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Interrelationships Among Ambient Temperature, Day Length and Milk Yield in Dairy Cows Under a Mediterranean Climate

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ABSTRACT

We examined the effect of calving month (CM) on the production of milk and milk protein by Israeli Holstein dairy cows located in the main climatic zone of Israel during their third and fourth lactations, and found it to be significant. Cows that calved in December produced the highest milk and milk protein yields, and those that calved in June produced the lowest, 92.8% of the maximum. The combined effect of the environmental average temperature and day length accounted for 0.96 of the variability in average milk production during lactation and 0.93 of that in average protein production during lactation. Average milk production was reduced by 0.38 kg/°C and average protein production was reduced by 0.01 kg/°C. Elongation of daylight increased average milk production by 1.2 kg/h and average protein production by 0.02 kg/h of daylight. Analysis of the temperature pattern effect on milk and protein yield during lactation indicated that cows at the second month (the pike of their milk yield) are more vulnerable to the negative temperature effect than cows on the ninth month of lactation.
(**Key words**: cow, milk-yield, temperature, light)

Abbreviation key: CM = calving month, **MY** = milk yield.

INTRODUCTION

Milk yield (MY) of lactating cows in Israel in the hot summer and autumn months is lower than during the winter and early spring (Bar-Anan et al., 1981; Barash et al., 1996; DeBore et al. 1989; Kahn, 1991; Wolfenson et al., 1988). High ambient temperature is the main cause of this phenomenon (Berman et al., 1985; Wolfenson et al., 1988). Heat stress is well known to depress milk yield (**MY**) and appetite in dairy cows (Armstrong, 1994; Sharma et al., 1988). However, at least two major questions regarding seasonal effects on MY remain open: 1) Do cows at different stages of lactation respond similarly to heat stress, or are cows in early lactation more vulnerable? 2) MY is positively affected by photoperiod (Bilodeu et al., 1989; Dahl et al., 1997, 2000; Peters et al., 1981; Philips et al., 1989; Stanisiewski et al., 1985). However, it is not clear whether the long summer days in Israel (the difference between the shortest and longest day in Israel is only about 4 h) have such a positive effect on MY. Analysis of the data from three herds in the Yizre'el valley in Israel by Aharoni et al. (1999) suggests that the increase in day length positively affects MY and milk protein percentage. However, that study, which covered only three herds in a very small area of Israel, is the only one to have addressed the question.

The aim of the present study was to answer these questions by analyzing production records of Israeli Holstein cows from large herds located throughout Israel.

MATERIALS AND METHODS

General

The production parameters analyzed in this study were based on monthly records of milk production and percentages of milk protein, fat and lactose, as published in the Israeli Holstein Herd Book. The records comprise data from 107 herds of cows in their third and fourth lactations that calved from 1992 to 1996. Data were discarded in the following cases: 1) The herd was located in mountainous areas in which heat stress is below average, or in the eastern valleys in which cows are exposed to extreme heat stress; 2) data came from herds with less than 200 cows, and 3) the calving interval was less than 278 d, because such data might include cows that were culled due to illness.

The average monthly temperatures were represented by the averages of the monthly maxima and minima from 1992 to 1996, as recorded by the Meteorological Service of Israel, which also provided the data on day lengths throughout the year (Tables 1 and 2). High correlations between temperature maximum and mini-

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Table 1. The monthly temperature (°C) minimum, maximum, and averages for 1992 to 1996.

	Minimum		Maximum		
Month	Average	SE	Average	SE	Average
Jan	7.1	0.9	17.8	0.4	12.5
Feb	6.9	0.9	18	0.8	12.5
Mar	8.8	0.8	20.2	0.2	14.5
Apr	11.2	0.4	25.1	1.2	18.2
May	15.3	0.5	27.6	0.8	21.5
Jun	19.0	0.1	30.5	0.7	24.8
Jul	21.6	0.2	31.6	0.3	26.6
Aug	21.9	0.1	32.3	0.5	27.1
Sep	20.2	0.5	31.9	0.7	26.1
Oct	16.9	0.6	30.1	1.4	23.5
Nov	11.7	0.7	23.5	0.7	17.6
Dec	8.0	0.8	19.9	1.2	14

mum and heat load in the area monitored in the present study have been observed by previous studies (Aharoni et al., 1999, Gat et al., 1998).

Effect of Calving Month

The analytical model used to study the effect of calving month (**CM**) was:

$$Y_{ijklmn} = R_i + H_j + CM_k + YR_l + PRG_m + DIL_n + DIL * CM * PRG + e_{ijklmn}, \quad (1)$$

where:

Y_{ijklm} = daily milk production or protein, fat, and lactose percentages in milk;
R_i = effect of region i (Coastal, west Yizre'el and Negev);
H_j = effect of herd j;
CM_k = effect of calving month k;
YR_l = effect of year I;
PRG_m = effect of pregnancy m;
DIM_n = effect of day in milking n; and
e_{ijklmn} = random residual effect.

The analysis was carried out according to the SAS PROC GLM (SAS, 1988). Type III analysis of significance was used to determine the significance of production parameters. Observation = The average milk production (kg/d) of cows in their third and fourth lactations from the same herd, which calved in the same month of the same year and whose monthly/daily milk yield records are for the same time fraction from their calving day. The number of observations in the dataset = 103,084.

GLM LSMeans were used to calculate the magnitudes of the effects of CM and DIM on MY and the percentages of milk protein, fat, and lactose.

Isolating the Seasonal Effect

To analyze the seasonal effects per se, we organized the GLM LSMeans given by equation (1) to create virtual lactation curves for each calendar month, covering all months during lactation. For example, for the virtual lactation of June, all the recorded data were sorted so that cows calving in June were grouped as mo 1 of June lactation, those calving in May and April were grouped as mo 2 and 3 of June lactation, and so on. This procedure was applied for each calendar month.

The effects of day length and average monthly temperature on the average milk and milk protein production in the calendar month were calculated by using the Jump Multiple Regression Model (JMP, 1995). The model used for the data analysis was:

$$Y_I = AMT_I + DL_I + e_I \quad (2)$$

where:

Y_I = milk or milk protein production,
AMT_I = the effect of the average monthly temperature,

Table 2. Average[1] day length throughout the year.

Month	Hours of light
Jan	10:41
Feb	11:33
Mar	12:25
Apr	13:27
May	14:17
Jun	14:43
Jul	14:32
Aug	13:50
Sep	12:54
Oct	11:55
Nov	11:03
Dec	10:35

[1]The average day length = the hours of sunlight + 10 min, on d 15 of each calendar month.

Table 3. Effect of calving month on average production of milk protein, fat, and lactose throughout lactation.

Month	Milk (kg)	Protein (kg)	Fat (kg)	Lactose (kg)
Jan	37.2	1.09	1.16	1.68
Feb	37.2	1.09	1.16	1.67
Mar	36.7	1.08	1.16	1.65
Apr	35.9	1.06	1.11	1.61
May	36.1	1.06	1.12	1.61
Jun	35.0	1.03	1.09	1.57
Jul	35.6	1.05	1.10	1.59
Aug	35.7	1.05	1.10	1.60
Sep	36.4	1.08	1.12	1.64
Oct	37.1	1.10	1.16	1.68
Nov	37.4	1.10	1.17	1.69
Dec	37.7	1.11	1.18	1.71

DL_I = the effect of average monthly day length, and
e_I = the random residual effect.

The partial effects of temperature and day length on milk and milk protein production were analyzed according to Genizi (1993).

RESULTS

The model in equation (1) accounts for 63.7% of the variability in MY, 43.7% in protein, 20.0% in fat and 12.9% in lactose ($P < 0.0001$). Cows calving in December produced the highest MY and protein, fat, and lactose contents, whereas those that calved in June produced the lowest MY and its components (Table 3).

The lactation curves of cows that calved in April, August, and December are depicted in Figure 1a. In general, daily MY was higher in cows milking between February and May comparison with daily MY of cows at the same lactation part milking between June and December. Protein yield was also affected by CM (Figure 1b); however, in this case, the highest daily yield was obtained if that part occurred between December and April, and the lowest yield if it occurred between May and November.

The lactation curves of MY and milk protein content that were analyzed for the calendar month effects of April, August, and December (by the virtual curve method), were more homogeneous than those based on CM (Figure 2a and b vs. Figure 1a and b). The average slopes of the linear regression of the last 9 mo of lactation were the same for the virtual as for the CM curves. However, the r^2 was larger and the SE in the virtual curves was half that in the CM curves (Table 4). According to the production curves of milk and protein during the virtual lactation, the highest MY occurred in April, and the highest protein yield in February (Figure 3a and b). The lowest MY (0.90 of the maximum) occurred in September, and the lowest protein yield (0.88 of the maximum) in August. The combined effect of average temperature and day length (the model in equation 2) accounted for 0.96 of the variability in milk production and 0.93 of that in protein production ($P < 0.0001$). The partial effect of average temperature accounted for 53% of the variability in milk production and 79% of the variability in protein production, whereas the partial effect of day length accounted for 38% of the variability in milk production and 14% of the variability in protein production. The calculated average effects of hour of day length and temperature degree on average milk and protein production are presented in Table 5.

Daily milk and protein yields of cows in the mo 2 and 9 of their virtual lactation at the different calendar months are presented in Figure 4a and b. The highest daily MY of cows in their second month of lactation was in February (47.0 kg/d), and the lowest was in September (40.8 kg/d, 86.8% of the maximum). The largest decline in MY occurred from June to September (summer), and recovery occurred from October to November (autumn). The highest daily MY of cows in 9 mo of lactation was in mo 5 (May) (30.7 kg/d), and the lowest was in September to October (27.6 kg/d, 90.0%

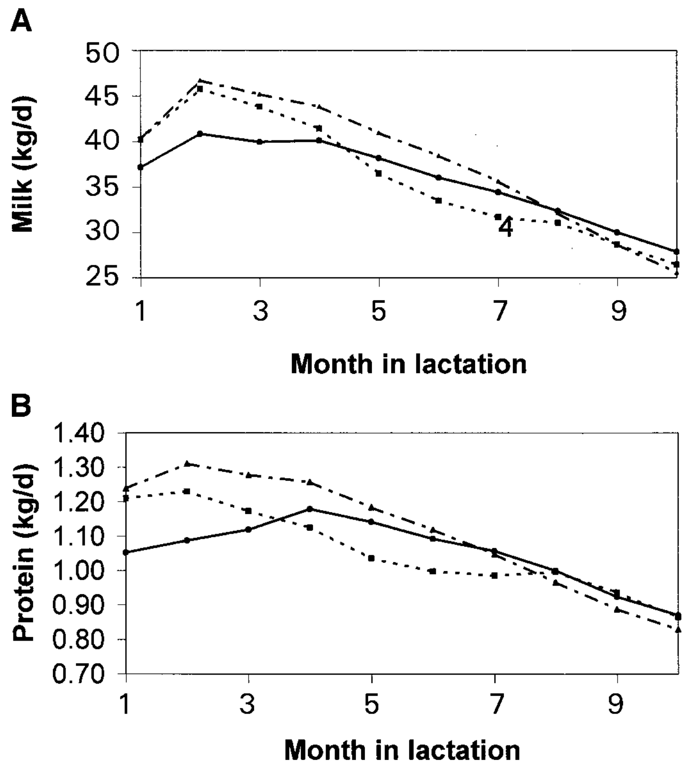

Figure 1. Lactation curves of (a) milk yield (kg/d) and (b) milk protein yield (kg/d) of cows calved in April (■ – – – ■), August (●———●), and December (▲— · —▲).

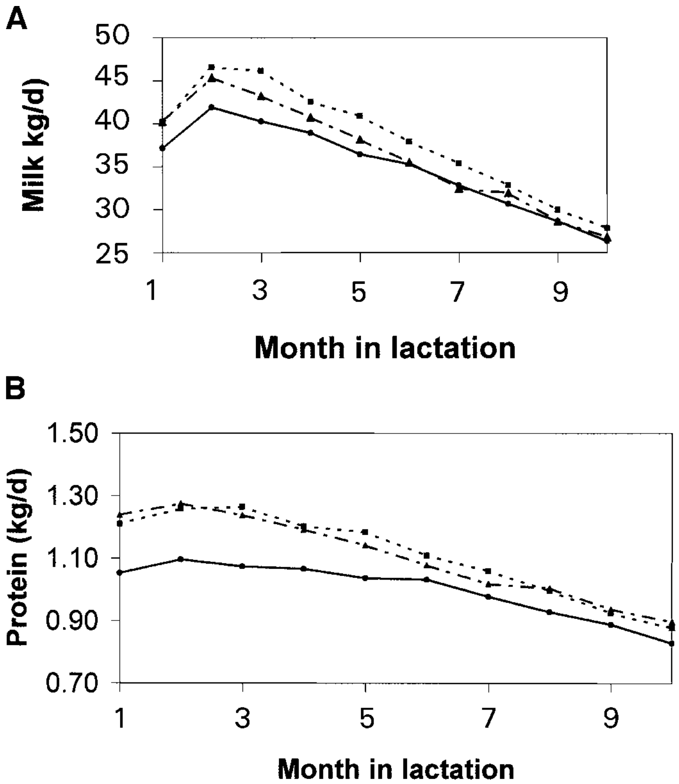

Figure 2. Lactation curves of milk yield (MY) (kg/d) and milk protein yield (kg/d) analyzed according the calendar effect (i.e., the virtual curve method) of cows calved in April (■ – – – ■), August (●———●), and December (▲— · —▲). Virtual lactation curve = curve that includes all the MY data of the relevant month. For example: the virtual lactation curve for June includes all the MY data recorded for that month such that cows calving in June, May, April, etc. were grouped as lactation mo 1, 2, 3, etc., respectively. This procedure was applied for each calendar month.

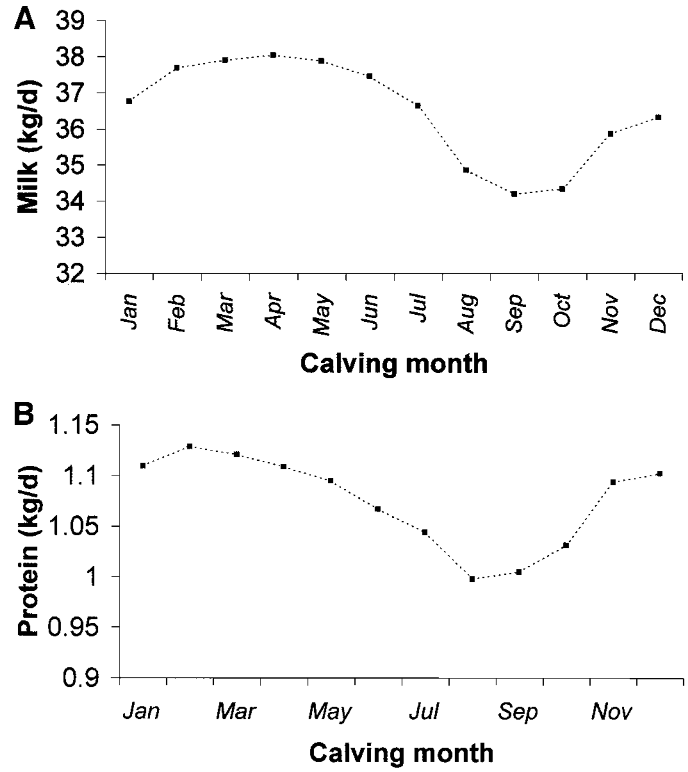

Figure 3. Patterns of (a) average daily milk (kg/d) and (b) protein yields (kg/d) during the virtual lactation.

of the maximum). The protein yield of cows in their second month of virtual lactation was maximal in mo 1 (January)-February (1.28 kg/d) and minimal in September (1.10 kg/d, 86% of the maximum). Thus, the protein yield of these cows was highest during the winter and declined sharply during the summer, with a sharp recovery in November. The maximum protein yield of cows in their ninth month of virtual lactation maximum yield was in November to February (0.95 kg/d), and the minimum protein yield in August to September (0.88 kg/d, 93% of the maximum). The pattern of protein yield during the ninth month of virtual lactation differed from that of MY. While the MY slowly increased during spring and early summer, the protein yield slowly decreased during late spring and early summer.

To analyze the interaction between environmental effects and stage of lactation, we calculated the ratio between MY in the ninth month of the virtual lactation and MY in the second month (the lactation peak) of the same virtual lactation for each calendar month, then expressed it as percentage of the yield in the second month. The same approach was taken with protein yield (Figure 5a and b). The following behavior was observed, 1) the largest difference between MY in the ninth and

Table 4. The differences in the slopes (kg/m ± SE) of the decaying parts[1] of the normal and virtual lactation curves and their r^2.

	Milk yield			Milk protein		
	Normal curve	Virtual curve	$P<$	Normal curve	Virtual curve	$P<$
Slope	–2.25 ± 0.44	–2.25 ± 0.22		–0.044 ± 0.014	–0.044 ± 0.008	
r^2	0.98 ± 0.009	0.992 ± 0.005	0.002	0.912 ± 0.089	0.964 ± 0.028	0.066

[1]The decaying portion of the lactation curve = the part of the lactation curve starting at the second month of lactation (the lactation peak) and terminating at the ninth month of lactation.

Table 5. The effects of the average monthly temperature and photoperiod on average daily milk (MY) and protein yields.

	Milk yield (kg/°C ± SE)	*P*<	Day length effect (kg/h ± SE)	*P*<
MY	–0.38 ± 0.02	0.0001	1.157 ± 0.870	0.0001
Protein yield	–0.011 ± 0.001	0.0001	0.017 ± 0.03	0.0017

second months was during the winter and early spring (December to April), and it was minimal in the summer, with the smallest difference in July. 2) The pattern of protein yield differences the ninth and second months of the virtual lactation differed from that of MY, mainly in the following points: protein yield was less affected by stage of lactation than MY. The average difference in the protein yield was 23.3 ± 1.1%, where as the difference in MY was 34.1 ± 0.74%, ($P < 0.0001$); the difference between protein yields in the ninth and second months of virtual lactation was almost constant during the late summer (July to September), whereas that of MY was variable.

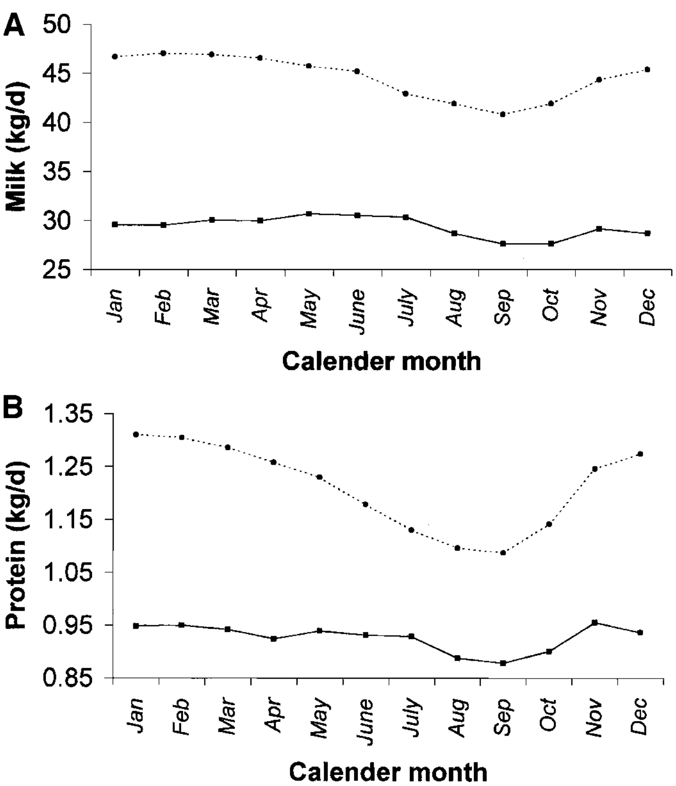

Figure 4. Yield patterns of (a) milk (kg/d) and (b) protein (kg/d) in the second (● – – – ●) and ninth (■——■) months of the virtual lactation.

DISCUSSION

The Seasonal and CM Effects

The rations in Israeli herds of 200 or more cows are provided, in most cases, by large feed centers. These rations are quite homogeneous all year round in terms of components and composition. In the present study, each monthly figure for milk and milk protein production was based on yield data from at least 200 cows. Over the last 20 yr, about 90% of the Holstein cows from the Israeli dairy herd have been descendents of about 10 bulls (J. I. Weller, personal communication), suggesting minor genetic sire effects. The effect of CM on MY and protein production could be separated from that of the cow's birth month. The effect of birth month is similar to that of CM only at the first parity, and is greatly reduced from the second parity onwards (Barash et al., 1996). Thus, the effects of CM on milk and protein yields observed in this study can be attributed to variations in ambient conditions of heat load and photoperiod rather than to seasonal variations in feed composition or to genetic variations. In support of this, 97% of the variations in milk production and 93% of the variations in protein production attributed to the effect of CM were explained by the variations in temperature and photoperiod throughout the year. The model in equation 2 indicated that Israeli high-yielding cows respond negatively to temperature in the early winter and spring in the Mediterranean zone. Thus, high-yielding cows became vulnerable to temperatures considered to be well within the thermoneutral zone, consistent with Silanikove et al., (1997) who showed that cows sweat at 13 to 14°C. Enhanced MY increases the overall thermal load on the cows, because of increased metabolic heat production (West, 1994).

The Antagonisict Effects of Heat and Photoperiod

The maximal average temperature for the year occurred in August and was 14.6°C above the minimum average temperature, in January and February. The temperature effect on MY (–0.38 kg of milk/°C) should produce a difference of –5.55 kg of milk/d between the milk production during the virtual lactation occurring

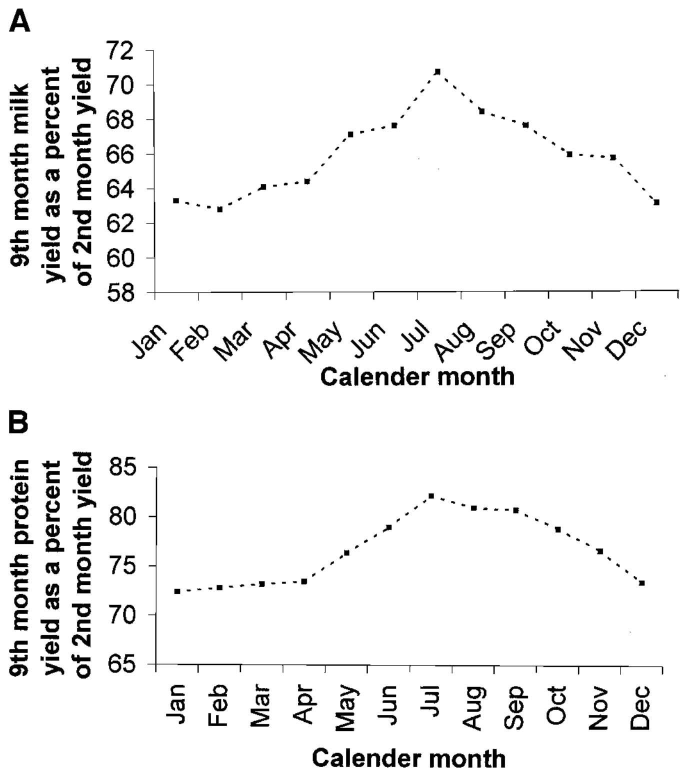

Figure 5. Patterns of the virtual lactation's 9-mo daily yields as percentage of second-month daily yields of (a) milk and (b) milk protein.

in January and that occurring in August. The difference in day length between January and August is 3.09 h. In terms of the light effect (1.157 kg of milk/h), should result in a difference of 3.65 kg of milk/d between the virtual lactations occurring in these two months. However, the actual combined effect of these two opposing factors was −1.9 kg of milk/d, which accounts for the difference between milk production during the virtual lactation in January (36.8 kg of milk/d) and that in August (34.9 kg of milk/d). Thus, the seasonal effect appears to be the actual effect out of these two opposing factors.

Increasing the exposure of cows to light, from less than 12 h of light/d (short-day photoperiod), to 16–18 h of light/d (long-day photoperiod) enhances milk production on average by 2.5 kg/cow per day (Dahl et al., 2000). Thus, the effect of 4 h of additional daylight is larger than that of 8 h of artificial light supplementation.

Conventional and Virtual Lactation Curves

The conventional lactation curves differ among themselves, due mainly to the effects of temperature and daylight variations during of the lactation period. By definition, the virtual lactation curves are obtained under uniform temperature and daylight and are therefore expected to better represent the response of MY to the seasonal effect. Indeed, our results suggest that the latter approach does better reveal the cows' response to seasonal effects. Heat and light affected mainly milk and milk protein yields, and they had less effect on the pattern of lactation decline. However, the virtual lactation curves were not completely parallel, possibly reflecting interactions between the seasonal effects and the level of milk and milk protein yields. This observation is consistent with West's (1994) and the observation of Silanikove et al. (1997) that high-yielding cows have increased metabolic heat production and are more vulnerable to heat stress.

Interactions Between Seasonal Effect and Milk and Protein Yields

In the case of a constant effect of temperature on MY, a constant ratio between the yields of the ninth and second months of virtual lactation throughout the year would be expected. However, in the case of MY, the smallest percent was observed during the winter, with a maximum difference of 20 kg/d between MY in the ninth and second months of virtual lactation. The production of 20 kg of milk would be expected to increase heat production by ~9 Mcal/d (calculated according to NRC, 1989). It seems that the low temperature in the winter enables a cow in the second month of lactation to express her full MY potential. This potential cannot be expressed in the summer because of the high ambient temperatures. In the ninth month of lactation, cows produce less heat because of the natural decline in MY. This situation presumably enables cows to express their MY potential even in summer.

The production of metabolic heat caused by the production of milk could also interfere with the photoperiod effect. As it has already been argued, MY in the ninth month of the virtual lactation is less vulnerable to the seasonal temperature changes than that during the second month. This enables the cow in the ninth month of lactation to better respond with increased MY to the increased day length, resulting in the smallest ratio between the MY of the ninth and second the months of virtual lactation in July (the longest day).

The differences between the patterns of protein yield percentage and the MY in the ninth month versus the second month of the lactation could be explained by the following phenomena: 1) The decline in protein yield during lactation is slower than that in MY (Auldist et al., 1998). This slow decline in protein yield results in ninth-month protein yield being a higher percentage of that in the second month of lactation. 2) As already shown, protein production is more sensitive than milk production to temperature and less to light. These differences result in the highest percentage of protein yield during June, July, August, and September, the hottest months of the year in Israel, and the almost unchanging low percentage of protein yield during the period of December through April.

CONCLUSION

The effect of CM on milk and protein yields observed in this study could be explained by the direct effects of temperature and day length. Milk and protein yields were affected by both temperature and day length: negatively by temperature, –0.38 kg of milk/°C and –0.01 kg of protein/°C and positively by day length, 1.16 kg of milk/h and 0.02 kg of protein/h. Protein yield was more sensitive to temperature and less sensitive to day length than MY. These differences in sensitivity explain the CM effect on milk protein percentage. The negative effect of heat load on milk or protein yield during lactation was not proportional and depended on the quantity of milk yield.

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