability that a cow did not become pregnant within 300 DIM.

†‡Similar symbol indicates a trend in difference among LSM from VWP or parity class ($P < 0.10$).

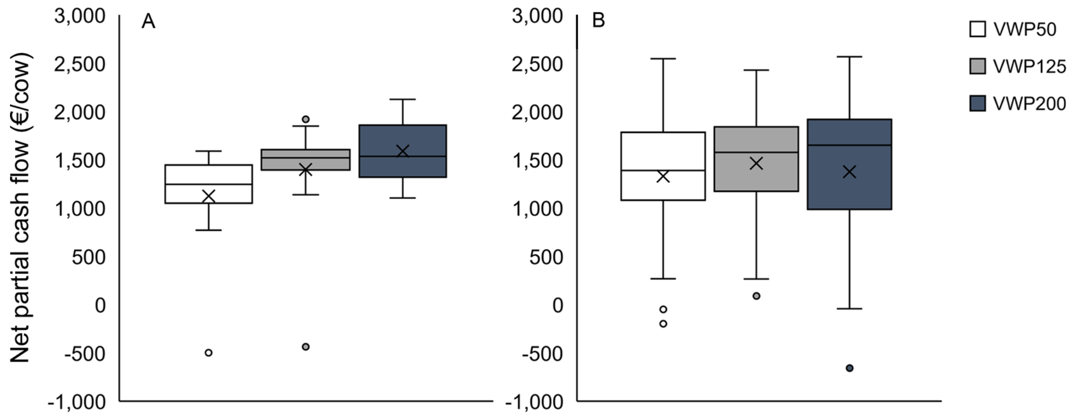

Figure 1. Net partial cash flow (€/cow) in the complete experimental period for primiparous (A) and multiparous (B) cows with a voluntary waiting period of 50, 125, or 200 d (VWP50, VWP125, VWP200; n = 153). The × in the box indicates the mean, the solid black line indicates the median, top and bottom of the box are the first and the third quartiles, and circles indicate outliers.

Sensitivity Analysis

When prices for fat, protein, and lactose were minimal or maximal, yearly NPCF of cows in VWP50 was more affected compared with yearly NPCF of cows in VWP200 (Table 7). A change in feed or calf prices, or a change in labor costs for calving cows or for inseminations also had a greater effect on yearly NPCF of cows in VWP50 compared with cows in VWP200. The VWP did not affect the change in yearly NPCF when labor costs for veterinary treatments were minimal or maximal.

When prices for fat, protein, and lactose were minimal or maximal, yearly NPCF of multiparous cows was more affected compared with yearly NPCF of primiparous cows. Moreover, a change in feed prices or labor costs for veterinary treatments had a greater effect on yearly NPCF of multiparous cows compared with primiparous cows. Parity class did not affect the change in yearly NPCF when calf prices were minimal or maximal, or when labor costs for calving cows or inseminations were minimal or maximal.

DISCUSSION

In this study, when VWP was extended until 125 or 200 d, cows had a greater CSFI, and a greater CInt. Moreover, over the complete experimental period, production of milk, protein, fat, and lactose was greater after longer VWP, as cows with a longer VWP had more lactating days during the experiment. Other studies also reported greater total lactation yields of milk, protein, fat, and lactose for cows with extended VWP or CInt, attributed to the greater lactation length of these cows (van Amburgh et al., 1997; Rehn et al., 2000; Österman and Bertilsson, 2003). Cows with an

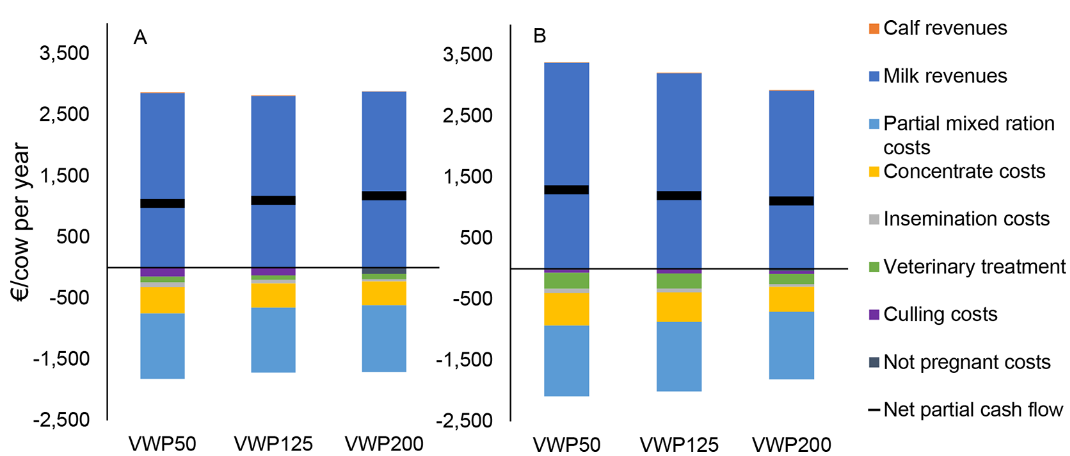

Figure 2. Revenues, costs, and net partial cash flow per cow year for primiparous (A) and multiparous (B) cows with a voluntary waiting period of 50, 125, or 200 d (VWP50, VWP125, VWP200; n = 150).

Table 3. Revenues and costs (€/cow per year) for milk, calves, partial mixed ration supply, concentrate supply, veterinary treatments,[1] culling, and inseminations, and the net partial cash flow (NPCF; €/cow per year) per cow for primiparous and multiparous cows with a voluntary waiting period (VWP) of 50, 125, or 200 d (VWP50, VWP125, VWP200); values shown are LSM ± SEM (n = 150)

	Voluntary waiting period						Parity class				*P*-value[2]	
	VWP50		VWP125		VWP200		Primiparous cows		Multiparous cows			
Item	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	VWP	Par
N cows	52		49		49		41		109			
Revenues[3]	3,169[a]	68	3,027[ab]	69	2,832[b]	70	2,845	73	3,173	45	<0.01	<0.01
Milk	3,159[a]	68	3,019[ab]	69	2,825[b]	70	2,837	73	3,165	45	<0.01	<0.01
Calves[4] (n = 127)	11[a]	0.2	9[b]	0.2	8[c]	0.2	9	0.2	9	0.1	<0.01	0.42
Costs[3]	1,964[a]	64	1,877[ab]	65	1,729[b]	66	1,743	69	1,970	42	0.03	<0.01
Partial mixed ration	1,122	15	1,106	15	1,088	16	1,075	16	1,136	10	0.27	<0.01
Concentrate	489[a]†	15	441[a]†	15	387[b]	15	403	16	475	10	<0.01	<0.01
Inseminations	69[a]	6	63[a]	6	41[b]	6	56	6	59	4	<0.01	0.67
Veterinary treatments	95	(70–129)	88	(64–121)	74	(53–103)	55	(39–77)	132	(107–162)	0.50	<0.01
Culling due to health issues[5] (n = 15)	1,489	187	1,116	150	1,034	190	1,912	232	514	95	0.20	<0.01
Mean for all cows[6] (n = 150)	72	45	88	47	34	18	98	68	53	18	NA	NA
Not becoming pregnant[7] (n = 14)	452	97	181	83	329	43	405	87	236	41	0.09	0.08
Mean for all cows[6] (n = 150)	14	10	6	4	55	19	30	17	23	8	NA	NA
Net partial cash flow[3]	1,205	71	1,150	72	1,103	74	1,102	76	1,203	47	0.58	0.26
Net partial cash flow,[8] weighted (n = 150)	1,281	NA	1,205	NA	1,130	NA	1,171	NA	1,211	NA	NA	NA
Net partial cash flow,[9] weighted (n = 153)	1,276	NA	1,205	NA	1,108	NA	1,171	NA	1,198	NA	NA	NA

[a–c]Different superscript indicates a difference among LSM from VWP or parity class ($P < 0.05$).

[1]Costs for veterinary treatments include medicine price, labor costs, and costs for discarded milk. *P*-values based on log-transformation, data are back-transformed, and CI is shown.

[2]Par = parity class. Interaction VWP × parity class was never significant and therefore not included in the models.

[3]Unweighted for the lactation length of an animal in the experiment.

[4]Revenues for calves; for cows that had a second calf in the experiment.

[5]LSM of culling costs for cows that were culled due to health issues in the experiment.

[6]Mean per group, also including cows that were not culled and that did become pregnant. No statistical analysis was performed, so *P*-values are not available (NA).

[7]LSM of culling costs for cows that did not become pregnant in the experiment within 300 DIM; these cows left the experiment at approximately 530 d in lactation or earlier when production <10 L/d.

[8]Mean, weighted for the lactation length of an animal in the experiment.

[9]Mean, weighted for the lactation length of an animal in the experiment, including all cows.

†Similar symbol indicates a trend in difference among LSM from VWP or parity class ($P < 0.10$).

Table 4. Number of cows from each voluntary waiting period group (50 d, 125 d, or 200 d: VWP50, VWP125, or VWP200) in each economic class (EC1: <€1,100/yr, EC2: €1,100–1,400/yr, EC3 >€1,400/yr)[1]

Item	VWP50	VWP125	VWP200	Total
EC1	14 (27)	15 (31)	21 (43)	50
EC2	18 (35)	18 (37)	15 (31)	51
EC3	20 (38)	16 (33)	13 (27)	49
Total	52 (100)	49 (100)	49 (100)	150

[1]Proportion of cows from each VWP in the 3 EC between brackets (%). $\chi^2 = 3.46$, P-value = 0.48.

extended VWP of 125 or 200 d had greater PMR supply in the experiment compared with a VWP of 50 d. An extended VWP, however, did not result in greater concentrate supply during the experiment. Therefore, cows with a VWP of 200 d received less concentrate per year compared with cows in VWP50. Similarly, number of inseminations or number of veterinary treatments during the complete experiment was not affected by VWP.

Moreover, probability of being culled due to health issues in the experiment was not affected by VWP. Numerically, more cows in VWP125 (7) and VWP200 (7) were culled during the experiment compared with VWP50 (4), possibly related to having more days in the experiment. From these culled cows in VWP125 and VWP200, 3 cows from each group were culled in the first 6 wk of the second lactation within the experiment. This could possibly be related to the increased BCS of cows with a longer VWP at the end of lactation and in the beginning of the next lactation (Burgers et al., 2021a). However, the sample size in this study was too small to draw conclusions about culling rate in the different VWP groups. In an earlier study with 2,711 cows, it was observed that multiparous cows with a waiting period of 88 d tended to have greater replacement costs within 1 lactation compared with multiparous cows with a waiting period of 60 d (Stangaferro et al., 2018).

The probability to not become pregnant within 300 DIM in the experiment tended to be affected by VWP. Although the 3 VWP groups did not statistically differ, numerically more cows in VWP200 did not conceive within the experiment compared with the other 2 VWP groups. In this study, all cows had until 300 DIM to conceive. As a result of this approach, cows with a longer VWP had less time to become pregnant. Moreover, 4 cows from VWP200 were never inseminated, from which 3 were culled before the end of the VWP or shortly after (219 d). Although 9 cows from VWP200 did not conceive in this study, the cows in this group had more normal ovarian cycles around the end of the VWP, and fewer days until pregnancy after the end of the VWP (Ma et al., 2020).

As an alternative to calculating output as the sum for the complete lactation, variables could be expressed per year to allow for the comparison of results of cows with different VWP and therefore different lactation lengths. Hence, in this study, revenues and costs were calculated for each VWP group per cow per year. Yearly revenues were lower in VWP200 compared with VWP50, mainly due to lower yearly revenues from milk. Earlier modeling studies also found a reduction in milk production or milk revenues for most cows when VWP was extended (Groenendaal et al., 2004; Steeneveld and Hogeveen, 2012; Kok et al., 2019). For example, when CInt was extended with 2 or 4 mo for both primiparous and multiparous cows, milk production was reduced by 4% or 7% (Kok et al., 2019). When another study included only high-producing cows, however, income from milk increased when VWP was extended from 90 to 150 d for primiparous cows or from 60 to 120 d for multiparous

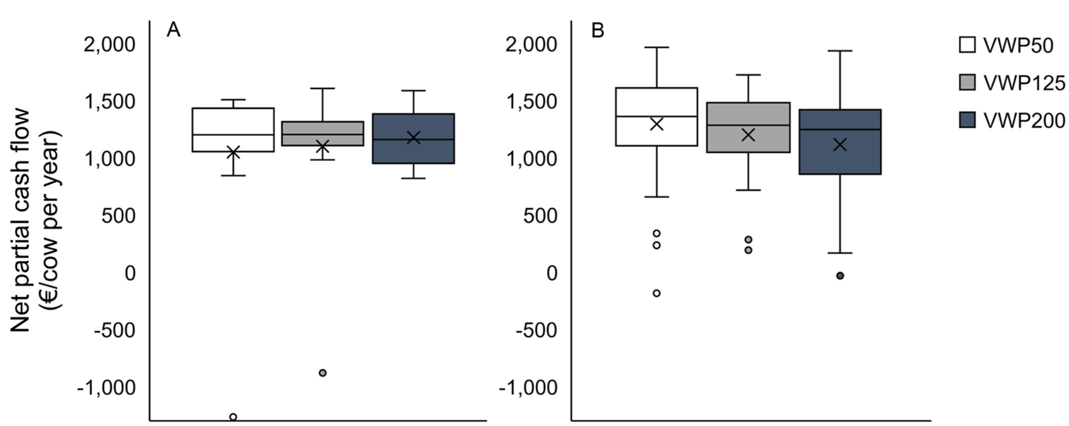

Figure 3. Net partial cash flow (€/cow per year) for primiparous (A) and multiparous (B) cows with a voluntary waiting period of 50, 125, or 200 d (VWP50, VWP125, VWP200; n = 150). The × in the box indicates the mean, the solid black line indicates the median, top and bottom of the box are the first and the third quartiles, and circles indicate outliers.

cows (Arbel et al., 2001). In practice, farmers that want to extend the CInt on their farm select specific cows for an extended VWP. For example, when farmers deliberately extended the CInt for (part of) their herd, cows with the greatest 305-d yield had longer CInt (Burgers et al., 2021a). Therefore, in those cases, the losses in milk revenues might be limited. Moreover, minimum or maximum price for milk solids had greater effect on the yearly NPCF of cows in VWP50 compared with cows in VWP200. Probably the reason is the greater MY for cows in VWP50, resulting in a relatively greater effect of fluctuation in milk price on the cash flow compared with cows in VWP200. Also in an earlier study, when costs for a lower milk production were lower, a delayed insemination had less negative effect on the yearly economic result of cows compared with when costs for a lower milk production were higher (Steeneveld and Hogeveen, 2012). Therefore, in the current study, when prices for milk solids were low, the yearly NPCF of cows with a VWP of 200 d approached the yearly NPCF of cows with a VWP of 50 d (€310 vs. 325). Next to the lower milk revenues, net returns from calves were lower when VWP was longer. In the current study, we assumed that the ratio of male to female calves born was 50% for all 3 groups. This assumption might not reflect the actual sex of calves born. Moreover, we did not distinguish between the value of heifers that were kept for replacement or the value of calves that were sold at 2 wk of age. As calf revenues did not have a large contribution to the net partial cash flow, the effect of these assumptions on the economic result is expected to be limited. Minimum or maximum prices for calves, or minimum or maximum costs for labor associated with calving cows, had greater effect on the yearly NPCF of cows in VWP50 compared with cows in VWP200, as more calves were born per year in this group.

In the current study, the lower revenues for cows in VWP200 were partly compensated by lower costs for cows in VWP200 compared with VWP50, mainly due to lower costs for concentrate supply. These lower costs for concentrate in longer VWP could be explained by more days with lower milk production per year and fewer days in peak yield per year (Dekkers et al., 1998; Lehmann et al., 2014; Kok et al., 2019). As more concentrate was supplied per year to cows in VWP50, minimum or maximum feed prices had greater effect on the yearly NPCF of cows in VWP50 compared with cows in VWP200. Next to the lower yearly feed

Table 5. Cow characteristics for cows in different economic classes (EC1: <€1,100/cow per year, EC2: €1,100–1,400/cow per year, EC3 >€1,400/cow per year) that were not culled during the experiment (n = 150)

	EC1		EC2		EC3		*P*-value[1]		
Item	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	EC	VWP	Par
N cows	50		51		49				
CFSI[2] (d)	140	2	138	1.7	140	1.9	0.67	<0.01	0.89
Calving interval (d)	452	8	444	7	435	7	0.26	<0.01	0.21
Lactation persistency[3]* (kg/d)	−0.061	0.005	−0.061	0.004	−0.067	0.004	0.50	<0.01	<0.01
Milk yield per ED[4] (kg/d)	23.3[b]†	0.6	25.2[b]†	0.6	28.2[a]	0.6	<0.01	<0.01	<0.01
Protein yield per ED** (kg/d)	0.84[c]	0.02	0.93[b]	0.02	1.04[a]	0.02	<0.01	0.16	<0.01
Fat yield per ED** (kg/d)	1.02[c]	0.02	1.12[b]	0.02	1.27[a]	0.02	<0.01	0.89	<0.01
Lactose yield per ED (kg/d)	1.05[b]†	0.03	1.14[b]†	0.03	1.27[a]	0.03	<0.01	<0.01	<0.01
Protein content[5] (%)	3.5	0.04	3.5	0.04	3.4	0.04	0.66	<0.01	0.58
Fat content[5] (%)	4.2	0.08	4.2	0.08	4.2	0.08	0.79	<0.01	0.09
Lactose content[5]*** (%)	4.2[a]	0.04	4.1[b]	0.03	4.1[b]	0.04	0.01	0.15	<0.01
Veterinary treatments[6]	7.8[a]	(6.1–10)	4.3[b]	(3.4–5.4)	2.9[c]	(2.3–3.7)	<0.01	0.50	<0.01
Body weight (kg)	657	8	660	8	665	8	0.79	0.63	<0.01
Body condition score	2.7	0.06	2.8†	0.06	2.6†	0.06	0.09	<0.01	0.29
Net partial cash flow** (€/cow per year)	658[c]	44	1,255[b]	44	1,598[a]	46	<0.01	0.20	0.43

[a–c]Different superscripts indicate a difference among LSM from VWP or parity class ($P < 0.05$).

[1]EC = economic class; VWP = voluntary waiting period; Par = parity class.

[2]Calving to first service interval.

[3]Lactation persistency between d 100 and start dry-off.

[4]ED = experimental day: yield per day in the experiment.

[5]Mean content during the experiment.

[6]Number of veterinary treatments in the experiment. *P*-values based on log-transformation, data are back-transformed, and CI is shown.

*Interaction EC × VWP in the model: $P = 0.04$.

**Interaction VWP × parity class in the model: protein yield: $P = 0.03$; fat yield: $P = 0.01$; net partial cash flow: $P = 0.04$.

***Interaction EC × parity class in the model: $P = 0.02$.

†Similar symbol indicates a trend in difference among LSM within the row ($P < 0.10$).

Table 6. Final multivariable model for prediction of net partial cash flow (€/cow per year) for cows with a voluntary waiting period (VWP) of 50, 125, or 200 d [VWP50, VWP125, or VWP200; n = 150; LSM ± SEM or regression coefficient (β) with SE and range][1]

Variable	Category	LSM (SEM)	Range[2]	*P*-value
VWP	50	1,572 (114)		0.23
	125	1,447 (117)		
	200	1,425 (115)		
Parity	Primiparous	1,821[a] (207)		0.06
	Multiparous	1,142[b] (42)		
		β (SE)		
Milk yield[3]		−77 (27)	17–52	<0.01
FPCM yield[4]		62 (17)	19–56	<0.01
BW[5]		1.8 (2.2)	493–870	0.16
BW × VWP	50[4]	0	520–836	0.02
	125	1.8 (1.3)	493–825	
	200	4.0 (1.4)	512–870	
BW × parity class	Primiparous[4]	0	493–646	0.03
	Multiparous	−4.4 (2.1)	526–870	
Maximum yield[3]		65 (21)	21–60	0.04
Maximum yield × VWP	50[4]	0	22–60	<0.01
	125	−31 (12)	24–59	
	200	−45 (13)	21–58	
Breeding value persistency		32	92–113	<0.01

[a,b]Different superscripts indicate a difference among LSM within one variable ($P < 0.05$).

[1]The final multivariate model was based on 13 univariate models, with individual early-lactation variables as independent variable, to identify potential predictors for net partial cash flow after different VWP.

[2]Range for milk yield FPCM (fat- and protein-corrected milk) yield, and maximum yield in kg/day; range for BW in kg.

[3]Measured in the first 6 wk after the first calving within the experiment.

[4]Reference category.

costs, yearly insemination costs were lower for cows in VWP200. These lower costs for insemination could be explained by better fertility of cows in VWP200 (Ma et al., 2020) and better fertility of cows with a longer VWP in general (Niozas et al., 2019b). The number of inseminations in the complete experiment did not significantly differ among the VWP groups, but more days in lactation with an equal number of inseminations per lactation leads to lower costs for inseminations per year. As cows in VWP50 had more inseminations per year, minimum or maximum costs for labor around inseminations had a greater effect on the yearly NPCF of cows in VWP50 compared with cows in VWP200. The mean yearly costs for culling due to health issues were €38 greater in VWP50 compared with VWP200, possibly related to similar culling within one lactation, so costs become greater for cows with shorter lactation lengths than for cows with longer lactation lengths when culling is expressed per year. The mean yearly costs for not becoming pregnant were €41 greater in VWP200 compared with VWP50, possibly related to their shorter time to become pregnant. Costs for veterinary treatments did not differ among the 3 VWP groups. The costs for culling and veterinary treatments, together with the insemination costs, also had a relatively small contribution to the yearly NPCF. Moreover, the VWP did not affect the change in yearly NPCF as a result of minimal or maximal costs for veterinary treatments, possibly associated with a low disease incidence and the relatively low number of cows for assessment of treatments. In addition, this study included only cows that had a SCC below 250,000 before the previous dry-off and that were expected to complete a full lactation. In theory this could have resulted in a selection bias, as only relatively healthy cows were included.

Due to the partial compensation of the lower revenues by lower costs after longer VWP, the difference in yearly NPCF among the VWP groups was reduced, and VWP was not significantly associated with the yearly NPCF. The sample size of the current study was, however, relatively small for an economic analysis including costs of culling. Yearly NPCF was, on average, €55/cow per year lower when cows had a VWP of 125 compared with a VWP of 50 d, and was €102/cow per year lower when cows had a VWP of 200 d compared with a VWP of 50 d. Although these differences were not statistically significant in this study, they could be relevant for farmers in practice. When VWP would be extended up to 200 d for all cows on a farm, the implications for the economic result could be large on a herd level if all these cows would realize lower cash flows. However, it can be expected that not all cows with a VWP of 200 d have €102 lower yearly cash flows, as some cows might be better suited for a

Table 7. Relative change of net partial cash flow (NPCF; €/cow per year) for minimum and maximum (min, max) prices of milk, feed, and calves, and for minimum and maximum labor costs around calvings (calving cow labor), inseminations (insemination labor), and veterinary treatments (veterinary treatment labor) for cows with a voluntary waiting period (VWP) of 50, 125, or 200 d (VWP50, VWP125, VWP200; n = 150)

	Voluntary waiting period						Parity class				P-value[1]	
	VWP50		VWP125		VWP200		Primiparous cows		Multiparous cows			
Item	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	LSM	SEM (CI)	VWP	Par
NPCF	1,205	71	1,150	72	1,103	74	1,102	76	1,203	47	0.58	0.26
Milk price, min	−880^{b}	18	−844^{ab}	18	−793^{a}	19	−795	19	−882	12	<0.01	<0.01
Milk price, max	+808^{a}	17	+775^{ab}	17	+728^{b}	17	+730	18	+810	11	<0.01	<0.01
Feed price, min	+237^{a}	4.1	+225^{ab}†	4.2	+212^{b}†	4.3	+214	4.5	+236	2.7	<0.01	<0.01
Feed price, max	−21^{b}	0.3	−20^{ab}†	0.3	−19^{a}†	0.4	−19	0.4	−21	0.2	<0.01	<0.01
Calf price, min	−58^{b}	2.9	−46^{a}	2.9	−38^{a}	3.0	−49	3.1	−46	1.9	<0.01	0.40
Calf price, max	+58^{a}	2.9	+46^{b}	2.9	+38^{b}	3.0	+49	3.1	+46	1.9	<0.01	0.40
Calving cow labor, min	+31^{a}	1.5	+25^{b}	1.6	+20^{b}	1.6	+26	1.7	+24	1.0	<0.01	0.40
Calving cow labor, max	−57^{b}	2.9	−46^{a}	2.9	−37^{a}	3.0	−48	3.1	−45	1.9	<0.01	0.40
Insemination labor,[2] min	+25^{a}	(21–30)	+22^{a}	(19–26)	+15^{b}	(13–18)	+20	(16–24)	+21	(19–24)	<0.01	0.47
Insemination labor,[2] max	−25^{b}	(21–30)	−22^{b}	(19–26)	−15^{a}	(13–18)	−20	(16–24)	−21	(19–24)	<0.01	0.47
Veterinary treatment labor,[2] min	+33	(24–46)	+35	(25–50)	+27	(19–38)	+19	(13–27)	+52	(41–65)	0.49	<0.01
Veterinary treatment labor,[2] max	−94	(73–120)	−87	(68–113)	−71	(55–93)	−61	(46–80)	−115	(97–136)	0.27	<0.01

[a–c]Different superscript indicates a difference among LSM from VWP ($P < 0.05$).

[1]Par = parity class. Interaction VWP × parity class was never significant and therefore not included in the models.

[2]P-values based on log-transformation, data are back-transformed, and CI is shown.

†Similar symbol indicates a trend in difference among LSM from VWP ($P < 0.10$).

longer VWP than others (Lehmann et al., 2017; Kok et al., 2019; Burgers et al., 2021b). This was also shown by the large variation in yearly NPCF among individual cows. Selecting the more suitable cows for a longer CInt might limit the reductions in NPCF on a herd level. To account for the lactation length of individual cows in the experiment, we calculated the weighted yearly NPCF per VWP group. As such, cows with fewer days in the study had a smaller contribution to the average NPCF than cows with more days in the study. The differences in NPCF among the 3 VWP were greater in the weighted averages compared with the unweighted NPCF. As the weighted yearly NPCF accounted for the lactation length of a cow, the 3 cows that were culled before 70 DIM and therefore had extremely high yearly costs for culling could be included. The difference between the weighted NPCF excluding these 3 cows and the weighted NPCF with all cows was small, and it can be concluded that these 3 cows made a limited contribution to the results of the experiment.

One of the reasons that the yearly NPCF among the 3 VWP groups did not significantly differ was probably the large variation in NPCF among individual cows. To evaluate why some cows performed better in terms of yearly NPCF than other cows, cows were divided into 3 EC based on their yearly NPCF. The effect of these EC on several cow characteristics was studied. The effect of EC on lactation persistency depended on VWP, where, only for cows in VWP125, the lactation persistency was greater in EC2 (€1,100–1,400/yr) compared with EC3 (>€1,400/yr). In contrast, earlier studies found an increased NPCF in extended lactations when lactation persistency was increased (Kok et al., 2019). Possibly, in the current study, the improved lactation persistency was related to a lower peak production (Dekkers et al., 1998), which is also an important factor for the economic results of cows. Lactation persistency, however, could be important for maintaining a healthy BCS at the end of an extended lactation. When BCS is increased in late lactation as a result of an extended VWP, this could result in an increased risk for diseases after the next calving (Roche et al., 2009).

In the current study, the interaction between VWP and parity class never affected the yearly revenues and costs. In other studies, when CInt was extended, results for MY, milk revenues, or NPCF were often different for primiparous cows than for multiparous cows (Österman and Bertilsson, 2003; Lehmann et al., 2016; Kok et al., 2019). When we forced the interaction between VWP and parity class in the model in the current study, numerically the yearly NPCF for multiparous cows decreased with longer VWP (€1,294 vs. 1,200 vs. 1,114 for VWP50, VWP125, and VWP200), but the yearly NPCF for primiparous cows did not decrease with longer VWP (€1,050 vs. 1,099 vs. 1,175 for VWP50, VWP125, and VWP200). Similarly, cash flow of primiparous cows numerically increased when VWP was extended from 60 d to 88 d, and cash flow of multiparous cows numerically decreased when VWP was extended (Stangaferro et al., 2018). This could be related to the greater lactation persistency of primiparous cows compared with multiparous cows (Lehmann et al., 2017; Kok et al., 2019; Burgers et al., 2021b), as for primiparous cows revenues from milk also did not decrease when VWP was extended (€2,857 vs. 2,809 vs. 2,879 for VWP50, VWP125, and VWP200).

Other cow characteristics than parity could also play a role in the lactation performance of cows. Yearly NPCF of cows with different VWP could be predicted by the maximum yield and the mean BW in the first 6 wk after the first calving in the experiment. In the model, maximum yield in the first 6 wk was positively related to NPCF per cow per year for cows in all 3 VWP, but less for cows in VWP125 and VWP200 compared with cows in VWP50. Possibly this could be explained by a reduced lactation persistency related to a greater peak yield (Dekkers et al., 1998). Moreover, when VWP and thus CInt is shorter, early lactation takes up a relatively greater part of the complete lactation; production during this period is therefore more important than when VWP, and thus CInt is longer. Mean BW in the first 6 wk was positively related to NPCF per cow per year for cows in all VWP, but mostly for cows in VWP200. It can be hypothesized that BW in early lactation could play a role in persistency later in lactation (Dekkers et al., 1998). Especially after longer VWP, persistency is an important factor to maintain MY in these extended lactations.

In the current study, cows were randomly divided over 3 different VWP. Moreover, the ration of the cows in the 3 VWP groups was the same. In practice, farmers often select specific cows for an extended lactation, based on MY level, body condition, or a combination of factors (Burgers et al., 2021b). Moreover, some farmers have deliberate final lactations, where cows are not inseminated but remain on the farm and are milked. In the current study, in total 3 primiparous cows and 11 multiparous cows left the experiment because they did not conceive within 100 d after the end of the VWP. These cows were mostly able to produce sufficient amounts of milk at the end of their lactation and stay in the experiment for a long time, as illustrated in Figure 4. Of these cows, 4 multiparous cows were culled because their production dropped below 10 L/d before 530 DIM, between 393 and 495 DIM. Possibly, 10 L/d is a low cut-off value in practice and cows are culled earlier on commercial dairy farms, as these production levels could be insufficient for a productive dairy farm. If, in this study, cows had been culled earlier in lactation due to a higher cut-off value, culling costs of these cows could be higher due to lower culling age. If, for example, the cut-off value had been 15 L/d, these 4 cows would have been culled 103 d earlier on average. This effect, however, can be expected to be limited because, on average, culling age of these cows would in that case be reduced with only ± 5%, or with ± 8% if the cut-off value had been 20 L/d. In addition, most cows were able to remain in the study until 530 DIM because they had adequate production levels (i.e., on average 16 kg/d in the final 7 d in the study). This study stopped following these other cows at approximately 530 DIM; however, in practice these cows might stay at the farm for an even longer period as long as they produce sufficient milk.

CONCLUSIONS

In an experiment where cows were randomly assigned to different VWP and managed accordingly, cows with a VWP of 50 d had greater total yearly revenues and

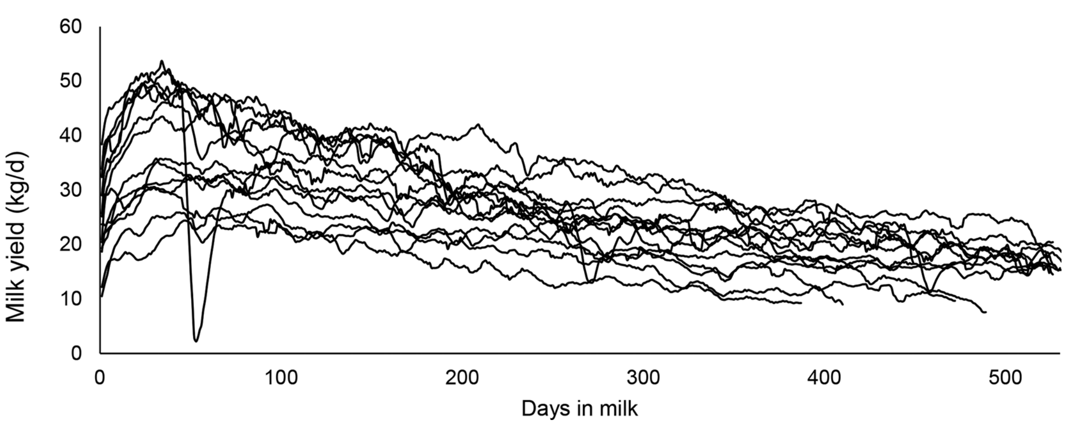

Figure 4. Milk yield based on the weekly rolling average of cows that did not conceive in the experiment and left the experiment at 530 DIM or earlier when their milk yield dropped below 10 L/d (n = 14).

greater total yearly costs compared with cows with a waiting period of 200 d. Total revenues and costs per year for cows in VWP125 were similar to those of cows in VWP50. The yearly NPCF was not affected by the VWP. Milk revenues and feed costs contributed the most to the yearly NPCF. Cows with a greater yearly NPCF had greater production of milk, protein, fat, and lactose, and a lower number of veterinary treatments. Neither VWP nor CInt were different for cows with greater yearly NPCF compared with cows with lower yearly NPCF. For cows in VWP50, a greater maximum yield in the first 6 wk was more strongly associated with a greater yearly NPCF than for cows after longer VWP.

ACKNOWLEDGMENTS

This study was financed by DairyNL (ZuivelNL; organization of the Dutch dairy supply chain, The Hague, Netherlands) and the Dutch Ministry of Agriculture, Nature and Food Quality (LNV, The Hague) as part of the research program One Health for Food (1H4F, The Hague). The authors thank the staff of the Dairy Campus (Leeuwarden, the Netherlands) and veterinarian Betsie Krattley of University Livestock Practice (Harmelen, the Netherlands) for information on the costs of treatments and related labor. The authors have not stated any conflicts of interests.

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APPENDIX

Table A1. Treatments, duration of treatments, price per complete treatment, labor costs, and waiting time for milk per treatment for all medication used in the experiment

Treatment	Treatment duration	Price (€/complete treatment)	Labor costs (€/complete treatment)	Waiting time (d)
Acegon (Laboratorios SYVA)	1 treatment, 1 d	8	15	0
Albipen (Intervet)	3 treatments, 3 d	26	30	6
Avuloxil (Zoetis)	3 treatments, 1.5 d	9.5	30	4
Biodyl (Merial)	1 treatment, 1 d	11.5	15	0
Borgal (Virbac)	3 treatments, 3 d	13	30	3
Rumination powder	1 treatment, 1 d	6.4	15	0
Bovikalc (Boehringer Ingelheim)	2 boluses	12	15	0
Buscopan (Boehringer Ingelheim)	1 treatment, 1 d	15	15	7
Mint udder cream (Cai Pan Benelux)	1 treatment, 1 d	2.9	5	0
Calcitat 25 (aniMedica)	1 treatment, 1 d	5	15	0
Calcium Magnesium intravenous drip (Eurovet Animal Health)	1 treatment, 1 d	5.69	15	0
Diatrim 24 (Eurovet Animal Health)	3 treatments, 3 d	22.5	30	2
Dinolytic (Zoetis)	1 treatment, 1 d	5	15	0
Dofatrim (Dopharma Research)	3 treatments, 3 d	22.5	30	3
Drench	1 treatment, 1 d	14	30	0
Engemycine 10 (Intervet)	3 treatments, 3 d	13.2	30	5
E-pill (energy pill, profs-products.com)	1 bolus	6.5	15	0
Fyto-stop powder (Virbac)	1 treatment, 1 d	6.35	15	0
Glucamagnesium (Bridgefarma)	1 treatment, 1 d	15	15	0
Glucose 30 (Eurovet Animal Health)	1 treatment, 1 d	10.88	15	0
Mamyzin (Boehringer Ingelheim)	3 treatments, 3 d	30	30	4
Placenta capsule (Virbac)	1 treatment, 1 d	4.7	15	4
Noroseal (Norbrook Laboratories)	1 treatment (4 teats)	8	5	0
Novem (Boehringer Ingelheim)	1 treatment	12.5	15	5
Orbenin dry (Zoetis)	1 treatment (4 teats)	6	5	42
Orbenin extra dry (Zoetis)	1 treatment (4 teats)	8.84	5	42
Orbenin lactation (Zoetis)	3 treatments, 6 d	13.92	30	4
Orbeseal (Zoetis)	1 treatment (4 teats)	8	5	0
P-pil (phosphorus pill, profs-products.com)	2 boluses	7	15	0
Pen and strep (Norbrook Laboratories)	3 treatments, 3 d	14	30	5
Prid Delta (CEVA Sante Animale)	1 treatment, 1 d	26.25	15	0
Procapen (aniMedica)	3 treatments, 3 d	15	30	6
Propylene glycol (Floris Veterinaire Produkten)	2 doses	10	15	0
Revozyn (Eurovet Animal Health)	3 treatments, 3 d	45.78	30	4
Rimadyl (Zoetis)	1 treatment, 1 d	14.54	15	0
Rotavec Corona (Intervet)	1 treatment, 1 d	16.49	5	0
RumiActif (Savetis)	1 treatment, 1 d	6.4	15	0
Trimethroprim/ Sulfamethoxazol (Dopharma Research)	3 treatments, 3 d	22.5	30	4
Ubrolexin (Boehringer Ingelheim)	2 treatments, 2 d	7.11	30	5
Ubropen (Vetcare Oy)	3 treatments, 3 d	14.63	30	6
Ubroseal (Univet Limited)	1 treatment (4 teats)	8	5	0