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Review: Dry period length in dairy cows and consequences for metabolism and welfare and customised management strategies

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Shortening or omitting the dry period improves the energy balance and metabolic status of dairy cows in early lactation. Metabolic, behaviour and welfare effects throughout lactation, however, are unclear. The current paper reviews long-term metabolic and welfare consequences of short and no dry period, as well as feeding strategies and individual cow characteristics that could support in optimising management of cows with a short or no dry period. The paper will conclude with impacts of short and no dry periods at herd level and in practice. Energy balance after no or a short dry period is more positive during the complete subsequent lactation. After the initial improvement in early lactation, cows after no dry period tend to fatten and may have a too low lactation persistency to be continuously milked until the onset of the subsequent lactation. Reducing dietary energy level for cows with no dry period reduced fattening during the complete lactation but did not improve lactation persistency. Feeding a more lipogenic diet for cows with a short or no dry period did not affect the energy balance or lactation persistency during the complete lactation, although a lipogenic diet resulted in lower plasma insulin and IGF-1 concentration and greater plasma growth hormone concentration, compared with a glucogenic diet. Effects of dry period length on udder health are ambiguous, whereas short and no dry periods improved fertility in most studies. Omission of the dry period changed behaviour of cows both before and after calving, with a longer lying time and greater feed intake after calving, suggesting a better adaptation to a new lactation. Individual cow characteristics like parity, genotype, prepartum *body condition score, and milk yield level determined the metabolic response of cows to a short or no dry period. In conclusion, short or no dry periods increase the energy balance in the complete lactation. Feeding strategies can be used to limit fattening of cows with no or short dry period, but the studied feeding strategies did not increase lactation persistency. Improved fertility and behavioural changes around calving suggest a better adaptation to a new lactation in case of no dry period. Customised dry period lengths for individual cows could improve metabolic status of cows at risk of a severe negative energy balance while minimising milk losses.*

Keywords: energy balance, behaviour, transition period, cow health

Implications

Customised dry period lengths for individual cows could improve metabolic status of cows at risk of a severe negative energy balance while minimising milk losses. The current paper reviews long-term metabolic and welfare effects of short and no dry period, as well as feeding strategies and individual cow characteristics that could support in optimising management of cows with a short or no dry period. Lastly, the paper discusses that a short or no dry period is most applicable for high-producing cows and for implication in practice also consequences for udder health and colostrum quality should be taken into account.

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Introduction

The dry period is the period before calving that cows are not milked, which is traditionally about 6 to 8 weeks. The dry period has multiple functions. Main functions are to treat the cow with antibiotics in case of persistent subclinical mastitis (Bradley and Green, 2001), to allow the cow a rest period before birth of the next calf (Kok *et al.*, 2017a) and to maximise milk yield in the next lactation. During the dry period, mammary cells renew at a faster rate than when cows would be milked up to calving (Capuco *et al.*, 1997). This results in a large concentration of renewed mammary cells at the moment of calving which explains the high peak milk yield in the next lactation after a dry period (Kuhn *et al.*, 2005; Van Knegsel *et al.*, 2013a).

Table 1. *Energy balance (MJ NE/d) of dairy cows in early lactation after a standard (56 to 60 days), short (28 to 30 days) or no (0 days) dry period*

Study	*n*	Weeks after calving	Dry period		
			Standard	Short	No
Andrée O'Hara *et al.* (2018)	69	2 to 12	−8.8	10.9	
Chen *et al.* (2016b)[1]	130	1 to 9	−36.4	−31.8	−28.9
De Feu *et al.* (2009)	36	1 to 4	−13.7	11.5	
De Feu *et al.* (2009)	36	5 to 12	5.3	17.1	
Rastani *et al.* (2005)	65	1 to 10	−29.0	−17.0	2.9
Van Hoeij *et al.* (2017a)	123	1 to 3		−30.2	−8.1
Van Hoeij *et al.* (2017a)[2]	123	4 to 7		−14.0	7.2 / −0.3
Van Knegsel *et al.* (2014)[1]	167	1 to 14	−17.3	−7.7	5.3

n = number of cows in the study.
[1] Studies of Van Knegsel *et al.* (2014) and Chen *et al.* (2016b) are based on the same experiment, where cows were subjected to a standard, short or no dry period for two subsequent lactations. Van Knegsel *et al.* (2014) report on the first lactation; Chen *et al.* (2016) report on the second lactation.
[2] Cows with no dry period were either fed a standard or a reduced level of concentrates (standard/reduced group).

The energy requirements for peak milk yield and maintenance in early lactation, however, generally exceed the energy intake in early lactation, resulting in a negative energy balance (**NEB**). Cows with a standard dry period (i.e. 6 to 8 weeks) have an NEB for the first 2 to 3 months in lactation (Rastani *et al.*, 2005; Van Knegsel *et al.*, 2014). A severe NEB, and mobilisation of body reserves to compensate for this energy deficit, is associated with altered metabolic status (Grummer, 1993), greater incidence of diseases such as ketosis, displaced abomasum, mastitis and decreased fertility (Collard *et al.*, 2000; Lucy, 2001). Increased incidence of diseases and disorders in early lactation are signs of a lack of adaptation to a new lactation (Ingvartsen, 2006).

Shortening (to 3 to 5 weeks) and omitting the dry period were opted as management strategies that lower the peak milk yield and partly shift milk yield from the critical period after calving to the period before calving when the cow can easily meet her energy requirements by feed intake (Grummer and Rastani, 2004). The lower milk yield in early lactation reduces the severity and duration of the NEB in early lactation (Rastani *et al.*, 2005; Van Knegsel *et al.*, 2014).

Shortening and omitting the dry period and consequences for lactation performance, metabolic status, health and fertility have been reviewed before (Bachman and Schairer, 2003; Van Knegsel *et al.*, 2013a). This paper aims to review work concerning dry period length in relation with: (1) metabolic status of cows in the complete lactation and over consecutive lactations; (2) feeding strategies to limit fattening and increase lactation persistency; (3) welfare of cows (udder health, fertility and behaviour); and (4) cow characteristics that affect the impact of a short (30-days) or no dry period. The paper will conclude with impacts of short and no dry periods at herd level and in practice.

Metabolic effects of short or no dry period

Energy balance in early lactation

Short or no dry period improved the energy balance of dairy cows in early lactation (Table 1). Shortening the dry period from 56 to 60 days to 28 to 30 days improved energy balance (Rastani *et al.*, 2005; Van Knegsel *et al.*, 2014; Andrée O'Hara *et al.*, 2018) in early lactation. Omitting the dry period improved energy balance (Rastani *et al.*, 2005; Van Knegsel *et al.*, 2014; Van Hoeij *et al.*, 2017a) compared with a short or standard dry period. The current understanding is that the primary reason for this improvement on energy balance and metabolic status is reduced milk yield in early lactation (Van Knegsel *et al.*, 2013a), with a similar (Andersen *et al.*, 2005; De Feu *et al.*, 2009; Van Knegsel *et al.*, 2014) or increased (Rastani *et al.*, 2005; Jolicoeur *et al.*, 2014; Kok *et al.*, 2017a; Van Hoeij *et al.*, 2017a) feed intake.

Energy metabolism in early lactation

In dairy cows after a standard dry period, energy intake is usually lower than energy requirements, which results in an NEB. The NEB is associated with altered energy metabolism and increased risks for metabolic disorders (Figure 1a, adapted from Van Knegsel *et al.*, 2005). In dairy cows after a short or no dry period, milk production after calving is reduced, which changed energy metabolism (Rastani *et al.*, 2005; Van Knegsel *et al.*, 2014). Moreover, omitting the dry period (Rastani *et al.*, 2005; Van Hoeij *et al.*, 2017a) and shortening the dry period (Jolicoeur *et al.*, 2014) can improve feed intake in early lactation but not in all studies (Andersen *et al.*, 2005; De Feu *et al.*, 2009; Van Knegsel *et al.*, 2014). As a consequence of the lower milk yield and similar or greater feed intake, energy balance improved and mobilisation of body reserves reduced for cows with no or a short dry period compared with cows with a standard dry period. Reduced mobilisation of body reserves resulted in lower plasma free fatty acids (FFA) concentration after no dry period (Andersen *et al.*, 2005; Rastani *et al.*, 2005; Klusmeyer *et al.*, 2009; Chen *et al.*, 2015), sometimes also after a short dry period (Pezeshki *et al.*, 2007; Klusmeyer *et al.*, 2009), but not in all studies (Rastani *et al.*, 2005; Chen *et al.*, 2015). Lower milk production after a short or no dry period requires less lactose production, which is related to the elevated plasma glucose and insulin

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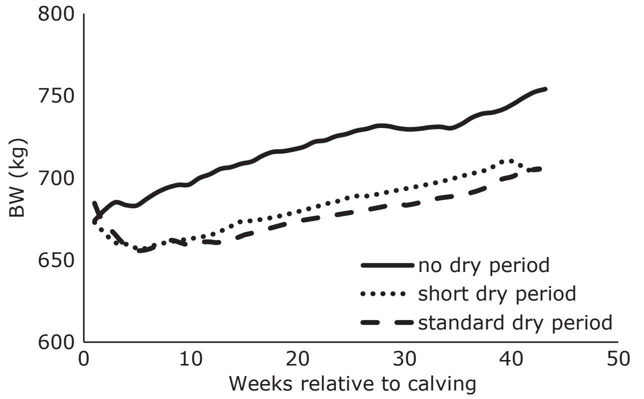

Figure 1 Body weight development during a complete lactation of dairy cows after a 0-d, 30-d or 60-d dry period (based on Chen, 2016).

concentration after no dry period (Andersen *et al.*, 2005; De Feu *et al.*, 2009; Chen *et al.*, 2015;Van Hoeij *et al.*, 2017a). Elevated plasma glucose and insulin concentration were, however, not reported after a short dry period, compared with a conventional dry period (Lotan and Adler, 1976; Rastani *et al.*, 2005; Pezeshki *et al.*, 2007; Chen *et al.*, 2015). As a consequence of the lower milk and lactose production, first, more glucogenic precursors can be expected to be available to form citrate and make energy available to the body in the form of ATP (Van Knegsel *et al.*, 2005). Second, associated with the increase in glucogenic precursors and lower mobilisation of body reserves, less lipogenic precursors are driven towards alternative metabolic pathways, resulting in a reduction in milk fat production (Van Knegsel *et al.*, 2013a), reduction in liver triacylglycerol accumulation (Andersen *et al.*, 2005; Rastani *et al.*, 2005; Chen *et al.*, 2015) and possibly a reduction in formation of ketone bodies, like β-hydroxybutyrate (BHBA). Some studies reported no effect of dry period length on plasma BHBA in early lactation (Rastani *et al.*, 2005; De Feu *et al.*, 2009; Chen *et al.*, 2015), while others reported a reduction of plasma BHBA due to omitting (Andersen *et al.*, 2005; Klusmeyer *et al.*, 2009; Van Hoeij *et al.*, 2017a) or shortening (Klusmeyer *et al.*, 2009; Schlamberger *et al.*, 2010) of the dry period. Three studies that reported ketosis after a conventional or no dry period described that ketosis did not occur in cows with no dry period, compared with an incidence of 5% (no statistical analysis presented; Rastani *et al.*, 2005), 10% (P = 0.05; Köpf *et al.*, 2014) or 25% (P = 0.18; Schlamberger *et al.*, 2010) in cows with a standard dry period. Furthermore, a meta-analysis reported a tendency (P = 0.09) for a lower odds for clinical ketosis in cows after a short dry period, compared with cows after a conventional dry period length (Van Knegsel *et al.*, 2013a).

The increased plasma insulin concentration after a short or no dry period has a role in recoupling of the growth hormone (GH)-IGF-1 axis (Lucy, 2004), resulting in increased plasma IGF-1 concentration (Pezeshki *et al.*, 2007; De Feu *et al.*, 2009; Van Hoeij *et al.*, 2017a) and reduced plasma GH concentration (Van Hoeij *et al.*, 2017a) after no dry period, which limits body fat mobilisation.

Metabolic status and energy balance in mid and late lactation

Omitting the dry period not only improved the energy balance in early lactation but resulted also in a more positive energy balance in mid and late lactation (Van Hoeij *et al.*, 2017b). This positive energy balance increased BW (Figure 1) and body condition score (**BCS**) at the end of the subsequent lactation (Chen *et al.*, 2016b) after omission of the dry period. So, greater energy balance in early lactation together with the excessive energy intake in mid and late lactation increases the risk of fattening in mid and late lactation, especially for cows with no dry period.

Lactation persistency

A more positive energy balance of dairy cows has been associated with an increased proliferation of mammary epithelial cells (Capuco *et al.*, 2001). Therefore, it can be hypothesised that an improved energy balance in early lactation due to shortening or omitting of the dry period is beneficial for lactation persistency later in lactation. However, effects of dry period length on lactation persistence are ambiguous. Shortening of the dry period was related with an increased lactation persistency in one study (Atashi *et al.*, 2013), but omitting of the dry period reduced lactation persistency in another study (Van Hoeij *et al.*, 2017b). In contrast, Chen *et al.* (2016a) did not find an effect of dry period length (no *v.* short *v.* standard) on lactation persistency. Possibly, differences in effects of dry period length on lactation persistency could be related to differences among studies in energy balance and disease incidence after different dry period lengths, as discussed earlier (Van Hoeij *et al.*, 2017b).

Feeding strategies to alter metabolism of dairy cows after a short or no dry period

A positive energy balance in early lactation, fattening in mid and late lactation, limited milk yield or limited lactation persistency could be reasons to adjust feeding strategies of dairy cows after a short or no dry period, which will be discussed in this section.

Early lactation

Both altering dietary energy source (Van Knegsel *et al.*, 2014; Chen *et al.*, 2015) and increasing dietary energy level (De Feu *et al.*, 2009) have been studied as nutritional strategies to improve the energy balance of cows in early lactation after a short or no dry period. A glucogenic diet, realised mainly by a greater contribution of corn to the diet, improved energy balance of cows (Van Knegsel *et al.*, 2014) and decreased plasma BHBA concentration (Chen *et al.*, 2015), compared with a more lipogenic diet, realised mainly with a greater contribution of palm fat and sugar beet pulp to the diet,

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regardless of dry period length. So, the improved energy balance after a short or no dry period was further improved by feeding a more glucogenic diet, compared with a more lipogenic diet. A greater dietary energy density decreased plasma FFA and BHBA concentrations in cows after a standard dry period, but not in cows after no dry period (De Feu *et al.*, 2009). In this study, the lack of improvement in metabolic status in cows with no dry period when fed a diet with a greater energy density was suggested to be caused by the already more positive energy balance due to omission of the dry period in these cows.

The reduction in milk yield in the subsequent lactation due to shortening or omitting of the dry period, however, would justify a reduction in availability of dietary energy for cow health, economic and environmental reasons (Chen *et al.*, 2016a; Kok *et al.*, 2017c). Van Hoeij *et al.* (2017a) reduced the energy level in the diet to the energy required for the expected milk yield of cows after a 0-day dry period and compared this with cows after a 0-day dry period fed a standard energy level (for cows with a dry period). Reducing dietary energy level of dairy cows after a 0-day dry period did not affect milk yield or milk composition but reduced the energy balance in the first 7 weeks of lactation (Van Hoeij *et al.*, 2017a). The metabolic status in early lactation, however, was not affected by dietary energy level. Lack of effect of dietary energy level on plasma FFA, BHBA, glucose, insulin and IGF-1 might be explained by the fact that energy status for cows both with a low and with a standard energy level was reasonably good during the first 7 weeks after calving (−2 *v.* 55 $kJ/kg^{0.75}$*d, for low *v.* standard energy level) (Van Hoeij *et al.*, 2017a).

Mid and late lactation

One of the risks of a short or no dry period is that cows fatten in late lactation or are not persistent enough to be continuously milked for a second subsequent lactation (Rémond *et al.*, 1997; Chen *et al.*, 2016b). We hypothesised that feeding a lower dietary energy level and a more lipogenic ration from peak milk yield onwards can stimulate lactation persistency and reduce fattening of cows without a dry period (Van Hoeij *et al.*, 2017b). Both dietary strategies (less energy and more lipogenic nutrients) would reduce glucose availability and consequently reduce plasma insulin concentration (Voelker and Allen, 2003; van Knegsel *et al.*, 2005), which reduces glucose channelling to muscle and adipose tissue which prevents fattening. Moreover, a more lipogenic diet could reduce plasma IGF-1 concentration, which would reduce the inhibition of GH release from the pituitary gland (Lucy, 2004) and consequently result in an increase of plasma GH concentration. Growth hormone increases nutrient partitioning towards milk and can stimulate lactation persistency.

Reducing dietary energy level for cows after a 0-day dry period reduced energy intake, energy balance and weekly BW gain during lactation week 1 through 44 but did not affect milk yield, milk composition or lactation persistency during this period (Van Hoeij *et al.*, 2017b). Although the energy balance was less positive for cows fed the low energy level, metabolic status, as indicated by plasma insulin, plasma IGF-1 and GH concentration, was not affected, compared with cows with a standard energy level.

In line with our hypothesis, feeding a more lipogenic diet, realised by a greater contribution of grass silage and sugar beet pulp, after a 0-day dry period reduced plasma insulin concentration, tended to reduce plasma IGF-1 concentration and tended to increase plasma GH concentration, during week 1 through 44 of lactation, compared with a more glucogenic diet, realised by a greater contribution of corn silage (Van Hoeij *et al.*, 2017b). In contrast with our hypothesis, the more lipogenic diet did not affect energy balance, weekly BW gain, fat-and-protein-corrected milk (**FPCM**) yield or lactation persistency, compared with the glucogenic diet. The dry matter intake (DMI) of the lipogenic diet, however, was lower than expected, possibly due to the lower DM content (Zom *et al.*, 2012) and the high contribution of sugar beet pulp (Voelker and Allen, 2003) to the diet. This possibly resulted in a lower energy intake from the lipogenic diet than from the isocaloric glucogenic diet. It can be hypothesised that a greater proportion of lipogenic nutrients in the lipogenic diet, or a better DMI for this group, could have resulted in significant effects of dietary energy source on the lactation curve.

Effect of short and no dry periods on cow welfare aspects

Good welfare has been defined as functioning well (i.e. good health), feeling well and being able to express natural behaviour (Fraser *et al.*, 1997). Short and no dry periods can affect metabolic health, udder health and fertility, as well as events during the lactation cycle which might affect feeling well. In this section, we review consequences of short or no dry period for udder health, fertility, events or transitions during the lactation cycle and cow behaviour.

Udder health

Effects of dry period length on udder health are ambiguous. Following a no or short dry period, somatic cell count (SCC) was not affected (Andersen *et al.*, 2005; Rastani *et al.*, 2005; Watters *et al.*, 2008) or increased (Klusmeyer *et al.*, 2009; Van Hoeij *et al.*, 2016) compared with a conventional dry period. No dry period resulted in a lower occurrence of cured intramammary infection (IMI) during the precalving period, compared with cows with a 30- or 60-day dry period (Van Hoeij *et al.*, 2016). Moreover, most studies could not relate incidence of clinical mastitis in the subsequent lactation to dry period length (Annen *et al.*, 2004; Watters *et al.*, 2008; Van Hoeij *et al.*, 2016). The effect of dry period length on udder health may be related to other cow characteristics such as parity, milk yield level at dry off or udder health status at dry off (Van Hoeij *et al.*, 2016). Furthermore, in the majority of studies, having a dry period was confounded with the use of dry cow antibiotics. When no and short dry periods were compared without the use of dry cow antibiotics,

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SCC was greater after calving for cows with no dry period, but not when SCC was corrected for a difference in milk volume (i.e. a dilution effect) between dry period lengths (Van Hoeij *et al.*, 2018). Further research on larger groups would be necessary to provide conclusive results.

Fertility

Omitting (Gümen *et al.*, 2005; Chen *et al.*, 2015) and shortening (Gümen *et al.*, 2005; Watters *et al.*, 2009) of the dry period improved the resumption of ovarian cyclicity *postpartum*. Improved resumption of ovarian cyclicity implied that both the number of days *postpartum* until onset of luteal activity (Gümen *et al.*, 2005; Watters *et al.*, 2009) and regularity of subsequent ovarian cycles were improved (Chen *et al.*, 2015). There are studies which also reported improved conception rates after insemination and reduced days open (Gümen *et al.*, 2005; Kok *et al.*, 2016) after shortening or omitting of the dry period, but not all (Pezeshki *et al.*, 2008; De Feu *et al.*, ; Chen *et al.*, 2015). Improved resumption of ovarian cyclicity of cows with a short or no dry period has been related to the improved energy status of these cows (Chen *et al.*, 2015). In some studies, but not all, the lack of effect on pregnancy rates and days open could be related to number of cows per study, heat detection protocol or applied voluntary waiting period.

Transitions

The onset of the dry period is a challenge for the cow, especially when milk yield is still considerable at the moment of dry-off (Zobel *et al.*, 2015). Moreover, a high milk production before dry-off increases the risk of intramammary infections at calving (Rajala-Schultz *et al.*, 2005). Short dry periods postpone the moment of dry-off, which results in a lower milk yield at dry-off compared with a standard dry period (Rastani *et al.*, 2005). Moreover, cows with a short dry period may require fewer or no ration and group changes, whereas cows with a standard dry period are often fed a far-off ration in the first and a close-up ration in the second half of the dry period, in different social groups (Rastani *et al.*, 2005). Omitting the dry period avoids dry-off, changes in ration and regrouping altogether, at the cost of a nonlactating rest period for the cow (Kok *et al.*, 2017a). The reduction in ration transitions could facilitate ruminal adaptation and increase energy intake in early lactation (Grummer and Rastani, 2004).

Feed intake and feeding behaviour

In the weeks before calving, cows with a short or no dry period that were still lactating had a higher feed intake than cows with a standard dry period (Rastani *et al.*, 2005; Van Knegsel *et al.*, 2014). After calving, despite having a lower milk yield, cows with no dry period had a similar (Andersen *et al.*, 2005; Van Knegsel *et al.*, 2014) or higher (Rastani *et al.*, 2005; Van Hoeij *et al.*, 2017a) feed intake than cows with a short or standard dry period. In early lactation, a greater feed intake of cows (39.1 *v.* 35.7 kg fresh feed/day) with no dry period was related with a higher feeding rate, but a similar feeding time (179 *v.* 183 min/day) compared with cows after a short dry period (Kok *et al.*, 2017a). Cows with a short dry period did not have a higher feed intake in early lactation than cows with a standard dry period in the study of Rastani *et al.* (2005), despite having no feeding transitions. In this study cows with a short dry period, but no feeding transitions peripartum, had a lower feed intake compared with cows with no dry period, which may partly be a carry-over effect of the lower feed intake of dry cows than of lactating cows before calving. Jolicoeur *et al.* (2014) reported that cows with a short dry period had a greater feed intake than cows with a standard dry period in early lactation, and suggest that fewer dietary changes before calving result in a better ruminal absorptive capacity after calving. However, benefits of short or no dry period on DM intake have not been observed in other studies (Andersen *et al.*, 2005; Van Knegsel *et al.*, 2014).

Lying behaviour

To our knowledge, behaviour other than feed intake, in relation to dry period length was only assessed in one study. Kok *et al.* (2017a) looked at lying behaviour and walking of cows with a short (30-day) dry period or no dry period before calving, to assess the impact of continuous milking in late gestation. Precalving, cows with a short dry period had a longer lying time per day (13.7 *v.* 12.6 h/day) and a lower step count (663 *v.* 1130 steps/day) than cows which were continuously milked until calving, which was largely explained by going through the milking parlour twice a day. Cows with no dry period, however, spent less time feeding on the lactation ration than cows with a short dry period spent on the dry cow ration (209 *v.* 240 min/day), which compensated part of time spent in the milking process. The increase in steps of cows with no dry period may be beneficial for their health in late gestation.

In early lactation, lying time was 1 h per day shorter for cows after no dry period, and 3 h per day shorter for cows with a short dry period compared with their lying time before calving (11.6 *v.* 10.7 h/day) (Kok *et al.*, 2017a). This confirms the idea that the dry period is a rest period. Moreover, behaviour in early lactation was related with metabolic status, independent of dry period length (Kok *et al.*, 2017a; van Hoeij *et al.*, 2018). Although only based on a limited dataset of 81 cows with short or no dry period, lying time and steps per day were positively correlated with energy balance (Kok *et al.*, 2017a), and lying time was negatively correlated with plasma concentrations of FFA, and positively correlated with IGF-1 (van Hoeij *et al.*, 2019) in week 4 of lactation. The increase in lying time after no dry period, in combination with the similar feeding time and higher feed intake than cows with a short dry period, suggests a better adaptation to a new lactation for cows after no dry period.

Customised dry period

The optimal dry period length can be hypothesised to differ for individual cows and may be based on consequences of dry period length for metabolic status, udder health or milk yield.

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Table 2 *Milk yield (kg/day) of young (parity = 2) or older (parity > 2) dairy cows after a standard (55 to 60 days), short (28 to 35 days) or no (0 days) dry period*

Study	*n*	Weeks in milk	Young cows (parity = 2)			Older cows (parity > 2)		
			Standard	Short	No	Standard	Short	No
Annen *et al.* (2004)[1]	69	2 to 17	44.1	38.3	35.1	47.7	46.6	43.4
Rastani *et al.* (2005)	65	1 to 10	39.8	36.1	31.6	43.4	39.9	36.3
Pezeshki *et al.* (2007)	71	1 to 44	39.1	34.6	–	35.6	36.7	–
Santschi *et al.* (2011)	850	1 to 48	31.5	30.1	–	32.7	32.7	–
Van Knegsel *et al.* (2014b)	167	1 to 14	41.8	37.9	28.6	44.1	39.2	34.8

n = number of cows in the study.
[1] Dairy cows in study of Annen *et al.* (2004) were supplemented with bovine somatotropin (bST).

From an economic point of view, an optimal dry period length may be a dry period length with a reasonably good metabolic status, without unnecessary milk losses. Here we review individual cow characteristics that could be relevant for the decision to shorten or omit the dry period for a specific cow under practical circumstances.

Parity

Omitting the dry period caused less milk yield losses in older cows, compared with young cows (parity 2; i.e. omitting the dry period before second calving) (Table 2). A possible explanation could be that omission of the dry period impairs continued mammary development between the first and second lactation, resulting in a greater reduction in milk yield for second-parity cows than for older cows (Collier *et al.*, 2012). These greater milk yield losses in young cows, however, are also related to a more pronounced improvement of the energy balance after omission of the dry period in young cows, compared with older cows (Van Knegsel *et al.*, 2014). In addition, milk losses in the subsequent lactation due to shortening or omitting of the dry period may be compensated to a larger extent in young cows, because of the greater additional milk yield before calving (Annen *et al.*, 2004; Van Knegsel *et al.*, 2014) and a more pronounced improvement in fertility after calving (Kok *et al.*, 2016 and 2017b).

Shortening the dry period resulted in similar milk yield losses in both young and older cows in some studies (Rastani *et al.*, 2005; Van Knegsel *et al.*, 2014), whereas others reported that shortening the dry period decreased milk yield after calving only in young cows, but not in older cows (Annen *et al.*, 2004; Pezeshki *et al.*, 2007) or the effect of short dry period is larger in young cows than in older cows (Santschi *et al.*, 2011). Discrepancies among studies might be related to genetic potential for milk yield, drying off process or actual length of the shortened dry period, i.e. was it long enough to sustain mammary development in young cows. Moreover, given that older cows generally have a higher milk yield and more severe NEB than young cows, and that shortening or omitting the DP seems to result in smaller losses for old cows, it may be sensible to shorten or omit the dry period for older cows only.

Lactation curve characteristics and milk yield level

Milk yield level precalving does not seem to influence the reduction in milk yield after calving due to short or no dry periods (Van Knegsel *et al.*, 2013a; Kok *et al.*, 2016). However, *prepartum* milk yield level and lactation persistency determine whether a cow is able to sustain milk production (or would spontaneously dry off), and how much additional milk would be realised in the months before calving when the dry period is shortened. Moreover, omitting the dry period can be expected to be more beneficial for cows with a high milk yield for two reasons: (1) drying-off cows with a higher milk yield increases the risk of new intramammary infections at dry-off (Rajala-Schultz *et al.*, 2005) and may compromise animal welfare (Zobel *et al.*, 2015) and (2) cows with a higher yield potential are likely to have a more severe NEB (Veerkamp, 1998) and to yield more additional milk when the dry period is shortened. Therefore, one might shorten or omit the dry period for higher yielding cows only.

Breed, genotype and body condition score

A limited number of studies addressed the impact of dry period length in cows of different breeds, genotypes and body condition.

So far, cow breed does not seem to affect the impact of a short or no dry period on milk yield or metabolism. The reported effects of omission of the dry period in Brown Swiss (Schlamberger *et al.*, 2010) and shortening the dry period in Swedish Red (Andrée O'Hara *et al.*, 2018) on metabolic status and milk yield were similar to results in Holstein cows.

In contrast, genotype was shown to affect the impact of dry period length. Specifically, cows of the diacylglycerol acyltransferase 1 (**DGAT1**) AK genotype had smaller milk yield losses and a reduced improvement of the energy balance after omission of the dry period, compared with cows of the DGAT1 AA and KK genotypes (Van Knegsel *et al.*, 2013b). The enzyme acyl-CoA DGAT1 has a role in triglyceride synthesis, and the DGAT1 K232A polymorphism is known to affect milk yield, milk fat percentage and milk energy output of dairy cows (Bovenhuis *et al.*, 2015).

Moreover, the earlier discussed effects of a short or no dry period on milk yield and energy balance were not present in

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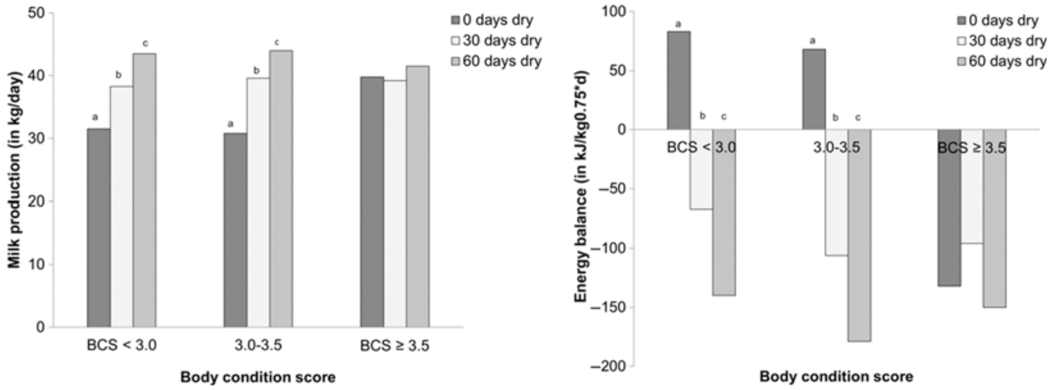

Figure 2 Milk yield (kg/day; left panel) and energy balance (kJ/(kg$^{0.75}$*day) in the first 14 weeks *postpartum* for cows after a dry period of 0, 30 or 60 days, in different *prepartum* BCS classes. [a,b,c]Different letters indicate differences between dry period lengths within BCS class (P<0.05). Number of cows for 0, 30 or 60 days dry was: for BCS <3.0: 20, 23 and 21; for BCS 3.0–3.5: 20, 16 and 24; for BCS ≥3.5: 16, 16 and 11. BCS = body condition score.

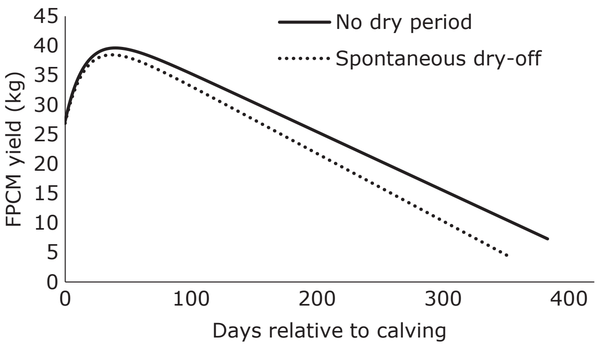

Figure 3 Estimated lactation curves after omission of the previous dry period for cows that achieved no dry period before their next calving and cows that spontaneously died off (i.e. a milk yield of < 4 kg/d at least 30 days before their next expecting calving; $n = 19$). Based on Chen (2016). FPCM = fat-and-protein-corrected milk.

cows with a high body condition *prepartum* (Figure 2) (Van Knegsel and Kemp, 2016). The lack of effect of dry period length on energy balance in fat cows was completely due to a lack of effect of dry period length on milk yield.

Consecutive lactations

Most research on short and no dry periods focussed on the short- or long-term effects in the next lactation. Some studies focussed on the impact of short or no dry periods over multiple lactations. Two decades ago, only 2 out of 21 cows achieved dry period omission for two consecutive lactations, whereas the rest of the cows spontaneously dried off due to a low milk yield (Rémond *et al.*, 1997). Recently, cows were subjected to a standard, short or no dry periods for two consecutive lactations (Van Knegsel *et al.*, 2014; Chen *et al.*, 2016a and 2016b). Shortening the dry period resulted in similar milk losses compared with a standard dry period in both lactations (Van Knegsel *et al.*, 2014; Chen *et al.*, 2016b). Applying a short dry period of 30 days therefore seemed suitable for multiple lactations in most dairy cows (Chen *et al.*, 2016b). Omitting the dry period for a second time, however, reduced milk losses in early lactation relative to cows with a standard dry period (Chen *et al.*, 2016b), compared with the first time (Van Knegsel *et al.*, 2014). Also in this experiment, almost half of the cows in the no dry period group dried off spontaneously before their dry period could be omitted a second time. In an observational study on commercial dairy farms, cows following the second subsequent omission of the dry period also had a higher milk yield and consequently a reduction in milk losses relative to cows with a standard dry period, compared with the first omission of the dry period (Kok *et al.*, 2017b). Farmers that shortened or omitted the dry period reported, however, that few cows dry themselves off (Kok *et al.*, 2016). These farmers generally had relatively short calving intervals (about 1 year for cows with no dry period) and may have selectively culled cows with a low milk yield, which could lower the risk of drying off spontaneously. Also in this observational study, cows with a short dry period had similar milk yields after the first or a subsequent shortening of the dry period (Kok *et al.*, 2017b), which is in agreement with earlier animal experiment (Van Knegsel *et al.*, 2014; Chen *et al.*, 2016b). Overall, results of a limited number of studies suggest that omission of the dry period for multiple lactations is easily achieved in cows with a greater milk yield and lactation persistency, and may be hindered by reproductive problems and prolonged calving intervals.

Smaller milk losses after the second than after the first omission of the dry period could be due to a selection effect, because only 20 out of 39 cows assigned to no dry period treatment achieved over two consecutive lactations (Chen *et al.*, 2016b). Indeed, the cows that dried off spontaneously were characterised by a lower milk yield and a lower lactation persistency, resulting in a higher milk yield and persistency in the remaining group (Figure 3; Chen, 2016). Moreover, calving interval tended to be longer in cows which dried off spontaneously, compared with cows which were continuously milked for a second time (410 *v.* 383 days; $P = 0.11$) (Chen, 2016). Another explanation for smaller milk losses after the second omission of the dry period could be increased regeneration of udder cells during the first lactation. No dry period resulted in a more positive energy balance and increased plasma IGF-1 concentration in the subsequent lactation, which could enhance mammary cell renewal and

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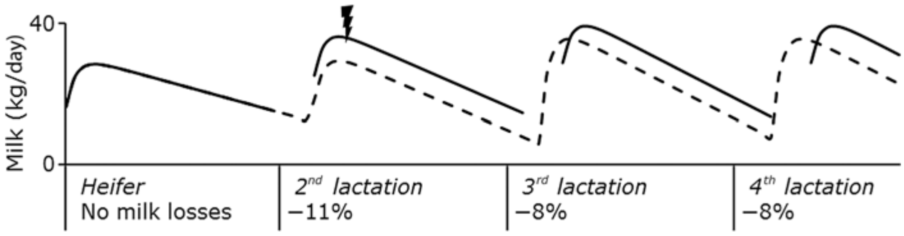

Figure 4 Schematic lactation of a cow for four calendar years from first calving. Differences in effective lactation yield* between a cow with a conventional dry period (solid line) and a cow with no dry period (dashed line) are given below the horizontal axis. Culling early in lactation (⚡) has less impact in the case of no dry period, because part of the milk is produced before calving. *: effective lactation yield is calculated as average daily yield from 60 days before calving to 60 days before next calving (Kok *et al.*, 2016). Adapted from Kok (2018).

survival (Capuco *et al.*, 2001) during this lactation, which could clarify the increased milk yield in the second subsequent lactation after omission of the dry period. Moreover, the increase in milk yield could be related with the increased age of the cows, because milk yield losses due to no dry period are greater for parity 2 cows than for older cows.

So, in conclusion, customising dry period length based on individual cow's characteristics can be hypothesised to be a valuable approach to benefit from the advantages of a short or no dry period (improved energy balance and metabolic status) but limit the effects of the disadvantages (milk yield losses and potential fattening). Apart from the parity effects, which were reported in several studies, knowledge on the relation between individual cow's characteristics, like breed, genotype, body condition and milk yield level, is limited and should be confirmed to be able to optimise dry period management at cow level. Last but not least, when customising the dry period, not only the length of the dry period should be considered but also the use of dry cow antibiotics, because a decision to omit or shorten the dry period would also imply limitations to treat cows with subclinical mastitis (Van Hoeij *et al.*, 2016).

Effect of short and no dry periods at herd level

For the application of short and no dry periods in practice, the overall impact on milk yield is of great importance. The meta-analysis in 2013 estimated that milk yield in the lactation following a short dry period was reduced by 4.5%, and following no dry period by 19% (Van Knegsel *et al.*, 2013a). However, even when standardised to the 305-day yield, *postpartum* milk yield does not provide a good estimate of total milk yield when cows differ in lactation length and dry period length, because part of these reductions in milk yield would be compensated by additional milk yield before calving and a shorter calving interval (Kok *et al.*, 2016).

At herd level, a decrease in milk yield of 3.5% was estimated in case of omitting the dry period and of 3% in case of shortening the dry period (Kok *et al.*, 2017c). This reduction in milk yield is smaller than the previously mentioned reductions at lactation level. The relatively small impact on estimated milk yield at farm level was due to three factors: (1) that heifers have no effect of dry period length on milk yield but an increased number of lactating days, (2) that cows with short or no dry periods were assumed (based on farmers data) to have an increased fertility which translated in shorter calving intervals and (3) that part of the milk yield per effective lactation was realised already before calving, which reduced the negative impact of culling early in lactation on milk yield (Figure 4; Kok *et al.*, 2017c).

Customising dry period length in practice

Omitting the dry period results in the greatest improvement of the metabolic status in early lactation but also in the largest reduction in milk yield. Reductions in milk yield could be limited, while improving the metabolism of the cows most at risk of a severe NEB, when short or no dry periods are applied for older or high-yielding cows only (i.e. a customised dry period length). A customised dry period length likely requires more planning and labour than no dry period or one dry period length for all cows. Therefore, the success of a customised dry period will depend on the attitude of the farmer and the possibilities to, for example, automatically adjust the feeding and milking regimes of individual cows.

The reduction in revenues from milk might be financially compensated by a reduction in disease costs: for example, no ketosis occurred in experimental studies where the dry period was omitted, whereas the incidence was 4.8% to 25% in the respective control groups with a standard dry period (Rastani *et al.*, 2005; Schlamberger *et al.*, 2010; Köpf *et al.*, 2014). Other aspects to consider are that: (1) no dry period reduces the concentration of antibodies in colostrum, which did not affect growth and development of calves but warranted a sufficient uptake of colostrum (Mayasari *et al.*, 2015); (2) no dry period can affect milk processing quality via affecting casein composition both in late and early lactation (De Vries *et al.*, 2015); and (3) reported effects of dry period length on SCC and mastitis incidence are ambiguous, but cows with a high SCC benefit from a dry period when they can be treated with dry cow antibiotics (Van Hoeij *et al.*, 2016).

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Declaration of interest

None.

Ethics statement

None.

Software and data repository resources

None.

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