Why Reevaluate Dry Period Length?*

R. R. Grummer and R. R. Rastani

Department of Dairy Science
University of Wisconsin, Madison 53706

ABSTRACT

Possible advantages of reducing length of dry period include increased income from milk production, simplified dry cow management, decreased metabolic disorders, and alleviation of overcrowded dry cow facilities. There is abundant data to support a 60-d dry period to maximize milk yield the next lactation. The great majority of data is from studies using farm records (e.g., DHI data). In these data sets, cows with less than 6- to 8-wk dry periods probably were not intended to have short dry periods and consequently were not managed for short dry periods. Additionally, recommendations from observational data may be biased due to interactions, e.g., between milk yield and length of dry period. Some experiments specifically designed to compare 30- and 60-d dry periods indicate that shorter dry periods are possible without sacrificing milk production the next lactation. There is a paucity of data to determine the effects of shortening the dry period on milk composition, metabolic disorders, and reproductive performance. The limited amount of information that is available indicates that shortening the dry period will probably not have negative effects on these parameters and may have slight beneficial effects. In some cases, the beneficial effects may have resulted, in part, due to negative effects on milk production. Cows with longer calving intervals and older cows may be more likely to avoid negative effects of shortening dry periods on subsequent milk yield. Shortening the dry period by initiating milking after a dry period but prior to parturition does not increase milk yield or improve animal health sufficiently to warrant consideration. Several studies indicated complete elimination of the dry period results in a 20 to 25% decrease in milk yield the following lactation. However, these studies have utilized low cow numbers and cows with extremely low milk production. As milk yield and persistency of lactation increases, either through genetic

selection or administration of exogenous agents such as bST, the likelihood of successfully shortening or eliminating the dry period should increase. Future studies to increase our knowledge of factors affecting mammary epithelial cell proliferation and apoptosis should yield strategies to reduce the length or completely eliminate the dry period.

(Key words: dry period length, milk yield, animal health, reproduction)

Abbreviation key: DP = dry period, EB = energy balance.

INTRODUCTION

Numerous factors influence lifetime milk production of dairy cows. Age at first calving, days open (calving interval), days dry, and herd-life are important parameters that impact the amount of milk produced in the lifetime of a cow. Herd-life varies considerably among cows and is usually determined by milk yield, health, or reproductive status of the cow. Conversely, age at first calving, days open, and days dry are management decisions that tend to be fixed for a given herd and are fairly consistent across herds. Recommendations for these parameters are usually based on extensive research and are thought to be applicable to most herds. However, the magnitude of importance of these recommendations dictate that they occasionally be reevaluated as advancements in genetics, technologies, and management practices take place.

The focus of this paper is to evaluate whether the recommendation for a 60-d dry period (**DP**) should be altered. Certainly, the optimal DP has been debated for a long time. Dickenson (1805, as cited by Arnold et al., 1936) indicated "There was a difference among English farmers...some favoring a two-month DP, while others believed periods as short as ten days sufficient." What criteria should be considered when determining the optimal DP length? Reducing the dry period from 60 d has been considered beneficial if additional milk yield from extending the lactation offsets or exceeds any loss in milk yield the following lactation. Milk components must also be considered when determining the economic feasibility of shortening the DP, especially for countries on a quota system (Remond et al., 1992, 1997). Effects of

Received July 10, 2003.

Accepted October 21, 2003.

Corresponding author: R. R. Grummer; e-mail: rgrummer@facstaff.wisc.edu.

*Presented at a symposium titled "Lactation Biology: Altering the Lactation Cycle in Dairy Cows" at the ADSA-ASAS Joint Annual Meeting, June 2003, Phoenix, AZ.

DP length or continuous milking on colostrum quality, metabolic and infectious diseases, and reproductive performance of cows should also be considered when selecting an optimal DP length. Impact of DP length on other aspects of management may also have economic ramifications. For example, elimination of a far-off DP may alleviate overcrowding of dry cow facilities or eliminate the need to house dry cows at locations remote to lactating cow facilities.

Traditionally, recommendations for DP length have been applied to the whole herd. However, optimal DP length may vary depending on parity, calving interval, level of milk production, etc. With increasing farm size and greater flexibility in grouping cows, it is realistic to have multiple pens of dry cows dedicated to different DP lengths if the aforementioned interactions are important. Most of the studies that led to the recommendation of a 60-d DP were completed before 1990. Today, technologies such as bST and management practices such increased milking frequency are commonplace. Perhaps the optimal DP length is different for cows under these management conditions compared with those implemented before 1990. Timed AI allows for greater accuracy in prediction of calving dates, which lessens the need to increase days dry to account for unexpected early calvings. Additionally, increasing knowledge of mammary biology may yield new strategies for reducing the length of DP.

The basis for current recommendations for DP length will be reviewed. An attempt will be made to determine whether factors other than milk yield should be examined when determining optimal DP length. We will examine the literature to determine whether a "one size fits all" recommendation is appropriate or whether there are opportunities to modify the DP length depending on characteristics of the animal. Finally, we will evaluate whether there are opportunities for reducing DP length in future years.

EFFECTS OF DRY PERIOD LENGTH ON MILK YIELD

Bachman and Schairer (2003) recently published an extensive review of the literature for effects of dry period length on milk yield; therefore, this section will be a synopsis of that literature. There is an extensive list of reports that indicate reducing the DP below 50 to 60 d results in a reduction in milk yield the following lactation (Sanders, 1928; Arnold et al., 1936; Dickerson and Chapman, 1939; Klein and Woodward, 1943; Swanson, 1965; Smith et al., 1967; Wilton et al., 1967; Schaefer and Henderson, 1972; Coppock et al., 1974; Gill and Allaire, 1976; Pandey et al., 1978; Dias and Allaire, 1982; Keown and Evert, 1986; Funk et al., 1987; Sorensen and Enevoldsen, 1991; Remond et al., 1992; Makzuka and McDaniel,

1996; Remond et al., 1997). Many of these studies were a retrospective analysis of farm records (Sanders, 1928; Arnold et al., 1936; Dickerson and Chapman, 1939; Klein and Woodward, 1943; Wilton et al., 1967; Schaefer and Henderson, 1972; Gill and Allaire, 1976; Pandey et al., 1978; Dias and Allaire, 1982; Keown and Evert, 1986; Funk et al., 1987; Makzuka and McDaniel, 1996). Use of data from these studies has been criticized (Bachman and Schairer, 2003) because cows with short DP typically calved early and were not intended to have a short DP (e.g., cows with twins, cows that spontaneously aborted, cows with incorrect breeding dates). Consequently, these cows were not managed for a short DP. Additionally, cows were not assigned randomly to "treatment" and, therefore, biases are likely to result. Dry period length can be confounded with other factors that influence subsequent milk yield, including age, parity, calving interval, and milk yield during the previous lactation. More recent retrospective analyses (Funk et al., 1987; Makzuka and McDaniel, 1996) facilitated by enhanced computational methods, have accounted for many of these biases and yielded similar conclusions regarding DP length.

An alternative to retrospective analysis of farm records for evaluating the effects of DP length are designed experiments (Swanson, 1965; Smith et al., 1967; Coppock et al., 1974; Lotan and Alder, 1976; Remond et al., 1992; Remond et al., 1997; Bachman, 2002; Gulay et al., 2003a, 2003b; Rastani et al., 2003), i.e., investigators randomly assign cows or quarters within a gland to treatments of different DP length. Likelihood of bias and misinterpretation of results is reduced; however, these studies usually employ limited cow numbers, and the chances of committing a Type II error may be high when declaring that shortening the DP caused no significant difference in subsequent milk yield. The first two studies (Swanson, 1965; Smith et al., 1967) that employed designed treatments to examine effects of eliminating the DP used interesting models for reducing variation: identical twins and treatment of quarters within a mammary gland (the half-udder model). Both studies indicated significant production losses in glands or quarters that were continuously milked. The validity of the half-udder model has been questioned (Fowler et al., 1991; Capuco and Akers, 1999). The assumption is that any difference in milk yield in the subsequent lactation between glands is due to decreased milk yield by glands that were continuously milked. It is possible that differences may be due, wholly or in part, to increased milk yield by glands that were not continuously milked. When one gland is no longer milked, mammary growth and milk production of the other gland may increase in a compensatory fashion (Hamann and Reichmuth, 1990), and this may enhance milk yield of that gland during the subsequent lactation. Additionally, it is possible that continuous milking may

induce lactation in the non-milked quarters before calving and the lack of removal of milk may have negative effects on the subsequent lactation. Unfortunately, the half-udder model does not allow one to determine whether *total* milk production by the gland was reduced. Addition of a third “treatment” consisting of cows in which all quarters received the control treatment helps interpretation of experiments employing the half-udder model (e.g., Gulay et al., 2003b).

Often missing in reports from designed studies, particularly the older studies, is a description of the management of cows during the treatment period. For example, information on diets and housing is often omitted. When that information is provided, one quickly realizes that length of DP is confounded with diet, housing, or both, and, therefore, the comparisons of DP length would more accurately be described as comparisons of dry cow management strategies.

Regardless of the model (identical twins, half-udder, random assignment of cows to treatment), all studies examining the effects of continuous milking and no DP on cows not treated with bST indicate that a DP is essential to avoid significant reductions in milk production the next lactation (Swanson, 1965; Smith et al., 1967; Remond et al., 1992, 1997; Rastani et al., 2003). The reduction in milk yield was quite consistent among studies, approximately 20 to 25%. Annen et al. (2003) indicated that continuously milked cows that had been treated with 500 mg of bST every 14 d pre- and postpartum produced similar amounts of milk for the first 17 wk postpartum as cows given a standard 60-d dry treatment and treated with bST as per label. These results are detailed in a companion manuscript within this symposium (Annen et al., 2004).

Several designed experiments have examined less drastic reductions in dry period than continuous milking, and results have been variable (Bachman and Schairer, 2003). Coppock et al. (1974) assigned cows on 65 commercial dairy farms (average size 65 cows) to 20-, 30-, 40-, 50-, or 60-d DP for 42 mo. Cows were dried off regardless of treatment when milk production was less than 9 kg/d. Consequently, few cows assigned to the short DP actually “qualified” for their treatment. For cows that adhered to their assigned days dry, they observed a net milk yield loss (additional milk from the previous lactation was considered) of about 5% when DP was reduced below 40 d. Perhaps there was an interaction between genetic ability to produce milk and ability to qualify for their treatment, i.e., a higher proportion of cows in the shorter DP treatments were high-producing cows. Red Danish or Danish Black and White cows ($n = 366$) on commercial farms were assigned to 4, 7, or 10 wk DP (Sorensen and Enevoldsen, 1991). Milk yield for the first 84 d of the subsequent lactation was reduced as DP was

shortened (25.1, 24.5, and 22 kg/d). For the first 70 d, postpartum milk (but not FCM) was significantly reduced in cows assigned to a 56 vs. 28 d DP (42.4 vs. 37.9 kg/d, Rastani et al., 2003). Several studies have reported no significant differences in milk yield when the DP was reduced from 60 to 30 d (Lotan and Alder, 1976; Bachman 2002; Gulay et al., 2003a). In each of these studies, diet was not kept consistent across treatments between 60 and 30 d prepartum; therefore, length of DP is confounded by diet. However, a recent study suggests that far-off DP diets have little carryover effect on the next lactation (Dann et al., 2003). Gulay et al. (2003b) used the half-udder model and reported lower production (14.2 vs. 18.3 kg/d) through the first 30 DIM of the following lactation from the 2 quarters allowed a 30-d DP compared with the 2 quarters allowed a 70-d DP. Cows in which all quarters were allowed a 70-d DP produced more milk (38.3 kg/d) than total production from cows with half-udders treated differently (32.2 kg/d). These results suggest that the difference in milk production the following lactation between quarters given a 30- vs. 70-d DP was due, at least in part, to impaired production by quarters given a 30-d DP rather than an enhancement of production by quarters given a 70-d DP.

INTERACTIONS BETWEEN DRY PERIOD LENGTH AND ANIMAL CHARACTERISTICS ON MILK YIELD

Milk yield response to shortened DP is variable, suggesting that there may be interactions between animal characteristics or management and length of the DP. While retrospective analysis of farm records has some limitations, one advantage is that large animal numbers are typically involved, which allows examination for interactions. If interactions exist, then cows that are most likely to respond favorably to a shortened DP may be identified. This can be particularly useful information for managers of large farms who can group cows and tailor different management schemes to specific groups.

By comparing second-lactation milk yields to first-lactation milk yields, Dickerson and Chapman (1939) noticed that the advantage of a longer DP was greater for low-producing herds than for high-producing herds. They speculated that low-producing herds were fed a lower plane of nutrition and that a longer “rest period” was needed when cows were underfed. In contrast, higher producing cows, as measured 100 d prior to expected calving, required longer DP to obtain peak milk the subsequent lactation, but the relationship was only evident for cows between their first and second lactations (Dias and Allaire, 1982). There is no evidence of interactions between breed and length of DP (Sorensen and Enevoldsen, 1991; Makuza and McDaniel, 1996); therefore, interactions with milk yield cannot be explained

by breed differences. Others have found no interaction between production level and length of the DP (Sanders, 1928; Sorensen and Enevoldsen, 1991).

Several studies have indicated that reducing the length of the DP to less than 60 d has a more detrimental effect between the first and second lactation than between later lactations (Sanders, 1928; Wilton et al., 1967; Dias and Allaire, 1982). Increasing days dry from 0 to 50 increased milk yield the subsequent lactation by 954 kg in the second lactation and by 354 kg in later lactations (Wilton et al., 1967). Wilton et al. (1967) suggested that a DP was more critical for young animals so that they could grow and develop without the additional stress of lactation. Optimal DP was estimated to be 27 d for cows following the fourth or later lactation and increased to 65 d for cows following the first lactation (Dias and Allaire, 1982), suggesting older cows need less recuperative time or less cell regeneration than younger cows. Annen et al. (2003) indicated that primiparous but not multiparous cows experienced a decrease in milk production for the first 17 wk postpartum following a shortened or no DP. Days dry required for maximum milk yield was decreased when calving interval was increased, and the interaction was stronger as parity increased (Dias and Allaire, 1982). However, other analyses have indicated no interaction between parity and optimal length for the DP (Keown and Everett, 1986; Funk et al., 1987; Sorensen and Enevoldsen, 1991).

EFFECTS OF DRY PERIOD LENGTH ON MILK COMPOSITION

Ultimately, the decision of whether to shorten the DP must be based on economic returns. Therefore, consequences of a shortened DP on milk composition the subsequent lactation must be considered. This may be particularly true for countries in which milk payments are based on a quota system (Remond et al., 1997). Unfortunately, the retrospective analyses of farm records have only considered milk yield. Some designed experiments have included milk composition data. However, there is limited information available on milk composition for samples obtained immediately before or after calving. Additional assessment of colostrum produced by cows experiencing short DP is needed to determine whether it is suitable for feeding the newborn calf.

Employing the half-udder model, Smith et al. (1967) indicated that there was no effect of continuous milking on milk fat content. Data were shown for only 2 of the 5 cows on experiment, but it was for the 2 that had the greatest drop in milk yield due to continuous milking. Remond et al. (1992, 1997) indicated that continuous milking increased milk fat percentage; however, this increase was significant in one experiment (4.34 vs. 3.94)

but not another (4.39 vs. 4.24). Reducing the DP from 8 to 4 wk tended to increase milk fat content in one experiment (4.08 vs. 3.86; Rastani et al., unpublished data) but had no effect in two other experiments (Lotan and Alder, 1976; Gulay et al., 2003a). Milk protein percentage increased during the following lactation in 2 experiments with cows that were continuously milked (Remond et al., 1992, 1997) and in 2 experiments in which the DP was shortened from approximately 8 to 4 wk (Gulay et al., 2003a; Rastani et al., unpublished data). There appears to be an inverse relationship between milk protein percentage and milk yield response when altering DP length. Yield of milk components is usually not reported, so statistical analysis is not available for those measures. However, increases in milk component percentages due to shortening the DP are not sufficient to compensate for the reduction in milk yield; therefore, component yields are decreased (Remond et al., 1997). When shortening the DP results in a decrease in milk yield, the impact is greater on lactose yield than fat or protein yields.

Feeding high quality colostrum is important to minimize early calf mortality. The effect of reducing the DP on colostrum composition has rarely been reported. Early reports (Eckles and Palmer, 1916; Wheelock et al., 1965) indicated that colostrum of cows that were continuously milked was abnormal; however, there were no control cows to make direct comparisons. Eckles and Palmer (1916) suggested that there was little effect of continuous milking on the fat fraction but a noticeable reduction in the concentration of heat-coagulable proteins (fraction containing immunoglobulins). Based on colostrum composition from 4 cows with DP ranging from 19 to 83 d, they concluded heat-coagulable protein content of colostrum was more dramatically reduced as DP length was reduced. More recent data of Remond et al. (1992) clearly shows that true protein content of milk from continuously milked cows increased during the final milkings prior to calving. Colostrum of cows that were continuously milked or given a 60-d DP contained 11.8 or 15.2% true protein, but considerable animal variation prevented these values from being significantly different. Calculated yield of true protein at the first milking was 447 and 879 g. This indicates that immunoglobulin production was probably lower in continuously milked cows. By the second milking, true protein content of milk was similar between groups (8.40 vs. 8.45%). Immunoglobulin concentration increased in milk immediately before calving in a commercial dairy herd that continuously milked cows (Remond and Bonnefoy, 1992). Rastani et al. (unpublished data) observed IgG concentrations of 4.98, 7.79, and 6.99 g/dL in colostrum of cows experiencing 0-, 28-, or 56-d DP; the difference between 0- and 28-d treatments was significant. These data suggest that

colostrum quality will be adversely affected in cows that are prevented from having a DP but not if DP was 28 d.

EFFECTS OF DRY PERIOD LENGTH ON ANIMAL HEALTH

Lactating cows are most susceptible to metabolic and infectious diseases during the first few weeks postcalving. During this period they are typically in negative energy balance (**EB**) because they cannot consume sufficient energy to meet requirements for maintenance and lactation. Negative EB can commence prepartum if depression in DMI is sufficient. Two consequences of negative EB are immune suppression (Burton et al., 2001) and mobilization of fatty acids from adipose tissue (Bertics et al., 1992). Excessive mobilization results in lipid-related metabolic disorders, such as hepatic lipidosis and ketosis, and elevated NEFA in blood prepartum has been associated with other complications such as retained placenta and displaced abomasum (Dyke, 1995; Cameron et al., 1998). During the periparturient period, cows undergo dramatic physiological changes associated with parturition and the initiation of lactation and experience numerous changes in feeding and management.

Shortening or eliminating the DP may be a management tool to lessen problems associated with the periparturient period. For example, the standard recommendation for the DP includes 3 diet changes, including 2 diet changes within 3 wk, one when the cow enters the "close-up" pen and another 3 wk later when lactation commences. Usually these diet changes are associated with facility and grouping changes or both. These management changes may predispose cows to a reduction in DMI (Grant and Albright, 2001) and initiation of negative EB. Shortening or eliminating the DP could minimize or eliminate such changes. For example, feeding a high-energy diet for the entire gestation-lactation cycle is usually not practical when a 60-d dry period is employed because cows are likely to become over-conditioned. However, if the DP is shortened sufficiently, continuous feeding of high-energy diets throughout the entire gestation-lactation cycle may be possible without the risk of over-conditioning the cow. Additionally, eliminating the DP may reduce some of the physiological changes that are associated with the initiation of lactation. Unfortunately, little information is available from the literature to describe the physiological changes cows undergo when DP are shortened or eliminated.

Metabolic disorders have been associated with BW or BCS loss. As might be expected, in experiments in which eliminating (Swanson, 1965; Remond et al., 1997) or shortening (Farries and Hoheisel, 1989) the DP reduced milk production in the subsequent lactation, BW losses were concurrently reduced. Eliminating (Swanson,

1965) or shortening (Gulay et al., 2003a) the DP did not have any effect on BW loss prior to calving. Body condition score loss was approximately one-quarter point greater after calving in cows given a 60-d DP relative to those given a 30-d DP; however, BW, DMI, and FCM yield was not different (Gulay et al., 2003a). Cows that had a 60-d DP consumed less DM as a percentage of BW (Gulay et al., 2003a). Calf BW was not affected by shortening or eliminating the DP (Farries and Hoheisel, 1989; Gulay et al., 2003a; Rastani et al., unpublished data). Level of milk production in late gestation was probably sufficiently low (e.g., <30 kg/d) that providing adequate nutrients for maintenance, milk production, and fetal growth was not difficult to achieve. Poor nutritional status is not a likely explanation for low milk production following a shortened or eliminated DP.

Plasma concentration of glucose was greater (67.7 vs. 58.2 mg/dL) and concentrations of BHBA and NEFA were lower (0.58 vs. 1.01 mmol/L and 0.29 vs. 0.75 mmol/L) at 10 d postpartum in cows continuously milked compared with those allowed a 60-d DP (Remond et al., 1997). The more favorable metabolic profile may have resulted from lower milk yield and similar DMI for cows not given a DP. Lotan and Alder (1976) noted less fluctuation in plasma glucose and NEFA during the periparturient period in cows that received a 30- vs. 60-d DP. Additionally, cows receiving the short DP had lower plasma NEFA and greater blood glucose concentrations despite there being no difference in milk production between treatment groups. Dry matter intake of the cows was not reported. Reducing the DP from 28 to 0 d lowered liver triglyceride concentrations (8.8 vs. 5.5%, DM basis) at calving and NEFA concentrations postcalving (394 vs. 235 μ Eq/L), but these changes were probably related to greater prepartum DMI (18.1 vs. 16.8 kg/d) and lower postpartum FCM yield (36.1 vs. 41.5 kg/d; Rastani et al., 2003).

Incidence of ketosis, milk fever, and retained placenta were not different when cows on commercial dairies were assigned to 20-, 30-, 40-, 50-, or 60-d DP (Coppock et al., 1974). However, the data are difficult to interpret because observations were recorded according to what treatment a cow was assigned rather than to actual days dry; only a small percentage of the cows that were assigned to short DP actually had short DP. When 366 cows in 8 commercial dairy herds were assigned to 4-, 7-, and 10-wk DP, there was little evidence that length of DP had any effect on risk of cows encountering a clinical disorder that would be expected to negatively affect milk yield (Enevoldsen and Sorensen, 1992). Davico et al. (1992) hypothesized that continuous milking may protect cows against hypocalcemia. Cows received a 60-d DP or were continuously milked until milk yield was less than 2 kg/d. Actual days dry were 58 and 4 for

the two groups. There were no treatment effects prior to calving, but at 12 h after calving, plasma calcium and phosphorous concentrations were significantly greater in the continuously milked group (10.1 and 6.7 mg/dL) than the control group (8.5 and 5.2 mg/dL). No treatment effects were observed at the next sampling time, 10 d postpartum.

A survey of drying-off practices on 36 commercial dairies in New York indicated that cows with ≤ 30 d had more infections respond to dry cow therapy and had fewer new infections during the DP (Natzke et al., 1975). A study examining dry cow therapy strategies on 232 cows indicated that new infection rate during the DP was lower in cows with ≤ 60 -d dry (Rindsig et al., 1978). Other studies suggest that there is little effect of DP length on incidence of clinical mastitis (Coppock et al., 1974; Enevoldsen and Sorensen, 1992).

To our knowledge, there are no reports on the health of calves born to cows experiencing different DP lengths. Three studies have indicated no effect of DP length on calf BW at birth (Farries and Hoheisel, 1989; Gulay et al., 2003a; Rastani et al., unpublished data). This suggests that the cow does not divert nutrients away from the fetus to support milk yield if lactation continues into late gestation. Assuming the calf receives good quality colostrum, there is no reason to expect greater health problems in calves born to cows with shortened DP.

EFFECTS OF DRY PERIOD LENGTH ON REPRODUCTION

Data regarding the effects of DP length on subsequent reproductive effects are lacking. Lotan and Adler (1976) reported numerically similar days open, number of inseminations, and pregnancy rates for cows with DP of 30 and 60 d, with similar milk production. However, there were only nine animals per treatment. Gumen et al. (2003) reported the time from calving to first postpartum ovulation was 14.5, 21.5, and 28.9 d for cows given a 0, 28, or 56 d DP. Differences between treatments in this trial may have been related to EB; postpartum EB and BW loss was inversely related to duration of the DP (Rastani et al., 2003, unpublished data). Time to first postpartum ovulation has been related to EB and time to positive EB (Butler and Smith, 1989; Lucy et al., 1991; Beam and Butler, 1998). Early resumption of estrous cycles may be important because there is some evidence that pregnancy rate (services per pregnancy) is decreased as the number of heats experienced by a cow prior to 60 d postpartum is increased (Thatcher and Wilcox, 1973). Others (Swansen et al., 1965; Farries and Hoheisel, 1989; Remond et al., 1997; Gulay et al., 2003a) have noted less BW or BCS loss when reducing or elimi-

nating the dry period; therefore, it is unlikely that doing so will have a negative impact on reproduction.

SHORTENING THE DRY PERIOD BY INITIATING PREPARTUM MILKING

A second option for shortening the DP is to dry the cow off at 60 d prepartum but start milking the cow prior to calving. Hypotheses forwarded to justify prepartum milking include additional milk production pre- and postpartum, higher DMI and lower liver triglyceride at calving (Grummer et al., 2000), lower incidence of prepartum IMI and hypocalcemia (Greene et al., 1988), and reduced udder edema in heifers (Zileger et al., 1973).

Akers et al. (1977) observed histological changes indicative of secretory epithelial cell development prior to parturition in cows that were milked prepartum. Milk yield of cows milked prepartum is highly variable. A large field study (7 herds, 80 cows/herd; Greene et al., 1988) indicated that 36, 33, and 31% of cows milked starting at 14 d prior to calving produced less than 4.5 kg, 4.5 to 9 kg, and greater than 9 kg of milk on the day before calving.

Immunoglobulin production during prepartum milking is fairly constant among cows (Zeliger et al., 1973); therefore, as milk yield prepartum increases, immunoglobulin concentration of milk at parturition is decreased (Rowland et al., 1953; Guy et al., 1994). Although there are reports of cows milked prepartum peaking earlier and producing more milk in early lactation (Gaunya and Eaton, 1953; Zeliger et al., 1973) milk yield for the entire lactation does not appear to be increased for primi- or multiparous cows (Greene et al., 1988; Bowers et al., 2002).

In most studies, prepartum milking was initiated 7 to 14 d prior to expected calving. Experiments have not been designed to determine whether initiating prepartum milking sooner (e.g., 28 d prior to expected calving) would increase the likelihood of harvesting significant amounts of milk prepartum or increasing milk yield postpartum. Prepartum milk yield was positively associated with postpartum milk yield in one study with limited cow numbers (Akers et al., 1977). However, other studies utilizing greater cow numbers indicated no relationship between days milked prepartum and prepartum or postpartum milk yield (Pennington and Malven, 1985; Greene et al., 1988). Most cows do not initiate copious milk secretion until 2 to 3 d prepartum (Zeliger et al., 1973; Pennington and Malven, 1985; Greene et al., 1988; Grummer et al., 2000). Therefore, it seems unlikely that initiating milking earlier than 14 d prepartum would have more beneficial results. The exception may be if prepartum milking was initiated prior to complete involution of the mammary gland so that some capacity of

the gland to produce milk was rescued and retained (Wheelock et al., 1967). In all likelihood, that would mean premature milking would have to begin before 35 d prior to expected calving (Capuco et al., 1997). Although some of the proposed benefits of prepartum milking such as reduced hypocalcemia, udder edema, and mastitis have been observed in some studies (Zileger et al., 1973; Greene et al., 1988; Bowers et al., 2002), it is unlikely that they would outweigh the drawbacks of little additional milk yield, lower quality colostrum, and increased labor costs.

FUTURE PROSPECTS FOR SHORTENING THE DRY PERIOD

Recently, knowledge of mammary biology in the bovine has increased substantially, and this should facilitate new strategies for successful shortening or elimination of the DP. Traditionally, the DP was defined as having three functional states: active involution characterized by regression of secretory tissue, steady-state involution (the "rest" period), and lactogenesis when secretory tissue regains its synthetic capacity (Smith and Todhunter, 1982). Recent evidence challenges this notion. Capuco et al. (1997) indicated that loss of mammary cells is insignificant during the DP and, therefore, the terms involution and regression may be inappropriate. They demonstrated that mammary growth commenced 25 d into the DP; therefore, there really is no steady state or rest phase. By comparing cows that were continuously milked with those that were given a standard 60-d DP, they concluded that the importance of the DP was to permit repair or replacement of damaged, lost, or senescent epithelial cells and to increase the percentage of epithelial cells in the mammary gland prior to the next lactation. This began at 35 d prepartum in cows provided a 60-d DP. It is not known whether this same timeline would apply to cows with shorter DP. Nevertheless, this study indicates that strategies to enhance epithelial cell proliferation could be applied during the final 35 d of gestation to allow for continual milking and successful elimination of the DP. Potential strategies include bST treatment (Annen et al., 2003, 2004) or increasing milking frequency (Wilde et al., 1987).

Milk yield is a function of the number of secretory cells and the activity of those cells. Cell numbers reflect a balance between cell proliferation and apoptosis (programmed cell death). In nonpregnant cows, the decline in milk production as lactation progresses is due to changes in cell number rather than to changes in cell activity (Capuco et al., 2001). If cows are pregnant, the decline in production may also be related to decreased secretory activity (Capuco et al., 2001). Any manipulation of the cow that results in increased in cell prolifera-

tion or decreased apoptosis will improve the persistency of the lactation curve (Stelwagen, 2001). If lactation curves were flat (100% persistent) the need for a DP might be eliminated. The number of calvings required of each cow would be reduced, as would the number of periparturient disorders per cow.

Tremendous advances have been made in understanding the regulation of apoptosis, and this knowledge may allow for the manipulation of persistency. Not surprisingly, many of the factors known to promote cell proliferation also inhibit apoptosis. In an excellent review, Stefanon et al. (2002) discussed factors affecting apoptosis and lactation persistency in dairy animals. Factors likely to be important include nutrition, frequency of milking, and galactopoietic and reproductive hormones. Preliminary evidence suggests that level of energy supplementation may influence persistency, even during the declining phase of lactation when cows are in positive EB (Vasquez-Anon et al., 1997; Knight and Sorensen, 2000). Oxidative stress may promote apoptosis, indicating a possible role for dietary antioxidants in maintenance of lactation (Stefanon et al., 2002). Increased milking frequency increased mammary cell proliferation and decreased apoptosis in goats (Quarrie et al., 1994; Li et al., 1999). As milk accumulates between milkings, a protein referred to as feedback inhibitor of lactation accumulates as well. This protein may be important in regulation of mammary cell numbers, perhaps through apoptosis (Stefanon et al., 2002). Dahl (2003) has suggested that increases in circulating prolactin resulting from frequent milking may play a role in proliferation of secretory cells. In addition to enhancing cell proliferation, bST may be anti-apoptotic, and the effects are likely mediated via IGF-1 (Capuco et al., 2001; Stefanon et al., 2002). Prolactin probably acts in concert with bST to influence apoptosis, possibly through modification of IGF-1 via IGF binding proteins (Stefanon et al., 2002). Progesterone has been shown to inhibit apoptosis in rodents during lactation and during involution (Feng et al., 1995; Berg et al., 2002). There may be a link between declining progesterone concentrations and milk production during late pregnancy.

SUMMARY AND CONCLUSIONS

Ultimately, the decision to shorten or eliminate the DP becomes a question of economics. Profitability of decreasing days dry will depend on milk yield and composition during the extra days of milking and the subsequent lactation, colostrum quality and calf survival, incidence of metabolic disorders and disease, reproductive performance, herd level effects, and management factors such as labor and housing costs. There is a growing body of literature on the effect of DP length on milk yield, but

information on other affected parameters is limited or nonexistent. Future studies must be conducted that are more comprehensive in describing the effects of reducing DP length.

Relative to milk yield, there is an abundance of literature that suggests cows will milk 20 to 25% less the following lactation when continuously milked. Lower milk yields are associated with higher concentrations of milk components and more favorable which is likely to result in healthier cows with improved reproductive performance. This emphasizes that decision making should not be based on milk yield response alone. Most retrospective analysis of farm records indicates that subsequent milk yield is compromised when the DP is reduced below 50 d, while others indicate below 40 d. In contrast, some, but not all studies specifically designed to evaluate different dry period lengths indicate that a 30-d dry period may be sufficient. Identification of factors that dictate the likelihood of success when reducing the dry period to 30 d must be an active area of future research. Studies must be conducted using large numbers of animals on commercial dairy farms to verify existing results and identify factors that interact with length to influence animal health and performance. However, basic research must also take place to investigate factors that affect mammary cell proliferation and apoptosis so that future strategies can be developed for further reducing or eliminating the dry period.

REFERENCES

- Akers, R. M., C. W. Heald, T. L. Bibb, and M. L. McGilliard. 1977. Effect of prepartum milk removal on quantitative morphology of bovine lactogenesis. *J. Dairy Sci.* 60:1273–1282.
- Annen, E. L., M. A. McGuire, J. L. Vicini, and R. J. Collier. 2003. Effect of Posilac (bST) and dry period management strategy on milk yield. *J. Dairy Sci.* 86(Suppl. 1):154. (Abstr.)
- Annen, E. L. et al., 2004. Title unknown. *J. Dairy Sci.*
- Arnold, P., T. Dix, and R. B. Becker. 1936. Influence of preceding dry period and of mineral supplement on lactation. *J. Dairy Sci.* 19:257–266.
- Bachman, K. C. 2002. Milk production of dairy cows treated with estrogen at the onset of a short dry period. *J. Dairy Sci.* 85:797–803.
- Bachman, K. C., and M. L. Schairer. 2003. Bovine dry period length studies: A review. *J. Dairy Sci.* 86:3027–3037.
- Beam, S. W., and W. R. Butler. 1998. Energy balance, metabolic hormones, and early postpartum follicular development in dairy cows fed prilled lipid. *J. Dairy Sci.* 81:121–131.
- Berg, M. N., A. M. Dharmarajan, and B. J. Waddell. 2002. Glucocorticoids and progesterone prevent apoptosis in lactating rat mammary gland. *Endocrinology* 143:222–227.
- Bertics, S. J., R. R. Grummer, C. Cadorniga-Valino, D. W. LaCount, and E. E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early postpartum lactation. *J. Dairy Sci.* 75:1914–1922.
- Bowers, S., S. Gandy, K. Graves, S. Eicher, K. Scott, M. Schutz, and S. Willard. 2002. The effects of prepartum milking on postpartum production performance in dairy heifers. *J. Dairy Sci.* 85(Suppl. 1):44. (Abstr.)
- Burton, J. L., S. A. Madsen, J. Yao, S. S. Sipkowsky, and P. M. Cousens. 2001. An immunogenetics approach to understanding immunosuppression and mastitis susceptibility in dairy cows. *Acta Vet. Scand.* 42:407–424.
- Butler, W. R., and R. D. Smith. 1989. Interrelationships between energy balance and postpartum reproductive function in dairy cattle. *J. Dairy Sci.* 72:767–783.
- Cameron, R. E., P. B. Dyke, T. H. Herdt, J. B. Kaneene, R. Miller, H. F. Buckholz, J. S. Liesman, M. J. Vandehaar, and R. S. Emery. 1998. Dry cow diet, management, and energy balance as risk factors for displaced abomasum in high producing dairy herds. *J. Dairy Sci.* 81:132–139.
- Capuco, A., and R. M. Akers. 1999. Mammary involution in dairy animals. *J. Mammary Gland Biol. Neoplasia* 4:137–144.
- Capuco, A. V., R. M. Akers, and J. J. Smith. 1997. Mammary growth in Holstein cows during the DP: Quantification of nucleic acids and histology. *J. Dairy Sci.* 80:477–487.
- Capuco, A. V., D. L. Wood, R. Baldwin, K. Mcleod, and M. J. Paape. 2001. Mammary cell number, proliferation, and apoptosis during a bovine lactation: Relation to milk production and effect of bST. *J. Dairy Sci.* 84:2177–2187.
- Coppock, C. E., R. W. Everett, R. P. Natzke, and H. R. Ainslie. 1974. Effect of dry period length on Holstein milk production and selected disorders at parturition. *J. Dairy Sci.* 57:712.
- Dahl, G. 2003. Milking Frequency Effects in Early Lactation. Proc. 2003 Annual Update Meeting for Dairy Health Management Certificate Program. Ontario Veterinary College, University of Guelph, Guelph, Ontario.
- Dann, H. M., N. B. Liherland, J. P. Underwood, M. Bionaz, and J. K. Drackley. 2003. Prepartum nutrient intake has minimal effects on postpartum dry matter intake, serum nonesterified fatty acids, liver lipid and glycogen contents, and milk yield. *J. Dairy Sci.* 86(Suppl. 1):106. (Abstr.)
- Davico, M. J., B. Remond, S. Jabet, and J. P. Barlet. 1992. Plasma osteocalcin concentrations in cows around parturition. The influence of a regular versus a very short dry period. *Reprod. Nutr. Dev.* 32:313–319.
- Dias, F. M., and F. R. Allaire. 1982. Dry period to maximize milk production over two consecutive lactations. *J. Dairy Sci.* 65:136–145.
- Dickerson, G. E., and A. B. Chapman. 1939. The effects of age and dry period on production at different levels of producing ability. Pages 73–76 in the Annual Proceedings of the American Society of Animal Production. [now the American Society of Animal Science, Savoy, IL]
- Dyke, P. B. 1995. The association of prepartum non-esterified fatty acids and body condition with peripartum health problems. M.S. Thesis, Michigan State Univ., East Lansing.
- Eckles, C. H., and L. S. Palmer. 1916. The influence of parturition on the composition and properties of milk and milk fat of the cow. *J. Biol. Chem.* 27:313–326.
- Enevoldsen, C., and J. T. Sorensen. 1992. Effects of dry period length on clinical mastitis and other major clinical health disorders. *J. Dairy Sci.* 75:1007–1014.
- Farries, E., and S. Hoheisel. 1989. The influence of reduced dry period on some performance and metabolism traits in dairy cows. *J. Dairy Sci.* 72(Suppl. 1):565. (Abstr.)
- Feng, Z., A. Marti, B. Jehn, H. J. Altermatt, G. Chicaiza, and R. Jaggi. 1995. Glucocorticoid and progesterone inhibit involution and programmed cell death in the mouse mammary gland. *J. Cell Biol.* 131:1095–1103.
- Fowler, P. A., C. H. Knight, and M. A. Foster. 1991. Omitting the dry period between lactation does not reduce subsequent milk production in goats. *J. Dairy Res.* 58:13–19.
- Funk, D. A., A. E. Freeman, and P. J. Berger. 1987. Effects of previous days open, previous days dry, and present days open on lactation yield. *J. Dairy Sci.* 70:2366–2373.
- Gaunya, W. S., and H. D. Eaton. 1953. Prepartum milking IV. The effect of prepartum milking on milk production and length of time required to reach peak of lactation. *J. Dairy Sci.* 36:168–172.
- Gill, G. S., and F. R. Allaire. 1976. Relationship of age at first calving, days open, days dry, and herd life to a profit function for dairy cattle. *J. Dairy Sci.* 59:1131–1139.

- Grant, R. J., and J. L. Albright. 2001. Effect of animal grouping on feeding behavior and intake of dairy cattle. *J. Dairy Sci.* 84(E. Suppl.):E156–E163.
- Greene, W. A., D. M. Galton, and H. N. Erb. 1988. Effects of prepartum milking on milk production and health performance. *J. Dairy Sci.* 71:1406–1416.
- Grummer, R. R., S. J. Bertics, R. A. Hackbart. 2000. Short communication: Effects of prepartum milking on dry matter intake, liver triglyceride, and plasma constituents. *J. Dairy Sci.* 83:60–61.
- Gulay, M. S., M. J. Hayen, K. C. Bachman, T. Belloso, M. Liboni, and H. H. Head. 2003a. Milk production and feed intake of Holstein cows given short (30-d) or normal (60-d) dry periods. *J. Dairy Sci.* 86:2030–2038.
- Gulay, M. S., K. C. Bachman, M. J. Hayen, and D. R. Bray. 2003b. Milk production from Holstein half-udders after concurrent 30 and 70 d dry periods. *J. Dairy Sci.* 86(Suppl. 1):154. (Abstr.)
- Gumen, A., R. R. Rastani, R. R. Grummer, and M. C. Wiltbank. 2003. Effects of varying dry period length and prepartum diet on reproduction in dairy cattle. *J. Dairy Sci.* 86(Suppl. 1):239. (Abstr.)
- Guy, M. A., T. B. McFadden, D. C. Cockrell, and T. E. Besser. 1994. Effects of unilateral prepartum milking on concentrations of immunoglobulin G₁ and prolactin in colostrums. *J. Dairy Sci.* 77:3584–3591.
- Hamann, J., and J. Reichmuth. 1990. Compensatory milk production within the bovine udder: Effects of short-term non-milking of single quarters. *J. Dairy Res.* 57:17–22.
- Keown, J. F., and R. W. Everett. 1986. Effects of days carried calf, days dry, and weight of first calf heifers on yield. *J. Dairy Sci.* 69:1891–1896.
- Klein, J. W., and T. E. Woodward. 1943. Influence of length of dry period upon the quantity of milk produced in the subsequent lactation. *J. Dairy Sci.* 26:705–713.
- Knight, C. H., and A. Sorensen. 2000. Manipulation of lactation persistence with maintenance of milk quality. *J. Dairy Sci.* 83(Suppl. 1):24. (Abstr.)
- Li, P., P. S. Rudland, D. G. Fernig, L. M. B. Finch, and C. J. Wilde. 1999. Modulation of mammary development and programmed cell death by frequency of milk removal in lactating goats. *J. Physiol.* 519:885–900.
- Lotan, E., and J. H. Adler. 1976. Observations on the effect of shortening the dry period on milk yield, body weight, and circulating glucose and FFA levels in dairy cows. *Tijdschr. Diergeneesk.* 101:77–82.
- Lucy, M. C., C. R. Staples, F. M. Michel, and W. W. Thatcher. 1991. Energy balance and size and number of ovarian follicles detected by ultrasonography in early postpartum dairy cows. 74:473–482.
- Makuza, S. M., and B. T. McDaniel. 1996. Effects of days dry, previous days open, and current days open on milk yields of cows in Zimbabwe and North Carolina. *J. Dairy Sci.* 79:702–709.
- Natzke, R. P., R. W. Everett, and D. R. Bray. 1975. Effect of drying off practices on mastitis infection. *J. Dairy Sci.* 58:1828–1835.
- Pandey, R. S., D. S. Bhatnagar, and M. Gurnani. 1978. Inheritance of dry period and its effect on subsequent lactation yield in Tharparkar cattle. *Indian Vet. J.* 55:935–939.
- Pennington, J. A., and P. V. Malven. 1985. Prolactin in bovine milk near the time of calving and its relationship to premature induction of lactogenesis. *J. Dairy Sci.* 68:1116–1122.
- Quarrie, L. H., C. V. Addey, and C. J. Wilde. 1994. Local regulation of mammary apoptosis in the lactating goat. *Biochem. Soc. Trans.* 22:1788.
- Rastani, R. R., R. R. Grummer, S. J. Bertics, A. Gumen, M. C. Wiltbank, D. G. Mashek, and M. C. Rich. 2003. Effects of varying dry period length and prepartum diet on metabolic profiles and lactation of periparturient dairy cattle. *J. Dairy Sci.* 86(Suppl. 1):154. (Abstr.)
- Remond, B., and J. C. Bonnefoy. 1992. Performance of a herd of Holstein cows managed without the dry period. *Ann. Zootech.* 46:3–12.
- Remond, B., A. Ollier, and G. Miranda. 1992. Milking of cows in late pregnancy: Milk production during this period and during the succeeding lactation. *J. Dairy Res.* 59:233–241.
- Remond, B., J. Rouel, N. Pinson, and S. Jabet. 1997. An attempt to omit the dry period over three consecutive lactations in dairy cows. *Ann. Zootech.* 46:399–408.
- Rindsig, R. B., R. G. Rodewald, A. R. Smith, and S. L. Spahr. 1978. Complete versus selective dry cow therapy for mastitis control. *J. Dairy Sci.* 61:1483–1497.
- Rowland, S. J., J. H. Roy, H. J. Sears, and S. Y. Thompson. 1953. The effect of prepartum milking on the composition of the prepartum and postpartum secretions of the cow. *J. Dairy Res.* 20:16–28.
- Sanders, H. G. 1928. The variations in milk yields caused by season of the year, service, age, and DP, and their elimination. Part IV: Dry period, and standardization of yields. *J. Agric. Sci.* 18:209–251.
- Schaeffer, L. R., and C. R. Henderson. 1972. Effects of days dry and days open on Holstein milk production. *J. Dairy Sci.* 55:107–112.
- Smith, A., J. V. Wheelock, and F. H. Dodd. 1967. The effect of milking throughout pregnancy on milk secretion in the succeeding lactation. *J. Dairy Res.* 34:145–150.
- Smith, K. L., and Todhunter. 1982. The physiology of mammary glands during the dry period and relationship to infection. Page 87 in *Proc. Annu. Mtg. Natl. Mastitis Council*, Louisville, KY. Natl. Mastitis Council Inc., Arlington, VA.
- Sorensen, J. T., and C. Enevoldsen. 1991. Effect of dry period length on milk production in subsequent lactation. *J. Dairy Sci.* 74:1277–1283.
- Stefanon, B., M. Colitti, G. Gabai, C. H. Knight, and C. J. Wilde. 2002. Mammary apoptosis and lactation persistency in dairy animals. *J. Dairy Res.* 69:37–52.
- Stelwagen, K. 2001. Effect of milking frequency on mammary functioning and shape of the lactation curve. *J. Dairy Sci.* 84(E. Suppl.):E204–E211.
- Swanson, E. W. 1965. Comparing continuous milking with sixty-day dry periods in successive lactations. *J. Dairy Sci.* 48:1205–1209.
- Thatcher, W. W., and C. J. Wilcox. 1973. Postpartum estrus as an indicator of reproductive status in the dairy cow. 56:608–610.
- Vasquez-Anon, M., S. J. Bertics, and R. R. Grummer. 1997. The effect of dietary energy source during mid to late lactation on liver triglyceride and lactation performance of dairy cattle. *J. Dairy Sci.* 80:2504–2512.
- Wheelock, J. V., J. A. F. Rook, and F. H. Dodd. 1965. The effect of milking throughout the whole pregnancy on the composition of cow's milk. *J. Dairy Res.* 32:249–254.
- Wheelock, J. V., A. Smith, and F. H. Dodd. 1967. The effect of temporary suspension of milking in mid-lactation on milk secretion after the resumption of milking and in the following lactation. *J. Dairy Res.* 34:151–161.
- Wilde, C. J., A. J. Henderson, C. H. Knight, D. R. Blatchford, A. Faulkner, and R. G. Vernon. 1987. Effects of long-term thrice-daily milking on mammary enzyme activity, cell population, and milk yield in the goat. *J. Anim. Sci.* 64:533–539.
- Wilton, J. W., E. B. Burnside, and J. C. Rennie. 1967. The effects of dry days and days open on the milk and butterfat production of Holstein-Friesian cattle. *Can. J. Anim. Sci.* 47:85–90.
- Zileger, Y., R. Volcani, and D. Sklan. 1973. Yield and protein composition in cows milked prepartum. *J. Dairy Sci.* 86:869–872.