9

BARD

FINAL REPORT

PROJECT NO. US-588-82

Hyperthermal and Nutritional Effects on Milk Production, and Reproduction of Dairy Cows

D. K. Beede, R. J. Collier, W. W. Thatcher, C. J. Wilcox,
A. Berman, D. Wolfenson, H. Schindler, S. Amir

630.72. 26
BAR/BEE
2nd copy

1989

30819

000000101868

Date 3-16-89

BARD
P. O. Box 6
Bet Dagan, ISRAEL

Bard Project No. US - 588 - 82

Title of Research Project: HYPERTHERMAL AND NUTRITIONAL EFFECTS ON MILK
PRODUCTION AND REPRODUCTION OF DAIRY COWS

Names of Investigators:

Principal Investigators: D. K. Beede, W. W. Thatcher, R. J. Collier and
C. J. Wilcox

Cooperating Investigators: A. Berman, D. Wolfenson, H. Schnidler, and S. Amir

Names and Adresses of Affiliated Institutions:

Principal Institution: University of Florida, Dairy Science Dept., Institute
of Food and Agricultural Sciences, Gainesville, FL 32611, USA

Cooperating Institution: Hebrew University of Jerusalem, The Levi Eshkol School
of Agriculture, Dept. of Animal Science, Rehovot 75-100, P. O. Box 12, Israel
and A. R. O. Volcani Center, Bet Dagan, Israel

Project's starting date: 3-7-84

Type Report: 1st Annual ☐ 2nd Annual ☐ 3rd Annual ☐ Final ☒

Signatures:

Principal Investigator

Institution's Authorizing Official

David H. Beede

Dillard Marshall

DILLARD MARSHALL
ASSISTANT DIRECTOR OF RESEARCH

630.72 , 636.21 ; 636.210.82 ;
BAR/BEE , 591.191.6 ; 636.082 ; 636.210.85
2nd copy

B. TABLE OF CONTENTS

	<u>page</u>
A. Title page.....	i
B. Table of Contents.....	ii
C. Abstract.....	iii
D. Objectives of Research Proposal.....	1
E. Findings and Achievements of the Research.....	3
F. Description of Cooperation.....	132
G. Evaluation of the Research Achievements.....	133
H. List of Publications.....	138

C. ABSTRACT

Objectives of this project were to study effects of heat stress and its abatement on productive and physiological functions of dairy cows.

Effects of sprinkling and forced ventilation of high producing pluriparous Holstein cows during their dry period during hot weather were examined. All cows were managed similarly postpartum. Cooling decreased diurnal increase in rectal temperature and increased fat-corrected milk yield. Results indicate benefits during the next lactation of cooling dry cows even under mild heat stress.

In another study, effects of prepartum body condition and postpartum cooling on reproductive performance, production and physiological responses were studied. During last trimester of lactation and the dry period cows received two feeding regimens to achieve target body condition scores (high = HC or low = LC) at beginning of the dry period. After calving in summer and for 150 d postpartum half of the cows in each body condition group were cooled (C) by sprinkling and forced ventilation during daytime or not cooled (NC). Rectal temperatures of cows in C were consistently below those in NC. Ovarian cyclicity resumed 6 d earlier postpartum in HC than LC cows; however, days to first observed estrus were not affected by body condition. Cooling completely prevented summer depression in fertility and doubled conception rates compared with NC. Higher body condition increased milk fat percent. There were no interactions of environmental treatment by body condition for any dependent variable.

An intensive experiment determined effects of pregnancy and lactation on cardiovascular changes and blood flow distribution during heat stress of laboratory rabbits. Cardiac output (CO) response was dependent on states of

pregnancy and lactation. The CO rose about 4% due to heat stress (pooled across physiological states). Heat stress increased blood flow to most tissues and organs involved in heat loss. Blood flow (BF) to the digestive tract organs was reduced by heat stress. Blood flow to the interstitial and luteal tissues of the ovary decreased. Blood flow to the uterus depended on pregnancy status and stage of lactation. No major changes on mammary blood flow were noted due to heat stress, stage of lactation, or pregnancy status.

Six lactating Holstein cows fitted with catheters in the hepatic portal vein, mesenteric vein and intercostalis posterior artery were exposed to treatments of thermal comfort environments with ad libitum or restricted (75% of ad libitum) intake and a thermal stress environment with ad libitum intake. Thermal stress increased rectal temperatures and respiration rates. Dry matter intake decreased from thermal comfort ad libitum level to lower level in thermal comfort restricted and thermal stress treatments. Portal plasma flow was related directly to level of dry matter intake, declining about 14% with thermal comfort restricted intake, and thermal stress environment treatments compared with thermal comfort ad libitum intake treatment. Net flux of alpha-amino N declined by 20 and 35% by thermal comfort restricted intake and thermal stress treatments. A part of the negative effects of thermal stress on milk production were explained by decreased nutrient intake and decreased nutrient uptake by the portal-drained viscera of the cow. Plasma somatotropin concentrations decreased during thermal stress but were unchanged by level of intake in thermal comfort environments. Concentrations of IGF-I were reduced by restricted feed intake in the thermal comfort environment and by the thermal stress environment. Thyroid hormone concentrations were decreased by thermal comfort restricted intake compared with thermal comfort ad libitum intake treatment; however,

triiodothyronine was decreased and thyroxine increased by thermal stress treatment.

In the second study, six lactating Holstein cows were exposed to similar treatments. Mammary blood flows (half udder) over the entire daily sampling interval (18 h) for the thermal comfort ad libitum, thermal comfort restricted, and thermal stress treatments were 5.1, 4.3, and 4.5 L/min. There was a positive relationship between daily dry matter intake and half udder mammary blood flow:

$$\text{MBF(L/min)} = (.19 * \text{DMI, kg/d}) + 1.70, R^2 = .34, P < .001.$$

D. OBJECTIVES OF RESEARCH

Overall objective of this research was to obtain applied and fundamental knowledge regarding responses of the lactating dairy cow to heat stress and to environmental modification to relieve heat stress during various phases of the production cycle. This knowledge was to be gained largely through field studies, so that findings would be relevant to actual production situations. Additionally, other research focused on learning more about the fundamental physiological responses of lactating cows to environmental stress and associated factors, and to its abatement so that this knowledge potentially could be incorporated into management schemes. The ultimate purpose of this research was to demonstrate plausible modifications of husbandry practices to enhance economic efficiency of dairying enterprises in the hotter regions of the USA and Israel.

Specific objectives were formulated to emphasize critical aspects for which additional knowledge was required, as follows:

a. Heat stress [and its relief] during the dry period. Preliminary reports suggested that protection of the cow from the harsh environment during the last trimester of gestation could affect calf birth weights, subsequent milk production (even though the majority of the lactation occurred during cooler weather) and reproductive performance; the purpose of this study was to evaluate this idea more extensively. This part of the work has been published (J. Dairy Sci. 71:809-818, 1988), and a copy of the publication is included with this report.

b. Body energy store at the onset of summer lactation. The stress of environmental heat during the summer is well known to reduce feed intake, thereby aggravating the negative energy balance during early lactation. Such a situation might have negative effects on lactation as well as on reproductive function. By increasing the energy intake during late lactation and dry period prior to summer calving, body energy stores available for use during the subsequent lactation might be increased. This study addressed the problem, examining whether such an increased energy store might compensate for reduced feed intake resulting from summer heat stress.

c. Postpartum cooling. This study also examined a new method for the relief of heat stress in dairy cows. This method, based on sequential wetting (for seconds) and forced-ventilation (for minutes), was tested for its efficiency in cows from parturition through 150 days postpartum. The design of the

experiment was such that it allowed determination of the interaction of cooling with that of body energy stores at parturition. The responses examined were milk production and reproductive function. As an increased fat store at calving might have negative consequences on energy turnover during early lactation, possible indications of such impairment were examined also.

d. Blood flow distribution. One of the major responses to heat is a peripheral vasodilation, i.e., an increased diversion of cardiac output to the periphery of the body. Such a diversion might compromise blood flow to other tissues and organs. Information on this aspect was needed to determine the extent of heat stress relief required to attain uncompromised physiological functions. This study examined, in detail, blood flow distribution in the heat stressed rabbit, and its interaction with state of pregnancy and of lactation. Similar experiments were carried out in the dairy cow, involving less than the whole animal blood flow, due to the obvious limitations because of the size of the animal.

E. FINDINGS AND ACHIEVEMENTS OF THE RESEARCH

EXPERIMENT I (ISRAEL). DRY PERIOD HEAT STRESS RELIEF EFFECTS ON PREPARTUM PROGESTERONE, CALF BIRTH WEIGHT, AND MILK PRODUCTION.

In Experiment 1, the effects of heat stress and environmental modification during the dry period on calf birth weights, reproductive performance and milk production were studied. Dependent variables measured during the subsequent lactation (150 d during cooler environmental temperatures) were key measures relating prepartum treatments to subsequent performance. This part of the total research project is published in J. Dairy Sci. 71:809-818, 1988. Reprints of the publication accompany this report.

EXPERIMENT II (ISRAEL):1. EFFECTS OF PREPARTUM BODY CONDITION AND POSTPARTUM COOLING ON REPRODUCTIVE PERFORMANCE.

Animals.

The experiment was carried out over two consecutive years (1985 and 1986) in the experimental herd of the Agricultural Research Organization at Bet Dagan.

It was performed on 82 Israeli-Holstein multiparous cows (38 in 1985 and 44 in 1986) in their second to sixth lactation. For creating experimental groups, the cows were paired during their preceding lactation by lactation number, milk yield and expected calving date, and then randomly allocated to two experimental groups, i.e. two body conditions during the dry period. The animals were expected to calve, in each year, between May 15 and July 30. By the beginning of the last trimester of lactation they were allocated to two feeding regimens, which were carried out over the last third of the lactation and during the dry period. These feeding regimens were aimed to bring the animals to either a high or a medium body condition by one month before calving. The body condition was assessed by the British body condition scoring system (Lowman et al, 1976), in which body condition is scaled on a 0 to 5 scale. The animals were brought to either a high (HC, 3.8) or low (LC, 2.75) body condition. Body condition score was assessed weekly by two trained scorers.

Feeding.

The cows allocated to a high body condition score (HC group) were fed ad libitum a complete ration mix while lactating and during the dry period till 1 week before expected calving. Cows allocated to the low body condition score (LC group), were fed till dry off the same ration, at 60% of the 16 kg milk/day production requirements and wheat hay to bring dry matter intake to 16 kg/day.

During the dry period this group was fed that hay only. Cows of both groups that reached the desired body condition were grouped together and fed a ration comprised of 20% complete ration mix and 80% hay. Cows of both groups were fed the latter ration from 1 week before expected calving. After calving, all animals were fed ad libitum the complete ration mix. The compositions of the complete ration mix and that of the hay are shown in table 1.

Table 1. Composition of complete ration mix and of hay fed in the prepartum period.

	Complete ration	Hay
Dry matter (%)	65	86
Total protein (%)	16.8	8.7
Crude fiber (%)	15.3	28
Metabolic energy (Mcal/kg)	2.90	2.13
Calcium (%)	0.72	0.42
Phosphorous (%)	0.40	0.40

Mean daily group feed intake during the prepartum feeding period in the various fore-mentioned groups is brought in table 2.

Table 2. Mean daily group feed intake of the animals during the prepartum late lactation and dry periods.

	Dry matter (kg/day)	Crude protein (g/day)	Crude fiber (g/day)	Metab. energy (Mcal/day)	Cal. (g/day)	Phosp. (g/day)
<u>Late lactation</u>						
LC group	16.0	2168	3260	41.2	-	-
HC group	16.0	2687	2447	46.4	-	-
<u>Dry period</u>						
CR mix	10.5	1756	1606	30.4	75.6	42.0
Hay	8.5	736	2380	18.1	35.7	34.0
20% CR + 80% hay	9.5	980	2420	21.7	45.6	38.0

Animal management and cooling.

After parturition in summer, and for 150 days post partum, half of each body condition group were cooled by a newly developed cooling system to relieve heat stress (C), the other half serving as non-cooled (NC) controls. After calving

the animals were housed in an east-west oriented two sided open shed structure with adjoining unshaded yards, allowing in total 15 sq.m./cow, out of which 6 sq.m./cow were shaded slatted floors. Animals allocated to be heat stress relieved were located in the northern side of the shed, in which a cooling system was installed. Animals allocated to the control group were kept in the southern side of the shed. Both sides were well exposed to the naturally occurring breezes, as the dairy is located about 7 km from the sea. Details on the cooling system installed and its efficiency in cooling cows have been reported (Flamenbaum et al, 1986). Briefly, this cooling system consisted of an array of inverted static garden sprinklers and fans operated by timers. The sprinklers (Model 943, Naan, Israel) were set upside down at a distance of 1.5 m of each other, covering the whole shaded area. Within it 4 fans (Model DDQ-632-6, free flow 12200 m³/h, Ziehl ABEGG, 7118 Kunzelsau FDR) were installed so that the whole area was ventilated at a rate of at least 2 m/s from 06 to 18 h. Back and sides of cows were wetted thoroughly by actuating sprinklers for 30 sec (while fans were idle) every 4.5 min during 30 min every 2 h from 06 to 24 h. The animals were allowed free movement in and out of the shaded area to the unshaded yard.

General measurements. Body weight (in 1986 only) and body condition score were determined at weekly intervals from about 60 day before expected calving to 150 days after parturition. Group (by cooling treatment) feed intake was carried out twice weekly in 1985 starting from July 15, and weekly in 1986 starting from June 23. These dates represented times when most cows had calved. The feed mixture was checked at biweekly intervals for dry matter, total protein, crude fiber, ash, calcium and phosphorus, on the basis of which feed energy content was calculated. Group daily water intake was determined also. Cows were milked daily and yields were recorded for individual milkings. Milk composition of proportionally taken samples was determined at biweekly intervals for protein, lactose, and fat content at the official DHI laboratory.

Temperature measurements. Daily minimum and maximum air temperatures and relative humidities were recorded from nearby (1 km) meteorological station. Rectal temperatures were recorded by thermistor probes (Flamenbaum et al., 1986), seven times per day during 8 representative days.

Blood sampling. Jugular blood samples were taken by noon time, once weekly from 60 days before expected calving till calving, twice weekly from calving till pregnancy was diagnosed or 20 d after 3rd insemination, and thereafter once

weekly till 150 days of lactation. Samples were centrifuged and plasma stored at -20°C .

Reproduction data. All cows were routinely checked one week after parturition. Cows were observed for behavioral estrus three times daily in 1985 (07, 13, and 18 h), and 4 times daily (07, 13, 18 and 23 h), in 1986. Each observation period lasted for 30 min. Cows exhibiting standing behavior or cows manifesting pronounced mounting behavior on two or more consecutive observations were considered as being in estrus. To further support the latter criterion, estrus was confirmed if progesterone (P4) concentration in plasma on estrus day (± 1 d) was below 0.5 ng/ml. Duration of estrus manifestation was calculated as interval between consecutive observations when estrus was noted, plus half the intervals between first observation and that preceding it, and last observation and that following it. Cows were treated for reproductive dysfunctions for 150 days after calving. Interval from calving to resumption of ovarian cyclicity was calculated by the average between date of last P4 concentration below 1 ng/ml and that of first P4 concentration above 1 ng/ml. Cows were first inseminated if 60 d or later after calving; this occurred on the average by 73 ± 3 d (SE) postpartum. All cows were inseminated with frozen semen obtained from a single ejaculate of one proven sire. Pregnancy was diagnosed by rectal palpation by 45 d post AI.

Progesterone determination. Progesterone (P4) concentrations in plasma were analyzed by a solid phase coated tubes radioimmunoassay kit (Zer Science Industries, Jerusalem, Israel). Fifty μl of plasma in duplicate were pipetted into polypropylene tubes in which antibody to P4 was covalently bound to the inner surface by the manufacturer. A volume of 1.0 ml 125-I-P4 in PBS (35000 cpm/tube) was added and tubes were mixed briefly. Following 15 h incubation at 20°C , content of tubes was decanted and radioactivity of bound P4 was counted in a gamma counter. Standard curve was constructed in triplicates in ovariectomized cow plasma, by adding 15.6, 31.2, 62.5, 125, 200, 250, 500 and 1000 pg/tube of P4 (4-pregnene-3, 20-dione, Sigma Chemicals Co., St. Louis, MO, USA). Standard data and interpolation of unknown samples were computed, using log-logit transformation. Average assay sensitivity was 20 pg/tube. The cross reactivity of the antibody at 50% displacement for other steroids was: testosterone -0.08%, 17α -hydroxyprogesterone -0.21%, deoxycorticosterone -2.9%, 20α -dihydroprogesterone -5%, cortisol -0.003%, pregnenolone -0.12%. Mean and SE of measured concentrations of two known quantities of P4 (1.70 and 4.20 ng/ml)

added to ovariectomized cow plasma were: 1.72 ng/ml and 4.15 ng/ml, reflecting 1% and 1.1% differences from expected values, respectively. Plasma samples containing 6.8 ng/ml were assayed in samples volume of 13 μ l, 25 μ l and 38 μ l; samples were brought to assay volume (50 μ l) with ovariectomized cow plasma. Differences between expected and measured P4 concentrations were 0.6%, 10% and 1.1%, respectively. The intraassay and interassay coefficients of variation were 11.2% and 5.6%, respectively.

Data Analysis.

Reproduction and body temperature (Tb) data. All but pregnancy rate and conception rate data were analyzed by least squares analysis of variance, using General Linear Models procedures (SAS Institute Inc., Cary, NC, USA, 27511). For Tb data, sources of variance in model were: postpartum treatment (C and NC), cow within treatment, date and hour of Tb measurement and interactions. For P4 data, sources of variance in model were: postpartum treatment, cow within treatment, and day postestrus as a continuous independent variable; differences in day trends of P4 curves among treatments were examined by a heterogeneity of polynomial regression. Statistical analysis of P4 data relating to cycle preceding insemination or following it was based on 1985 data only. This resulted from the fact that in 1986 blood sampling during the fore-mentioned period was less frequent. Body condition (BC) main effect and interactions were not significant in initial analyses of Tb and P4 data and were excluded from further models. For estrus behavior and onset of ovarian cyclicity sources of variance in model were BC, postpartum treatment, and their interaction. The year term was excluded, as initial analysis indicated it was not significant.

Pregnancy rate and CR were analyzed by chi-square analysis; data of both years were pooled as no difference between the two years was noted. Only summer inseminations (before October 10th) were included in the CR analysis. Eight out of 82 cows which started the experiments were excluded from the analysis of CR: one sick cow was culled, one was not inseminated, one showed irregular ovarian activities and abnormal and intensive estrous behavior, and five cows were inseminated, by mistake, when not in estrus according to the fore-mentioned criteria for estrous behavior. For a more detailed and accurate analysis, five more cows (5 C and 1 NC cows) out of 74 cows left were not included due to abnormal P4 profiles: P4 concentrations remained at 0.5 ng/ml or below until at least d 10 and only then increased to levels above 2 ng/ml. These were regarded as cows which did not ovulate during normal expected time.

RESULTS

Reproductive performance.

Body Temperatures in Insemination period.

The following refers only to the major effects of cooling regimen on the thermal state of the animals about the insemination period. Environmental conditions during insemination period are summarized in Table 1 and average Tb of C and NC cows during this period are presented in Figure 1.

TABLE 1. Environmental temperatures (°C) and relative humidities (%) during the insemination period.

	X	SE	Range
Maximum temperature	30.6	.2	26-36
Minimum temperature	19.2	.2	12-25
Maximum humidity	71	.6	48-94
Minimum humidity	53	.5	35-70

Tb of C cows were significantly ($P<.01$) lower than those of NC cows for most of the 24 h period. Tb of NC cows was above 39.0°C for most of the day and night hours; it peaked at 1900 h, reaching about 39.7°C on the average, and declined thereafter. In contrast, Tb of C cows remained below 39°C level over the 24 hour cycles; it remained below 38.5°C during peak air temperatures hours, to increase slightly (by .4°C) after cessation of cooling in the evening. About 1°C difference between C and NC cows was recorded in hot afternoon hours. During the night and early morning hours Tb of both groups remained relatively high. This might be related to the relatively warm (>25°C) and humid (>90%) night and early morning conditions which probably impaired cooling capacity of cows.

Estrous Activity

Resumption of ovarian cyclic activity, as determined by P4 levels criteria, was affected by BC at partum, but not by postpartum cooling: in H group it started about 6 d earlier than in L group (31.6 vs. 25.8 d, $P<.05$; Table 2). Days to first observed estrus did not differ between L and H cows of C and NC groups. Cooling increased estrus duration (16 h), as compared with NC cows (11.5 h) in L group only, while in the H cows no difference in estrus duration was noted between C and NC cows. The BC by cooling interaction was statistically significant ($P<.01$).

TABLE 2. Estrous behavior and resumption of cyclicity in cooled and non-cooled cows of high and low body condition.

Treatment	High				Low			
	Cooled		Non-Cooled		Cooled		Non-Cooled	
	X	SE	X	SE	X	SE	X	E
Days to resumption of cyclicity	25.1	2.7	26.5	2.8	29.9	2.7	33.3	2.6
Days to first estrus	43.2	4.8	43.7	5.1	45.3	2.7	47.9	4.6
Duration of first estrus ² (h)	9.9	1.2	13.0	1.2	15.0	1.2	10.1	1.1
Duration of estrus on AI ² (h)	12.6	1.2	13.6	1.0	16.0	1.0	11.5	1.0

1 - High and low body condition main effects differ, $P < .05$.

2 - Significant treatment by body condition interaction, $P < .01$.

Conception Rate.

Reproductive performance of C and NC cows is presented in Table 3. Cooling increased CR on first inseminations from 17% in NC to 59% in C group ($P < .01$). This effect was also evident in CR from all inseminations (up to 3 during the experimental period), which in which cooling increased CR from 20% to 57% ($P < .01$).

CR for all cows, including the 5 which were excluded from the analysis due to abnormal P4 profile, was similar to the former (55% and 22% for C and NC cows, respectively; $P < .01$). Percent of cows pregnant (pregnancy rate) of C group were significantly higher than those of NC group at 90, 120 and 150 d postpartum ($P < .01$). Body condition had no significant effect on CR; it was 40% for L and 34% for H groups (NS). Number of animals did not allow reliable estimates of the BC by cooling interaction.

TABLE 3. Conception rate¹ (%) and pregnancy rate² (%) of cooled and non-cooled cows.

Group	Cooled		Non-Cooled	
	%	(n)	%	(n)
<u>Conception rate.</u>				
First insemination	59*	(20/34)	17	(6/35)
All inseminations	57*	(32/56)	20	(14/70)
<u>Pregnancy rate.</u>				
at 90 days	44*	(15/34)	14	(5/35)
at 120 days	59*	(20/34)	31	(11/35)
at 150 days	73*	(25/34)	31	(11/35)

1 - Number of cows diagnosed as pregnant by day 45 post AI, divided by number of inseminations.

2 - Percent of pregnant cows, by days after calving.

* - Cooled and non-cooled groups differ, $P < .01$.

Most non-pregnant cows, of both C and NC groups, were detected in estrus within 24 d after insemination: only 19% of them (5 C and 7 NC cows) manifested estrus later than 25 days post AI. This was also true when recurrence of cyclicity was estimated by P4 criteria: most non-pregnant cows, of both groups, had P4 concentration below 0.5 ng/ml at 21-24d post AI, and in only 13% it remained high (>3 ng/ml) until day 25.

Progesterone Concentration.

Progesterone concentrations of C and NC cows are presented as 2nd and 4th order polynomial regressions curves of day trends, respectively. Analysis was performed for the cycle preceding insemination (Figure 2), and for cows non-pregnant or pregnant on 1st AI (Figures 3 and 4, respectively). Least square means for P4 and P4 day trends of pregnant cows did not differ between C and NC groups. Means and curves of cyclic cows and inseminated non-pregnant cows were very similar. In both latter groups, mean P4 was higher in C animals than in NC ones ($P < .05$); the difference was evident during the second half of the luteal phase. The P4 day trends of non-pregnant and cyclic C cows were significantly different from those of corresponding NC cows ($P < .05$). Curve of pregnant cows was only slightly and not significantly higher than that of non-pregnant cows

Figure 1. Body temperatures of cooled (○) and noncooled (□) cows during eight representative days. Standard errors for individual means ranged from .02 to .07.

Figure 2. Polynomial regression curves and mean daily least square progesterone concentrations of cooled (○, n=9) and noncooled (□, n=8) cows during estrous cycle preceding first insemination.

Figure 3. Polynomial regression curves and mean daily least square progesterone concentrations of cooled ($\circ$, n=7) and noncooled ($\square$, n=11) cows during 23 days following first insemination.

Figure 4. Polynomial regression curves and mean daily least square progesterone concentrations of cooled ($\circ$, n=9) and noncooled ($\square$, n=4) pregnant cows during 23 days following first insemination.

until about d 17 post AI, when luteal regression started as normally expected for non-pregnant cows.

DISCUSSION

Body temperature of NC cows was above 39°C during most of the day, in contrast to that of C cows, which remained below 39°C. On hotter days Tb differences between C and NC groups were larger, more than 1°C, and Tb of NC cows was higher than 40°C from midday to night hours. In the present study cows were not cooled during night hours. Consequently, Tb in C cows were higher in the early than in later morning hours. Cooling during night hours could be beneficial especially on nights when temperature and humidity were in the higher range of scale (Table 1). The importance of low morning Tb to maintain homeothermia during later hotter hours was suggested (Ingraham et al., 1979).

Ovarian cyclic activity resumed in H animals about 6 d earlier than in L ones. This is in line with negative relation between prepartum level of nutrition and interval between calving to resumption of ovarian activity (Haresign, 1979). Days to first observed estrus however, were not affected by BC, as was similarly reported (Gardner, 1969). This might reflect a differential effect of prepartum nutrition on the two phenomena involved in resumption of cyclicity. Duration of estrus was shorter in NC cows than in C cows, similarly to other reports on the negative effect of heat stress on estrous behavior (Gangwar et al., 1965). This was however true for L cows only, for reasons unclear to us.

Cooling the cows by this system completely prevented the summer depression of fertility. Conception rate on first AI was even higher (59%) than average winter CR for the country (about 50%), which might be due to careful selection of cows included in the analysis. From the practical point of view, cooling doubled pregnancy rate at 150 d post calving as compared with control cows. Conception rate of C cows in the present experiment was higher than in cows cooled by evaporative cooler (31%; Stott et al., 1972), air-conditioning (40%; Thatcher, 1974) or shade (44%; Roman-Ponce et al., 1977). Improvement of CR in the present study contrasts lack of effect following similar cooling between d-1 prior to d+8 post AI (Her et al., 1987). This discrepancy suggests either a long term effect of thermal stress on fertility or, another period before d-1 and/or after d+8 particularly sensitive to heat stress.

Decreased fertility of heat stressed cows might be partly due to ovarian dysfunction. This includes ovulation failure, delayed ovulation, and impaired

corpus luteum function. Pre and post insemination P4 curves (relative to estrus day) were almost identical until day 10 in C and NC, pregnant and non-pregnant animals. This suggests similar occurrence of ovulation in these groups, and that the low fertility of NC animals was probably not due to delayed ovulation. This presumption is based, however, on relatively infrequent blood sampling, which permits detection of gross changes only. This finding is in line with report that the proestrus rise in estradiol was reduced by thermal stress, but not sufficiently to prevent the preovulatory surge of LH and induction of estrous behavior (Roman-Ponce et al., 1981).

The present study cannot differentiate between fertilization failure and early embryonic losses in NC cows, both of which could contribute to the lower fertility of NC cows. Recent studies by Putney et al. (1986) and Biggers et al. (1987) in dairy and beef cows, indicated that post fertilization heat stress impaired embryonic development by day 7 and 16 post AI, respectively. A similar study in the rabbit, also indicated increased incidence of impaired embryo development and embryonic death (Wolfenson and Blum, 1987). However, in the majority of non-pregnant cows in the present study, CL regressed and/or cows manifested estrus within 3-3.5 weeks after AI. Thus, most embryonic losses (when fertilization was successful) probably occurred by d 16, as presence of conceptus in utero after d 17 was shown to prolong the estrous cycle in cows (Northey and French, 1980). Hence, it is probable that thermally depressed fertility is unlikely to be diagnosed by extended estrous cycles, if silent ovulations are accounted for.

Progesterone concentrations during the second half of luteal phase in cyclic and in inseminated non-pregnant NC cows were lower and luteal regression started earlier than in C cows. This suggests probable CL susceptibility to thermal stress, and that earlier regression of the corpus luteum might cause infertility in thermally stressed cows. In line with it is report that HCG administration on d 15 post AI increased pregnancy rate of dairy cows in a hot summer climate (Thatcher et al., 1987). In the pregnant rabbit, heat stress during the formative stage of the CL (days 3-5 post mating) reduced P4 concentration only at the end of heat exposure, with further decline on following days (Wolfenson and Blum, 1987). If same is true for the bovine CL, than lower P4 in second half of luteal phase could result of heat stress in the earlier, developing stage of the CL. It is noteworthy that progesterone curves of cows found pregnant on d 45 post AI, were similar for C and NC groups. This might suggest

that presence of a normally developed and alive conceptus could prevent the thermally stress induced decline in P4.

The effect of heat stress on progesterone concentration is equivocal. Increases (Abilay et al., 1975), no change (Biggers et al., 1987) as well as decreases (Stott et al., 1972; Folman et al., 1983) in P4 concentration were recorded. These differences might be related to the thermal state of animals.

Since plasma samples were collected around noon hours, when hyperthermia only started to develop in NC cows, it is possible that lower P4 levels in NC cows reflect mostly the P4 output of the CL; in other studies, when blood was sampled while animals were heat stressed and increases in P4 concentrations were found (Thatcher, 1974), adrenal contribution to systemic P4 concentrations might be more pronounced. Low P4 concentration might be associated with reduced ovarian blood flow, as found in the rabbit during early pregnancy (Lublin et al., 1984), or with morphological changes in CL tissue as found in the hyperthermic rabbit (Wolfenson and Blum, 1987). Possible alterations in uterine environment and embryo transport during thermal stress and their relationship to embryo survival and corpus luteum maintenance, need further examination.

In the present study no effect of BC at calving on later fertility was noted. Absence of such effect is important, as a decline in fertility in fatty liver cows was reported (Reid, 1982). Examination of liver enzymes and other metabolites in cows in the present study (J. Avisar et al., unpublished results) did not indicate presence of fatty liver syndrome in cows brought to high body condition during the dry period.

REFERENCES

- 1 Abilay, T. A., H. D. Johnson, and M. Madan. 1975. Influence of environmental heat on peripheral plasma progesterone and cortisol during the bovine estrus cycle. J. Dairy Sci. 58:1836.
- 2 Armstrong, D., and F. Wiersma. 1986. An update on cow cooling methods in the west. Am. Soc. Agr. Engin. Summer meeting CA, U.S.A.
- 3 Berman, A., D. Wolfenson, and I. Flamenbaum. 1987. Low-cost efficient cooling method for dairy cows and its effects when used pre and post partum. 11th Inter. Biometeorol. Cong. Indiana, U.S.A.
- 4 Biggers, B. G., R. D. Geisert, R. P. Wettelman, and D. S. Buchanan. 1987. Effect of heat stress on early embryonic development in the beef cow. J. Anim. Sci. 64:1512.

5 Cavestany, D., A. B. El-Wishy, and R. H. Foote. 1985. Effect of season and high environmental temperature on fertility of Holstein cattle. *J. Dairy Sci.* 68: 1471.

6 Dunlap, S. E., and C. K. Vincent. 1971. influence of postbreeding thermal stress on conception rate in beef cattle. *J. Anim. Sci.* 32: 1216.

7 Flamenbaum, I., D. Wolfenson, M. Mamen, and A. Berman. 1986. Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system. *J. Dairy Sci.* 69:3140.

8 Folman, Y., M. Rosenberg, I. Ascarely, M. Kaim, and Z. Herz. 1983. The effect of dietary and climatic factors on fertility, and on plasma progesterone and estradiol-17 β levels in dairy cows. *J. Steroid Biochem.* 19:863.

9 Gangwar, P. C., C. C. Branton, and D. L. Evans. 1965. Reproductive and physiological of Holstein heifers to controlled and natural climatic conditions. *J. Dairy Sci.* 48:222.

10 Gardner, R. W. 1969. Interaction of energy levels offered to Holstein cows prepartum and postpartum. 2. Reproductive performance. *J. Dairy Sci.* 52:1985.

11 Gauthier, D., 1983. A technique for improving the fertility of French Friesian cows in a tropical climate. Effect on plasma progesterone profile. *Reprod. Nutr. Develop.* 23:129.

12 Gwazdauskas, F. C., C. J. Wilcox, and W. W. Thatcher. 1974. Environmental and management factors affecting conception rate in a subtropical climate. *J. Dairy Sci.* 58:88.

13 Haresign, W. 1979. Body condition, milk yield and reproduction in cattle. In *Recent Advances in Animal Nutrition*. W. Haresign and D. Lewis ed, P. 107, Butterworths, London.

14 Her, E., D. Wolfenson, I. Flamenbaum, Y. Folman, M. Kaim, and A. Berman. 1987. Thermal, productive and reproductive responses of high yielding cows exposed to short term cooling in summer and autumn. *J. Dairy Sci.*, accepted for publication.

15 Ingraham, R. H., D. D. Gillette, and W. D. Wagner. 1974. relationship of temperature and humidity to conception rate of Holstein cows in subtropical climate. *J. Dairy Sci.* 57:476.

16 Ingraham, R. H., Stanley, R. W., and W. C. Wagner. 1979. seasonal effects of tropical climate on shaded and nonshaded cows as measured by rectal temperature, adrenal cortex hormones, thyroid hormone, and milk production. *Am.*

J. Vet. Res. 40:1792.

17 Lowman, B.G., Scott, N.A., and S.H. Somerville. 1976. Condition scoring of cattle. Animal Production Advisory and Development Department, East of Scotland College of Agric. Bull. No. 6.

18 Lublin, A., D. Wolfenson and A. Berman. 1984. circulatory adaptations to heat stress and their relationship to fertility. 35th Ann. meeting, Europ. Assoc. Anim. Prod. the Netherlands, p. C3B.3.

19 Northey, D. L., and L. R. French. 1980. Effect of embryo removal and intrauterine infusion of embryonic homogenates on the lifespan of the bovine corpus luteum. J. Anim. Sci. 50:298.

20 Putney, D. J., M. Drost, and W. W. Thatcher. 1986. Embryonic development in dairy cattle exposed to elevated ambient temperatures between days 1 to 7 post insemination. 19th Ann. meeting, Soc. for the study of Reprod. p.100.

21 Reid, I. M. 1983. Reproductive performance and fatty liver in Guernsey cows. Anim. Reprod. Sci. 5:275.

22 Ron, M., R. Bar-Anan, and G. R. Wiggans. Factors affecting conception rate of Israeli Holstein cattle. J. Dairy Sci. 67:854.

23 Roman-Ponce, H., W. W. Thatcher, D. E. Buffington, C. J. Wilcox, and H. H. Van-Horn. 1977. Physiological and production responses of dairy cattle to a shade structure in a subtropical environment. J. Dairy Sci. 60:424.

24 Roman-Ponce, H., W. W. Thatcher, and C. J. Wilcox. 1981. Hormonal interrelationships and physiological responses of lactating dairy cows to a shade management system in a subtropical environment. Theriogenology 16:139.

25 Stott, G. H., F. Wiersma, and J. M. Woods. 1972. Reproductive health program for cattle subjected to high environmental temperatures. J. Am. Vet. Med. Assoc. 161:1339.

26 Thatcher, W. W. 1974. Effect of season climate and temperature on reproduction and lactation. J. Dairy Sci. 57:360.

27 Thatcher W. W., L. E. Larson, M. Drost, and D. J. Putney. 1987. HCG-induced alterations in pregnancy rate of lactating dairy cows during summer months in South Florida. 82nd Ann. Meeting, Am. Dairy Sci. Assoc. Missouri U.S.A. p.307.

28 Wolfenson, D., I. Flamenbaum, and A. Berman. 1987. Dry period heat stress relief effect on prepartum progesterone, calf birth weight and milk production. J. Dairy Sci., accepted for publication.

29 Wolfenson, D., and Orly Blum. 1987. Embryonic development, conception rate, ovarian function and structure in pregnant rabbits heat-stressed before or during implantation. Submitted for publication.

EXPERIMENT II (ISRAEL):2. EFFECTS OF PREPARTUM BODY CONDITION AND POSTPARTUM COOLING ON 150 DAYS OF LACTATION MILK AND MILK COMPONENTS YIELD, BODY CONDITION SCORE AND BODY WEIGHT DURING 150 DAYS OF LACTATION.

Experimental procedures relating to this part of the report have been detailed in part (EXPERIMENT I (ISRAEL):1).

Body weight.

The effects of prepartum body condition on body weight changes during the dry period are presented in tables 1-2 and figure 1. Body weight in the prepartum period was measured in the second year of the study only, due to technical problems during this period in the first year. The results presented for the prepartum period represent data collected from 33 to 37 animals/week for weeks -1 to -7 prepartum. These are almost equally distributed among the experimental subgroups. It may be expected therefore that the results do not depart greatly from the estimate obtained had the animals been weighed during the prepartum period in the first year also.

Feeding the HC animals to reach a mean body condition score of 3.5 by about 1 month before calving (figures 1 and 3) was associated with a gradual increase in body weight; from week -8 to week -1 it increased by about 40 kg, from 663 to 704 kg. During this period, little if any change occurred in the body weight of the LC animals, which remained almost stable at about 635 kg. If one takes into account the concurrent growth in conceptus and related components, this indicates an actual loss of body substance during this period in the LC animals. Such a loss is also indicated by the small, but consistent decrease in body condition during this period in the LC animals. The outcome of the contrasting feeding regime imposed on the two groups of animals was the significant difference in mean body weight for the dry period.

Following calving, body weight rapidly decreased, similarly to body condition. The effect of the differential feeding regime during the prepartum period remained evident over the whole of the postpartum observation period (significant condition term in table 1). The trends for the two groups were not similar during this period. For HC, body weight declined from 703 kg on week -1 to about 580 kg on week 10, with a slight increase on week 18. In group LC, on the other hand, body weight declined from 635 kg on week -1 to about 550 on week 3, at which level it stayed till week 12, at which time a light, but steady increase started to take place. These are reflected in the significant week and

Figure 1. Effect of prepartum body condition on body weight during dry period and lactation.

Figure 2. Effect of postpartum cooling on body weight.

week by condition interaction terms. The result of these contrasting changes was that the difference in body weight between the two groups became minor after week 14 (figure 1).

Table 1. Analysis of variance of body weight and body condition score during the 60 days dry period.

Source of variance	body weight			condition score		
	DF	MS	<P	DF	MS	<P
Condition ¹ (BC)	1	155174	**	1	88.89	**
Cows (BC) ²	39	19285	**	73	1.07	**
Week ² (W)	7	1325	**	7	.18	**
BC * W ²	7	1352	**	7	.50	**
Residual	191	270		493	.04	
R ²		.95	**		.91	**

1- Tested versus cows (BC)

2- tested versus residual

* - P<.05

** - P<.01

Cooling the animals postpartum produced an increase in body weight, though not in body condition score, in the course of the lactation period (figure 2). This effect was not immediate, but started to become evident by week 9 postpartum. It produced a difference of about 20 to 30 kg liveweight between the two groups; this difference stabilized, and did not further increase in the course of the lactation period.

TABLE 2. Means (and SEM) of body condition score and body weight (kg) during the dry period in the high (HC) and the low (LC) body condition groups.

	Body Condition	
	HC	LC
condition score	3.52±.07	2.68±.06
body weight	689±13.6	634±13.3

Body condition.

The animals were fed as from about 15 weeks prepartum to reach the preallocated target body condition scores. The animals allocated to the high condition group and those allocated to the low condition group were, on the average, at similar body condition states (about score 2.2) by 15 weeks before

calving. The HC animals reached the target condition score (3.5) by about 6 weeks before calving. From this time and until calving body condition remained more or less stable (figure 3). As for the LC animals, they were, on the average,

close to the target body condition (2.5) by the end of the lactation period. Mean body condition for the 8 weeks preceding calving was significantly higher in the HC than in the LC group (tables 3 and 4). The significant interaction between the week and condition terms reflects the relative stability of condition in the LC group and the gradual increase in the HC group until 4 weeks before calving. In fact, a small decline in body condition during late pregnancy might be indicated by the LC group data.

TABLE 3. Analysis of variance of body condition score and body weight during 150 days postpartum.

Source of variance	body weight			condition score		
	DF	MS	<P	DF	MS	<P
Cooling ¹ (C)	1	43108		1	.48	
Condition ¹ (BC)	1	335141	**	1	92.67	**
C * BC ¹	1	165182	.07	1	4.31	
Cows (C * BC)	70	50791	**	73	3.19	**
Week ² (W)	21	7492	**	21	.94	**
C * W ²	21	4893	**	21	.79	
BC * W ²	21	610	**	21	.05	**
W * C * BC ²	21	270		21	.04	
Residual	1389	303		1292	.05	
R ²		.91	**		.85	**

1 - Tested versus cows (C * BC)

2 - tested versus residual

During the postpartum period (tables 3 and 4) mean condition was not affected by cooling the animals. The HC group maintained a significantly higher mean body condition over the whole of the 150 days period. The nonsignificant condition by cooling interaction term indicated the two effects were not interdependent.

TABLE 4. Means (and SEM) of body weight and body condition score for the different treatments combinations during the postpartum period. C=cooled, NC=control, HC=high condition, LC=low condition.

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
Body weight	582±.8	571±.9	592±.9	561±.5
Body score	2.3±.1	2.4±.1	2.6±.1	2.1±.1
	C*LC	C*HC	NC*LC	NC*HC
Body weight	2.2±.1	2.6±.1	2.1±.1	2.7±.1
Body score	577±11	587±12	545±11	597±13

The significant week term underlines the large and rapid decline in body condition after calving. The decline was larger in the HC group; in this group, the animals declined from a score of 3.6 one week before calving to a minimum of 2.6 by seven weeks after calving. In contrast, the animals of the LC group declined from a condition score of 2.6 one week before calving to a minimum of 2.1 by the second week after calving. The HC animals remained at the fore-mentioned level for the duration of the experimental period, while in the LC group body condition slowly started to increase by about 10 weeks after calving. The result of this diverse changes after calving is that the difference in condition between the two groups at the time of calving and gradually decreased thereafter. These differences between the two condition groups are reflected in the significant week by condition interaction:

Milk and FCM yields.

Mean daily milk and 4% FCM yields during 150 days of lactation (22 weeks) was 35.0±3.0 and 28.0±3.0 kg/day respectively. The analysis of variance table for milk and FCM yields is presented in table 5.

Figure 3. Effect of prepartum body condition on body condition score during dry period and lactation.

Figure 4. Postpartum cooling effect on body condition.

TABLE 5. Analysis of variance of daily milk and FCM yields over 150 days of lactation.

Source of variance	DF	Milk yield MS	<P	FCM Yield MS	<P
Cooling ¹ (C)	1	2184.7	0.19	78.7	
Condition ¹ (BC)	1	31.9		300.2	.07
C * BC ¹	1	390.7		12.0	
Cows (C * BC) ²	74	1263.6	***	88.1	***
Week ² (W)	21	1634.3	***	140.7	***
C * W ²	21	22.0	***	11.6	.20
BC * W ²	21	82.0	***	8.3	
W * C * BC ²	21	21.8	***	12.4	.14
Residual	6220	9.0		9.2	
R ²		.71	.01	.70	.01

1- Tested versus cows (C * BC)

2- tested versus residual

* - P<.1 ** - P<.01

Mean daily milk and FCM yields for the first 22 weeks of lactation in the different experimental groups are shown in table 6. Mean milk yield for the first 22 weeks of lactation was higher by 1.6 kg/day in the C vs the NC cows, this difference being significant at the P<.19 level only. It should be noted that by this pattern of analysis lactation weeks were not necessarily concomitant in the different animals. The effect of cooling on milk yield (figure 6) started to become evident by week 3 of lactation and remained more or less constant thereafter. Cooling had no effect yields expressed as FCM. Body condition had no effect on milk yield, but increased FCM yields by 1.5 kg/day (P<.07). The latter effect was evident mostly during peak lactation period, i.e. weeks 5 to 15 (figure 5), fading out in later weeks of lactation.

117-111

Figure 5. Effect of prepartum body condition on milk yield.

Figure 6. Effect of postpartum cooling on milk yield.

Figure 7. Effect of prepartum body condition on FCM (4%) yield.

Figure 8. Postpartum cooling effect on FCM (4%) yield.

Table 6. Least square means ($\pm$ SEM) of milk and FCM daily yields for different experimental groups over 150 days of lactation (C = cooled, NC = control, HC = high body condition, LC = low body condition).

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
<u>Milk Yield</u>				
Mean	34.9	33.3	34.0	34.2
SEM	.8	.9	.9	.8
N	41	38	36	43
<u>FCM Yield</u>				
Mean	28.1	27.3	28.5	27.0
SEM	.6	.6	.6	.5
N	41	38	36	43
	C*LC	C*HC	NC*LC	NC*HC
<u>Milk Yield</u>				
Mean	35.3	34.5	33.0	33.5
SEM	1.2	1.4	1.1	1.4
N	21	20	22	16
<u>FCM Yield</u>				
Mean	27.5	28.8	26.4	28.3
SEM	.8	.8	.7	1.0
N	21	20	22	16

Mean concentrations (%) of fat, protein and lactose for the 22 weeks period were $2.73 \pm .5$, $2.90 \pm .2$ and $4.35 \pm .2$ respectively. Their mean daily yields for fat, protein, lactose and total solids (kg/d) for the same period were $0.93 \pm .15$, $1.00 \pm .1$, $1.52 \pm .15$ and $3.45 \pm .3$ respectively. The analysis of variance and means are presented in tables 7 to 9.

These data suggest that body condition at calving increased fat concentration in milk, as well as its mean daily yield. High body condition (4.0) increased fat % by about .3% units, and its daily yield by about .1 kg/d versus low (2.75) body condition. On the other hand, cooling increased protein concentration as well as its mean daily yield. This effect was smaller than that of body condition, as protein content was increased by about .1% units, producing an increase of about .05 kg in the daily protein milk output. It is perhaps significant that in no case was there a significant interaction between these two factors, neither for the mean values (estimated by the BC * C term) nor during any particular period of the lactation curve (estimated by the BC * C * W term). The lack of such interaction indicates that the effects of body

condition and those of cooling are independent of each other. The concentration of lactose in milk and its mean daily yield were not affected by either body condition or the cooling treatments.

The effects of body condition at partum and of cooling postpartum over the 22 weeks of the lactation period are presented in figures 7 to 16. These suggest that the main effects of both body condition and of cooling seem to prevail during weeks 5 to 15 of lactation, gradually fading out later. It is mostly for the body condition effect on milk fat that the effect starts from early lactation.

TABLE 7. Analysis of variance of milk components (%) fat, protein and lactose over 150 days of lactation.

Source of variance	DF	% fat		% protein		% lactose	
		MS	<P	MS	<P	MS	<P
Cooling ¹ (C)	1	1.50		1.20	*	.18	
Condition ¹ (BC)	1	11.72	*	.04		.05	
C * BC ¹	1	.11		.14		.68	.14
Cows (C * BC) ²	74	1.15	*	.22	**	.31	**
Week ² (W)	21	2.73	**	.96	**	.15	**
C * W ²	21	.32	*	.02		.03	
BC * W ²	21	.24		.04		.03	
W * C * BC ²	21	.17		.04		.06	
Residual	542	.22		.03		.05	
R ²		.58	**	.72	**	.57	**

1- Tested versus cows (C * BC)

2- tested versus residual

TABLE 8. Analysis of variance of milk components (kg/d) fat, protein, lactose and of total milk solids yields for 150 days of lactation.

Source of variance	DF	fat		protein		lactose		solids	
		MS	<P	MS	<P	MS	<P	MS	<P
Cooling ¹ (C)	1	.20		.28	*	.84		2.16	.16
Condition ¹ (BC)	1	1.26	**	.01		.12		1.13	
C * BC ¹	1	.04		.06		.01		.16	
Cows (C * BC)	74	.16	**	.07	*	.24	**	1.10	**
Week ² (W)	21	.19		.05	**	.62	**	1.60	**
C * W ²	21	.04		.01		.02		.10	
BC * W ²	21	.02		.01		.02		.03	.10
W * C * BC ²	21	.03		.01		.03	*	.10	*
Residual	542	.03		.01		.02		.09	
R ²		.59	**	.63	**	.78	**	.75	**

1- Tested versus cows (C * BC)

2- tested versus residual

TABLE 9. Least square means ($\pm$ SEM) of milk components (% and kg/d) fat, protein, lactose and total milk solids during 150 days of lactation for the experimental groups (C = cooled, NC = control, HC = high body condition, LC = low body condition).

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
<u>Fat</u>				
%	2.84 $\pm$.06	2.74 $\pm$.06	2.94 $\pm$.06	2.65 $\pm$.06
Kg/d	.95 $\pm$.02	.92 $\pm$.02	.99 $\pm$.02	.89 $\pm$.02
<u>Protein</u>				
%	2.98 $\pm$.02	2.89 $\pm$.03	2.93 $\pm$.03	2.95 $\pm$.03
kg/d	1.02 $\pm$.02	.97 $\pm$.02	.99 $\pm$.02	.99 $\pm$.02
<u>Lactose</u>				
%	4.35 $\pm$.03	4.31 $\pm$.03	4.34 $\pm$.04	4.32 $\pm$.03
kg/d	1.51 $\pm$.03	1.47 $\pm$.03	1.50 $\pm$.03	1.48 $\pm$.03
<u>Total Solids</u>				
kg/d	3.48 $\pm$.06	3.35 $\pm$.07	3.46 $\pm$.07	3.37 $\pm$.06

Figure 9. Effect of prepartum body condition on fat yield (kg/d).

Figure 10. Effect of postpartum cooling on fat yield (kg/d).

Figure 11. Effect of prepartum body condition on fat % in milk.

Figure 12. Effect of postpartum cooling on fat % in milk.

Figure 13. Effect of body condition at partum on daily mean milk protein yield.

Figure 14. Effect of postpartum cooling on daily yield of protein.

Figure 15. Effect of body condition at partum on milk protein content (%).

Figure 16. Effect of postpartum cooling on milk protein content (%).

EXPERIMENT II (ISRAEL):3. EFFECTS OF PREPARTUM BODY CONDITION AND POSTPARTUM COOLING ON MILK AND MILK COMPONENTS YIELDS DURING THE SUMMER PERIOD.

The data used for this part of the study comprised the period from July 22 to October 16 during the two years of the experiment. Included in the analysis were data collected from day 35 to day 150 of lactation. It assessed the effects of cooling dairy cows in summer on their productive performance, i.e. milk yield, milk composition, body condition and body weight functions and intake of water and food (the effects on reproductive performance will be reported separately). For this purpose milk yields over the 150 days were analyzed in a model which included year, treatment (cooled or non-cooled), body condition at partum and their interactions, cows (nested within year, treatment and condition), week in the period and its interactions with main effects. Statistical analyzes were carried out using General Linear Model statistical procedures (Cary, 1985).

RESULTS

Climatic conditions.

Climatic conditions prevailing during the experimental periods are presented in figures 1 to 3.

The weather prevailing during each of the two years was quite variable. The data presented in Figures 1-3 indicate a definite seasonal pattern of the weather. Quite large day to day variation was present, as well as a marked hot spell towards the end of summer in both years. The variation in minimal and maximal values, as well as that in diurnal amplitude was such, that minimal and maximal values almost overlapped.

Milk and FCM yields.

Mean milk production of the animals over the 87 days between July 22 and October 16 in the two years was 35.2 ± 1 kg/day. On July 22, they were on the average on day 53 of lactation, and by October 16 the animals were on the average on day 119 of lactation. The difference between the two figures is about 66 days, less than the 87 days between July 22 to October 16. This is mostly due to animal's data being collected only till they reached 150 days of lactation. It should be noted that the cooled and noncooled groups were similar for the respective days in lactation at start and at end of period in both years (table 1).

Figure 1. Weekly means for maximum and minimum air temperatures during the main experiment periods in the two years.

Figure 2. Weekly means for maximum and minimum relative humidities during the main experiment periods in the two years.

Figure 3. Weekly means for temperature-humidity index (THI) during the main experiments periods in the two years.

Table 1. Number of animals, days in lactation and milk yield (means $\pm$ SEM) on day 1 (July 22) and on day 86 (October 16) of the observation period in experimental groups by year. Means and SE.

	1985			1986		
	N	Day 1	Day 86	N	Day 1	Day 86
<hr/>						
<u>Days in milk</u>						
Cooled	16	51±3	126±3	20	55±4	112±5
Control	16	54±4	123±3	18	53±4	116±6
<hr/>						
<u>Milk yield</u>						
Cooled	16	38±1	31±2	20	39±2	32±1
Control	16	38±1	32±1	18	38±1	31±1

Table 2. Analysis of variance of daily milk and FCM yields over the summer period.

Source of variance	Milk yield			FCM Yield		
	DF	MS	<P	DF	MS	<P
Cooling ¹ (C)	1	4498.3	*	1	212.4	*
Condition ¹ (BC)	1	209.8		1	186.0	.06
C * BC ¹	1	197.8		1	53.6	
Cows (C * BC)	74	1025.7	**	74	52.1	**
Week ² (W)	12	2196.6	**	12	113.3	**
C * W ²	12	80.2	**	12	1.4	
BC * W ²	12	35.5	**	12	3.8	
W * C * BC ²	12	17.3	**	12	2.3	
Residual	5683	7.9		312	7.1	
R ²		.71	**		.73	**

1 - Tested versus cows (C * BC)

2 - tested versus residual

** - P<.05

*** - P<.01

A preliminary analysis of the data indicated that parity 2 to 4 had no significant effect on milk yield or its responses to cooling. The year term in the analysis of variance was not significant ($P>.25$), neither were its interactions with other main effects in the model. These two terms were therefore deleted from the analysis of milk yield. The analysis of variance of milk yield and least squares means for main effects are presented in tables 2 and 3.

Table 3. Least square means ($\pm$ SEM) of milk and FCM daily yields for different experimental groups over the summer (C = cooled, NC = control, HC = high body condition, LC = low body condition)

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
<u>Milk Yield</u>				
Mean	36.2	34.3	35.4	35.0
SEM	.6	.7	.7	.6
N	41	38	36	43
<u>FCM Yield</u>				
Mean	28.9	27.4	28.9	27.4
SEM	.5	.6	.6	.5
N	41	38	36	43
	C*LC	C*HC	NC*LC	NC*HC
<u>Milk Yield</u>				
Mean	36.2	36.2	33.9	34.7
SEM	.9	.9	.8	1.0
N	21	20	22	16
<u>FCM Yield</u>				
Mean	28.6	29.3	26.2	28.5
SEM	.7	.7	.7	.8
N	21	20	22	16

The model accounted for 73% of variance. The interactions of week in experimental period with treatment (C or NC) or with BC at partum (L or H) were statistically significant ($P < .01$), as was the week by treatment by BC. The latter represent effects due different climatic conditions during the experimental period.

Mean milk yield during the hot period was higher by 1.9 kg/d in the cooled animals than in the control ones (36.2 vs 34.3 kg/d, $P < .05$, table 3, figure 4). Cooling increased FCM yield by 1.5 kg/d (figure 5), the increment being similar percentagewise to the milk yield increment. Body condition did not affect milk yield, neither did it interact with cooling to affect mean milk yield during the summer period. Body condition at calving did however affect mean FCM yield, increasing it by 1.5 kg (from 27.4 to 28.9 kg/d, $P < .06$, figure 6); neither in this case did cooling interact with body condition.

Figure 4. Effect of cooling on milk yield during summer.

Figure 5. Effect of cooling on milk yield during summer.

Figure 6. Effect of cooling on FCM (4%) yield during the summer.

Milk components

The mean values for fat, protein and lactose concentrations during the summer (as by biweekly determinations) were $2.61 \pm .37$, $2.84 \pm .20$, and $4.36 \pm .17$ respectively. The daily yields for milk components and milk solids were $.92 \pm .15$, $1.00 \pm .08$, $1.55 \pm .15$ and $3.49 \pm .32$ respectively. Analysis of variance and means are presented in tables 4 to 6.

The percentage of protein in milk was the single component to be significantly increased by cooling the animals, its mean concentration being increased by cooling from 2.82% to 2.91%. Fat concentration was increased by body condition, although the animals were at least 53 days after partum at the start of this period. The concentrations of the three components significantly changed during the summer, which probably reflects the effect of advancing lactation. The significant interaction of protein concentration with week probably suggests effects of weather on protein concentration, in light of the significant effect of cooling on protein concentration. It is noteworthy that body condition and cooling did not interact to affect the concentration of any of the three milk components.

Table 4. Analysis of variance of milk components (%) fat, protein and lactose over the summer period.

Source of variance	DF	% fat MS	<P	% protein MS	<P	% lactose MS	<P
Cooling ¹ (C)	1	.06		.71	*	.36	
Condition ¹ (BC)	1	6.00	**	.01		.01	
C * BC ¹	1	.64		.03		.37	
Cows (C a BC)	74	.83	**	.18	**	.25	**
Week ² (W)	5	.60	**	.23	**	.01	**
C * W ²	5	.11	.1	.04	*	.01	
BC * W ²	5	.09		.01		.01	
W * C * BC ²	5	.09		.01		.01	
Residual	316	.14		.04		.03	
R ²		.64	**	.57	**	.71	**

1 - Tested versus cows (C * BC)

2 - tested versus residual

* - P<.05

** - P<.01

The daily yields of the three components and of milk solids were all significantly increased by cooling. The mean daily protein yield was increased

by about 8% in the cooled cows. This indicates that the increase in milk volume, attained by cooling, reflects an increased synthesis of milk, and not merely an increased water transfer through the mammary gland, or an increase in the production of a single component. This contrasts the effect of body condition, which was limited to one milk component only, namely milk fat. In this case too, no significant interaction was observed between body condition and cooling.

Table 5. Analysis of variance of milk components (kg/d) fat, protein, lactose and of total milk solids yields for the summer period.

Source of variance	DF	fat		protein		lactose		solids	
		MS	<P	MS	<P	MS	<P	MS	<P
Cooling ¹ (C)	1	.33	.1	.64	**	.91	*	5.50	**
Condition ¹ (BC)	1	.82	.1	.01		.05		1.38	.15
C * BC ¹	1	.13		.05		.01		.45	
Cows (C * BC)	74	.10	**	.05	**	.18	**	.70	**
Week ² (W)	5	.20	**	.04	**	.02	**	.90	**
C * W ²	5	.01		.01		.01	*	.03	
BC * W ²	5	.01	.1	.01		.01		.04	
W * C * BC ²	5	.03		.01		.03	*	.10	*
Residual	314	.02		.01		.02		.07	
R ²		.59	**	.63	**	.78	**	.75	**

1 - Tested versus cows (C * BC)

2 - tested versus residual

* - P<.05

** - P<.01

TABLE 6. Least square means ($\pm$ SEM) of milk components (% and kg/d) fat, protein, lactose and total milk solids during summer period for the experimental groups (C = cooled, NC = control, HC = high body condition, LC = low body condition).

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
<u>Fat</u>				
%	2.68 $\pm$.07	2.65 $\pm$.07	2.80 $\pm$.06	2.54 $\pm$.06
Kg/d	.96 $\pm$.02	.90 $\pm$.02	.98 $\pm$.02	.89 $\pm$.02
<u>Protein</u>				
%	2.91 $\pm$.03	2.82 $\pm$.03	2.86 $\pm$.03	2.87 $\pm$.03
kg/d	1.04 $\pm$.01	.96 $\pm$.01	1.00 $\pm$.01	1.00 $\pm$.01
<u>Lactose</u>				
%	4.37 $\pm$.04	4.31 $\pm$.01	4.36 $\pm$.04	4.32 $\pm$.03
kg/d	1.58 $\pm$.03	1.48 $\pm$.03	1.54 $\pm$.03	1.51 $\pm$.03
<u>Total Solids</u>				
kg/d	3.59 $\pm$.06	3.34 $\pm$.06	3.53 $\pm$.06	3.40 $\pm$.06

Figure 7. Effect of cooling on milk protein content (%) during summer.

Figure 8. Effect of body condition at partum on milk fat content (%) during summer.

EXPERIMENT II (ISRAEL):4. PERIPARTUM CHANGES IN HORMONES, METABOLITES, BODY WEIGHT AND BODY SCORE.

The high producing dairy cow is liable to be in a precarious nutritional homeostatic state, specifically so during her peak milk production period. This situation is further aggravated by environmental heat which imposes additional thermoregulatory limitations on feed intake, milk production and reproductive function. High producing dairy cows probably are particularly sensitive to the stress of environmental heat, due to additional metabolic heat arising from their intensive milk production.

The periparturient period probably is a critical phase in the production cycle of the dairy cow. It is the period during which mammary gland capacity is determined, as well as that during which factors involved in determination of peak milk production are operant. Previous studies examined the effect heat stress effects during the late pregnancy period. They indicated that relief of heat stress during this period increases milk production as well as calf birth weight (Collier et al., 1982; Wolfenson et al. 1987). Relief of mild prepartum heat stress, which increased prepartum progesterone, also increased milk yield, although there was no between cow correlation between mean 60 days prepartum progesterone and milk production (Wolfenson et al, 1986). It might thus be postulated that environmental heat stress effects on dairy cow performance are particularly dominant during the peak lactation period, when metabolic heat production is maximal, and during late gestation, when mammary gland capacity is determined and lactogenesis is initiated.

Heat stress effects on dairy cow performance may be prevented by cooling cows during the high milk production period to an extent sufficient for dissipation of metabolic heat production. Such an approach requires however proper animal shelters, as well as availability of technology, and investment in its application. The period of peak lactation seems to be a feasible target period for cooling dairy cows, as it is the period of both maximal metabolic heat load, as well as the period during which relief of heat stress effects on reproduction is required. If the effects of heat stress are mediated through its action on feed intake, it seems that an alternative to cooling exists. Increasing energy stores in the animal prepartum might compensate for the reduced feed intake postpartum. Such an approach is being currently examined.

This presents the metabolic consequences of increasing energy stores prepartum were examined on a subgroup of animals. The need for such an examination arises from the known negative effects of high body condition prepartum on subsequent performance of dairy cows, which in its more extreme cases might lead to postpartum ketosis and fatty liver syndrome.

EXPERIMENTAL PROCEDURES

In the animals of this study, plasma concentrations of T3, T4, insulin, glucose, FFA, and urea were determined as described by Kunz and Blum (1985). These parameters were determined for the last 6 weeks prepartum and for the 8 weeks following calving, in 48 cows, 24 cows in each year, which were a subset of the animals of the main experiment. During the prepartum period, half of the cows were from the HC and the other half from the LC group. After calving animals of each condition group were paired by age, yield, and calving date, and members of the pairs randomly allocated to C and NC groups. Procedures followed with this subset of the animals did not differ from those followed with the other animals, but in the analyses carried out on blood samples. Analyses of the fore-mentioned were carried out as described in Kunz and Blum (1985).

RESULTS

PREPARTUM PERIOD

Thyroid function

The statistical model used for all the prepartum blood data analyses is brought in table 1 for the thyroid function data. Mean T4, T3 (nmol/l) and T4/T3 ratio during the last 40 days prepartum were 58.3 ± 1.1 , 1.78 ± 0.3 and 33.9 ± 1.1 respectively (table 2). Animals brought to a higher body condition had T4 and T3 plasma concentrations higher by about 20% ($P < .02$), with no change in T4/T3 ratio. The concentrations of T4 and T3 declined during the last 3 weeks of pregnancy (figures 1, 2) to reach close to half the value recorded at about 40 days prepartum. The decline was similar in the two condition groups, although a trend for a different rate of change due to condition was reflected in the significant interaction week by condition in the T4/T3/ratio. This trend is expressed in the earlier decline in T3 and T4 concentrations in the LC cows than in the HC cows. As a result, in the last week prior to calving, T4 and T3 were higher by 137% and 118% respectively in the HC cows.

Figure 2. Prepartum body condition effect on T3 plasma concentration.

Figure 1. Prepartum body condition effect on plasma T4 concentration.

Table 1. Analysis of variance of T4, T3 (nmol/l) and T4/T3 ratio during the last 40 days of the prepartum period.

Source of variance	DF	MS	T4 <P	MS	T3 <P	MS	T4/T3 <P
Condition ¹ (BC)	1	8578	.02	6.6	.02	30	
Cows (BC) ²	44	1554	**	1.2	**	348	**
Week ² (W)	4	4326	**	.5	**	899	**
BC * W ²	4	424	.3	.1		246	*
Residual	178	354		.1		102	
R ²		.62	**	.71	**	.55	**

1- Tested versus cows (BC)

2- tested versus residual

* - P<.05

** - P<.01

TABLE 2. Effects of body condition on T4, T3 (nmol/l) and T4/T3 ratio (means $\pm$ SEM) during the last 40 days prepartum period.

	Body Condition	
	HC	LC
T4	66.6 $\pm$ 4.2	53.0 $\pm$ 4.0
T3	1.97 $\pm$.10	1.59 $\pm$.10
T4/T3	34.3 $\pm$ 2.0	35.1 $\pm$ 1.9

Glucose

The R² of the statistical model was .42 (P<.01). Mean prepartum glucose level was 3.48 $\pm$.06 mmol/l. This level was slightly higher in the HC cows (3.54 vs 3.43, tables 3, 4) but the difference was not statistically different. Glucose levels decreased slightly with advancing gestation (P<.06). Prepartum body condition did not significantly affect this rate of change, although a trend was evident (P<.26) for a difference in rate of decrease in the two groups (figure 3).

Insulin

The R² of the statistical model was .49 (P<.01). Mean insulin level during the prepartum period was 13.2 $\pm$.76 mU/l (table 3, figure 4). This level was significantly higher in the HC condition group (17.4 vs 10.7, table 4, P<.01).

Insulin levels gradually decreased with approaching calving ($P<.01$), its level in the last week of pregnancy reaching about a third of the level at 5 weeks prepartum. Prepartum body condition did not significantly affect this pattern.

Free fatty acids

The R^2 of the statistical model was .36 ($P<.01$). Mean FFA level was $.56\pm.01$ mmol/l, and was not affected by prepartum condition level (.49 vs .58 in the HC and LC condition groups, respectively, $P<.24$, tables 3, 4). FFA remained more or less stable during 6 to 4 weeks before calving, to increase markedly in the last weeks of gestation ($P<.01$). The increase was affected by prepartum condition : in the HC group it started in week 3 prepartum, while in the LC group it started 1 week later (figure 5). Also, the increase was smaller in the LC than in the HC group.

Table 3. Analysis of variance of glucose (mmol/l), insulin (mU/ml) and FFA (mmol/l) during the last 40 days of the prepartum period.

Source of variance	DF	Glucose		Insulin		FFA	
		MS	<P	MS	<P	MS	<P
Condition ¹ (BC)	1	.6		2071	**	.4	.24
Cows (BC) ²	44	.8	**	205	**	.3	.04
Week ² (W)	4	.8	.06	725	**	1.0	**
BC * W ²	4	.3		114	.26	.2	
Residual	178	.3		86		.2	
R ²		.42	**	.49	**	.36	**

1- Tested versus cows (BC)

2- tested versus residual

* - $P<.05$

** - $P<.01$

Table 4. Effects of body condition on glucose (mmol/l), insulin (mU/ml) and FFA (mmol/l) during the last 40 days of the prepartum period. Means and SEM.

	Body Condition	
	HC	LC
Glucose	3.54 $\pm$ 1.0	3.43 $\pm$ 0.9
Insulin	17.5 $\pm$ 1.6	10.7 $\pm$ 1.4
FFA	.49 $\pm$.1	.58 $\pm$.1

Figure 3. Prepartum body condition effects on plasma glucose concentration.

Figure 4. Prepartum body condition effect on plasma insulin concentration.

Figure 5. Prepartum body condition effects on plasma FFA concentration.

Urea

The R^2 of the model was .50 ($P < .01$). Mean prepartum urea level was $4.44 \pm .11$ SE, and was significantly increased at the higher body condition level (5.84 vs 4.29, $P < .01$, tables 5, 6). This difference in urea levels probably reflects not only the body condition state, but the difference in the nutrition the animals received during the dry period. The two condition groups also differed ($P < .12$) in that in the LC group urea increased in the last week before partum, while in the HC group a decline was evident in the last 3 weeks (figure 6).

Total protein

Total protein in plasma was only determined in the first year of the study. The R^2 of the model was .50 ($P < .01$, table 5). Mean protein in plasma was $8.06 \pm .03$ SE g%. There was a trend for it to be lower in the HC group than in the LC group (7.98 vs 8.18, table 6, $P < .03$). Total plasma protein decreased with advancing pregnancy from 8.1 g% in week -3 to 7.85 g% in week -1 ($P < .01$). This effect of gestation was likely to be affected by prepartum body condition ($P < .12$, figure 7).

TABLE 5. Analysis of variance of urea (mmol/l) and total protein (g%) during the last 40 days of the prepartum period.

Source of variance	DF	Tot. prot. MS	<P	DF	Urea MS	<P
Condition ¹ (BC)	1	1.3	.03	1	108.3	**
Cows (BC) ²	35	.3	**	44	9.4	**
Week ² (W)	3	.7	**	4	2.8	
BC * W ²	3	.1		4	5.6	.12
Residual	101	.1		178	3.0	
R ²		.57	**		.50	**

1- Tested versus cows (BC)

2- tested versus residual

Figure 6. Prepartum body condition effect on plasma urea concentration.

Figure 7. Effect of body condition on plasma total protein concentration.

TABLE 6. Effects of body condition on urea (mmol/l) and total protein (g%) during the last 40 days of prepartum period. Means $\pm$ SEM.

	Body Condition	
	HC	LC ^A T
T. prot.	7.98 $\pm$.10	8.18 $\pm$.10
Urea	5.84 $\pm$.30	4.29 $\pm$.30

Body weight and body condition score. Due to technical problems, body weight was not determined during the prepartum period in the first year of the study. Mean body condition of the animals was 3.30 $\pm$.01 SE. The two body condition groups differed in their mean body condition during the dry period: it was 3.91 $\pm$.02 SE for the HC group and 2.68 $\pm$.02 for the LC group ($P < .001$). Mean body condition score slightly decreased in the terminal week of gestation by about .12 body condition score unit ($P < .05$). There was no significant prepartum body condition by week interaction, indicating similarity of prepartum body condition score changes in the two condition groups.

POSTPARTUM PERIOD

Body weight

Mean body weight in the first week postpartum week was 639 $\pm$ 3.5 SE in the HC group, and 567 $\pm$ 3.5 in the LC group. Neither prepartum condition, nor postpartum cooling, nor their interaction significantly affected mean postpartum body weight. Body weight however significantly changed during the postpartum period ($P < .001$), and this change was significantly affected by prepartum body condition ($P < .001$). This interaction is reflected in the pattern of body weight change which differed in the two groups. In the HC group body weight decreased by 71 kg, and stabilized by week 7; in the LC group, postpartum decrease in body weight was 27 kg only, and body weight stabilized by week 4 postpartum. The stable body weight in the LC group was about 28 kg lower than in the HC group.

Body condition score

Mean postpartum body condition score was 2.47 $\pm$.02 SE. It was significantly affected by prepartum condition ($P < .001$): in the HC group mean postpartum body score was 2.82 $\pm$.04 SE, while in the LC group it was 1.94 $\pm$.04 SE. It significantly decreased with time after calving, in a nonsignificantly different pattern ($P > .10$) in the two prepartum condition groups. It decreased from a mean

of 2.88 score units in the first postpartum week to 2.05 in the 8th week. The effects of cooling postpartum and its interactions were not statistically significant.

Thyroid function

The R^2 of the models for T4, T3 and T4/T3 ratio were .63, .68 and .45 respectively, all significant at $P < .01$ (table 7). Means (and SEM) for T4, T3, and T4/T3 ratio over the 54 days postpartum period were $48.4 \pm .6$, $1.78 \pm .02$ nmol/l and $28.3 \pm .34$ (table 8).

TABLE 7. Analysis of variance of T4, T3 and T4/T3 ratio during the first 54 days of the postpartum period.

Source of variance	DF	T4		T3		T4/T3	
		MS	<P	MS	<P	MS	<P
Cooling ¹ (C)	1	366		1.3		722	.09
Condition ¹ (BC)	1	1		.3		168	
BC * C ¹	1	460		.1		150	
Cows (BC) ²	43	1202	**	2.1	**	247	**
Week ² (W)	7	4215	**	4.9	**	32	
C * W ²	7	130		.2		35	
BC * W ²	7	158		.2		34	
BC * C * W ²	7	248	.10	.2		23	
Residual	352	145		.2		42	
R ²		.63	**	.68	**	.45	**

1 - Tested versus cows (BC)

2 - Tested versus residual

* - $P < .05$

** - $P < .01$

Neither prepartum body condition, nor postpartum cooling significantly modified means of T4 or T3. However, the T4/T3 ratio was slightly reduced by cooling ($P < .09$), owing to the inverse trends for mean effects of cooling on T4 (decrease) and T3 (increase). In no case was there a significant interaction between body condition and postpartum cooling. Both T4 and T3 increased after calving in a similar pattern, as indicated by the nonsignificant cooling by week or body condition by week interactions, and by the nonsignificant week term for the T4/T3 ratio. The increase in T4 and T3 was not immediate, it started about 2 weeks after calving. T4 increased by about 65% between the first and the eighth postpartum week, while the concomitant increase in T3 was about 40% only (figures 8, 9). Mean rate of increase of T4 after calving was 3.53 nmol/week ($P < .01$). Both T4 and T3 reached a plateau by week 4 in the 2C condition group, but continued to increase in the HC group ($P < .1$). Cooling affected the

Figure 8. Postpartum cooling effect on plasma T4 concentration.

Figure 9. Postpartum cooling effect on plasma T3 concentration.

postpartum pattern of change of T4 ($P<.4$)). T4 in the cooled animals plateaued by week 4 postpartum, while in the control animals this was reached by week 6 postpartum.

TABLE 8. Effects of prepartum body condition and of postpartum cooling on T4, T3 (nmol/l) and T4/T3 ratio (means $\pm$ SEM) during the first 54 days postpartum.

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
T4	50.0 $\pm$ 2.5	52.0 $\pm$ 2.6	50.9 $\pm$ 2.5	51.0 $\pm$ 2.6
T3	1.95 $\pm$.1	1.83 $\pm$.1	1.92 $\pm$.1	1.86 $\pm$.1
T4/T3	26.6 $\pm$ 1.6	29.4 $\pm$ 1.2	27.3 $\pm$ 1.1	28.7 $\pm$ 1.2
	C*LC	C*HC	NC*LC	NC*HC
T4	51.1 $\pm$ 3.6	48.8 $\pm$ 3.6	50.9 $\pm$ 3.8	53.0 $\pm$ 3.5
T3	1.91 $\pm$.1	2.00 $\pm$.1	1.81 $\pm$.1	1.84 $\pm$.1
T4/T3	27.9 $\pm$ 1.6	25.3 $\pm$ 1.6	29.4 $\pm$ 1.7	29.4 $\pm$ 1.6

Glucose

Mean postpartum glucose (3.29 $\pm$.6 mmol/l) was not affected by postpartum cooling (tables 9, 10, figure 10). Mean glucose was slightly lower in the LC animals (3.23 for the HC vs 3.44 for the LC animals, $P<.17$). There was no significant interaction between body condition and postpartum cooling. Glucose declined after parturition, reached a minimum by the second week postpartum and gradually increased in the subsequent weeks ($P<.01$). These changes were not affected by either body condition or postpartum cooling, as indicated by the nonsignificant interactions between the week term and the body condition and cooling terms. It should be noted that in no group did glucose reach levels considered to be indicative of subclinical or clinical ketosis.

TABLE 9. Analysis of variance of glucose (mmol/l), insulin (mU/l) and FFA (mmol/l) during the first 54 days of the postpartum period.

Source of variance	DF	Glucose		Insulin		FFA	
		MS	<P	MS	<P	MS	<P
Cooling ¹ (C)	1	.43		433	.13	.13	
Condition ¹ (BC)	1	4.09	.17	1		1.33	**
BC * C ¹	1	.24		89		.04	
Cows (BC) ²	43	2.19	**	1131	**	.13	**
Week ² (W)	7	1.37	**	383	**	2.00	**
C * W ²	7	.24		91	**	.01	
BC * W ²	7	.31		24		.25	**
BC * C * W ²	7	.27		34		.18	**
Residual	352	.32		34		.04	
R ²		.50	**	.51	**	.60	**

1 - Tested versus cows (BC)
 2 - Tested versus residual
 * - P<.05
 ** - P<.01

TABLE 10. Effects of prepartum body condition and of postpartum cooling on glucose, FFA (mmol/l) and insulin (mU/l) mean (SEM) during the first 54 days postpartum.

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
Glucose	3.30±.1	3.37±.1	3.23±.1	3.44±.1
Insulin	10.5±1.0	12.7±1.0	11.6±1.0	11.5±1.0
FFA	.36±.1	.32±.1	.40±.1	.28±.1
	C*LC	C*HC	NC*LC	NC*HC
Glucose	3.43±.1	3.17±.1	3.45±.2	3.29±.1
Insulin	10.9±1.4	10.0±1.4	12.1±1.5	13.2±1.4
FFA	.31±.1	.41±.1	.25±.1	.40±.1

Insulin

Mean postpartum insulin was 11.0±.3 SE μ U/l, and was not modified by prepartum body condition. A definite trend for insulin to be lower in the cooled animals was evident (tables 9, 10, 10.5 for the C group vs 12.7 for the NC group, P<.17). This trend was not affected by body condition, as indicated by the nonsignificant body condition by cooling interaction term.

Insulin reached its lower level by the second week of lactation, and increased subsequently ($P < .01$). The rate of increase, similarly to the mean level, was lower in the cooled animals (figure 11), as indicated by the significant interaction between the week and cooling terms (table 9). The net effect was an increase in the difference in insulin concentrations between cooled and noncooled animals over the 54 first days of lactation.

Free fatty acids

Mean FFA postpartum was $.39 \pm .01$ SE mmol/l. It was not modified by postpartum cooling. High prepartum body condition markedly reduced it: mean value for the LC group was .28 mmol/l, while in the HC group it was .40 mmol/l (tables 9, 10). Mean FFA significantly decreased with time after calving ($P < .01$). The pattern of the decrease was affected by body condition ($P < .01$). In the LC animals, FFA decreased to below the prepartum concentration by the first week after parturition, while in the HC animals the preparturient increase still continued by this time, FFA reaching their peak value by that time (figure 5). As a result, FFA concentrations were lower in the LC animals than in the HC animals during most of the early postpartum period. In the first week postpartum, FFA level was 60% larger in the HC group than in the LC group, but the difference between the groups rapidly decreased thereafter, the condition groups reaching closely similar FFA concentrations by the 5-6th week postpartum. Postpartum heat stress relief did not alter FFA levels postpartum, neither did it modify the pattern of change with time after calving (figure 12).

Urea

Mean urea level during the postpartum period was $6.84 \pm .08$ SE mmol/l. It was significantly lower ($P < .03$) in the cooled animals (tables 11, 12, figure 13).

It was also lower in the HC animals ($P < .04$), the magnitude of the effect being similar to that of the cooling postpartum. However, no trend for a significant interaction of cooling with body condition was evident ($P < .45$). Urea plasma concentrations gradually increased after parturition ($P < .01$). The differences due to body condition or to cooling remained similar until 54 days after calving, as indicated by the nonsignificant interactions between the week term and the body condition or cooling terms ($P < .98$ and $P < .74$, respectively).

Figure 10. Postpartum cooling effect on plasma glucose concentration.

Figure 11. Postpartum cooling effect on insulin concentration in plasma.

Figure 12. Postpartum cooling effects on FFA concentration in plasma.

Figure 13. Postpartum cooling effect on plasma urea concentration.

Figure 14. Postpartum cooling effect on plasma total protein concentration.

TABLE 11. Analysis of variance of urea (mmol/l) and total protein during the first 54 postpartum days.

Source of variance	DF	Urea MS	<P	Tot. Prot. DF	MS	<P
Cooling ¹ (C)	1	54.8	.03	1	.1	
Condition ¹ (BC)	1	44.9	.04	1	2.6	.04
BC * C ¹	1	6.1		1	.2	
Cows (BC C) ²	43	10.7	**	34	.6	**
Week ² (W)	7	34.7	**	20	.2	**
C * W ²	7	1.2		20	.01	
BC * W ²	7	1.3		20	.01	
BC * C * W ²	7	1.0		20	.02	
Residual	351	2.1		630	.02	
R ²		.55	**		.66	**

1 - Tested versus cows (BC)

2 - Tested versus residual

* - P<.05

** - P<.01

Table 12. Effects of prepartum body condition and of postpartum cooling on mean and SEM of plasma urea (mmol/l) and total protein (g%) during the first 54 days postpartum.

TREATMENT GROUPS MEANS				
	C	NC	HC	LC
Urea	6.70±.2	7.48±.2	6.74±.2	7.44±.2
T. Prot.	7.75±.1	7.73±.1	7.80±.1	7.68±.1
	C*LC	C*HC	NC*LC	NC*HC
Urea	6.92±.3	6.48±.3	7.96±.3	7.00±.3
T. Prot.	7.67±.1	7.82±.1	7.68±.1	7.77±.1

Total protein. Total protein in plasma was only determined in the first year of the study. The R² of the model was .66 (P<.01). Mean plasma protein during the postpartum period was 7.73±.01 SE. Plasma protein was not affected by cooling the animals (figure 14). However, it was higher in the HC animals. It also changed during the periparturient period (P<.01). The peripartum fall in plasma protein was followed by an increase in its concentration, so that the postpartum level was attained by 3 to 4 weeks.

DISCUSSION

This study aimed to examine the effects of prepartum body condition and its interactions with postpartum heat stress relief on the patterns of metabolites and metabolic hormones. The period examined comprised the last 40 prepartum days and the first 50 postpartum days. In the following discussion the effects of prepartum condition on prepartum state will be examined firstly, then the effect of prepartum condition and postpartum heat stress relief on mean postpartum responses, ending with the latter effects on the postpartum pattern of change of responses.

A study on body fat distribution in British Friesian and Jersey steers fed ad libitum from 13 to 507 days, indicated that the first breed had significantly more relative subcutaneous and carcass fat and less abdominal fat depots (Butler-Hogg and Wood, 1982). Fattening of mature Holstein cows, which increased total body dissectable fat from 20.5 kg to 30.8 kg, was associated with a uniform relative increase in abdominal, intermuscular and subcutaneous fat (Jones, 1983). In nonpregnant, nonlactating dairy cows body condition scores accounted for 85.8 to 90.8% of variance in body energy content (Wright and Russel, 1984). These suggest that body condition scores, which are based mostly on subjective assessment of subcutaneous fat, might be a sensitive measure of changes in body fat stores in British Friesian and Holstein cattle.

A study (Russel and Wright, 1983) on the effects of energy balance from -30 to 0 MJ ME/day during final 12 weeks of pregnancy in Hereford x Friesian and Blue Grey (White Shorthorn x Galloway) cows, concluded that glucose levels are positively related to energy balance, accounting for about 70% of variance in energy status; FFA levels were negatively related to energy status, and were a more sensitive index of energy status, as they accounted for 98% of its variance. Kunz and Blum (1985) extended this to the post partum period and to positive energy balances. Their data indicate that a relationship between glucose and FFA and between energy balance is evident mostly for negative energy balances, during both the prepartum and the postpartum periods. Feeding dairy cows during the dry period at a level which produced a light negative energy balance was sufficient to elicit an increase in FFA vs cows fed to gain weight during this period (Kunz et al., 1985), though a sparing effect of low body condition on energy requirements was demonstrated (Ferrell and Jenkins, 1984). The lack of difference in FFA levels during the prepartum period between the LC and HC groups in this study, as well as in another study (Reid et al, 1986)

indicates thus that a LC body condition maintains an energy intake sufficient to support energy requirements during this period.

In this study, high prepartum body condition was associated with higher T4, T3, glucose, insulin, but not FFA, urea or total protein. In another study, fat body condition increased FFA, but not glucose level (insulin was not determined), in non-lactating British Friesian cows, switched over 5 months between fat and thin body condition (Bines and Morant, 1983). It should be noted that FFA levels were very low in the thin cows, which might reflect the fact they their empty body weight was reduced by about 240 kg (36% of empty body weight in the fat state). This difference in FFA levels might thus merely reflect depletion of body fat depots in the thin state. Higher insulin, but not glucose, and lower urea levels, associated with high prepartum energy intake were reported (Kunz et al, 1895). The present study and that of Kunz et al (1985) are not however directly comparable, as in the latter study FFA were higher in the lower prepartum energy intake group; this group was in a slight negative energy balance, which might explain the higher FFA as well as higher urea levels, as stemming from body tissue breakdown. Overconditioning dry Holstein cows increased insulin levels, but not FFA, with no effect on glucose levels (Fronk et al., 1980). In a study carried out in British Friesian cows, very similar in design to this study, insulin and total protein were significantly higher in the high condition group, with no significant treatment effect on glucose, FFA, and urea levels (Reid et al, 1986). It seems thus that high body condition generally increases insulin levels, with less uniform effects upon glucose and FFA levels. The rise in insulin is indicative of increased fatty acids esterification, and seems to be typical of high body condition.

The effect of high body condition on FFA levels probably depends upon the energy balance of the animals to which it is compared; it is likely that high body condition does not affect FFA levels as long as they are compared to those of animals in a positive energy balance. The levels of FFA increase in lower condition animals in negative energy balance, as long as sufficient fat depots are maintained. Glucose was increased by high condition only in the present study and was positively related to energy intake in animals in negative energy balance (Wright and Russel, 1983). Part of the differences in glucose responses to body condition states between studies might be due to differences in glucose availability in animals relative to their glucose needs. These data do not allow

to derive a clear unequivocal picture of prepartum body condition effects on blood metabolites or hormones involved in their control. The relationship of prepartum body condition and metabolic state to development of postpartum ketosis is even less clear, as indicated by lack of prepartum differences in insulin and metabolites between normal cows and cows which developed ketosis postpartum (Schwalm and Schultz, 1975).

The pattern which emerged during the postpartum period differed from that during the prepartum period. High body condition at partum increased mean postpartum concentrations of FFA, and total protein, reduced those of glucose and urea, and was without effect on mean insulin, T3 and T4 or their ratio. It should be stressed that at no time did glucose concentrations reach levels indicative or suggestive of subclinical ketosis, even when at their lowest levels by 2 weeks after calving. Cooling the animals after calving reduced T4/T3 ratio, insulin, urea, but did not affect T4, T3, FFA or glucose mean concentrations during the postpartum period. In no case was there a significant interaction between the main effects of body condition prepartum and cooling postpartum.

In the study of Garnsworthy and Topps (1982) the medium and high body condition produced prepartum groups were closely similar to those in this experiment; its results were similar to those of this experiment with respect to nonsignificant effects of prepartum body condition on insulin, glucose and a significant increase in FFA levels during the first 7 postpartum weeks. Similar results were obtained in another experiment (Fronk et al, 1980), in which overconditioning cows prepartum increased FFA during 1-28 days postpartum (only period examined), with no effect on glucose and insulin concentrations or β -hydroxybutyrate, triglycerides and cholesterol. Similar results were also obtained in the study of Reid et al (1986). It seems therefore that increasing body condition of dairy cows to levels such as in this study does not induce significant risk of compromising metabolic patterns. However, the benefit of such an energy store seems limited to only a moderate increase in milk fat, which is of questionable value even in hot climates but in specific economic conditions.

REFERENCES

- Bines, J.A. and Morant, S.V. 1983. The effect of body condition on metabolic changes associated with intake of food by the cow. *Brit. J. Nutr.* 50: 81-89.

Butler-Hogg, B.W. and Wood, J.D. 1982. The partition of body fat in British Friesian and Jersey steers. *Anim. Prod.* 35: 253-262.

Ferrell, C.L. and Jenkins, T.G. 1984. A note on the energy requirements for maintenance of lean and fat Angus, Hereford and Simmental cows. *Anim. Prod.* 39: 305-309.

Fronk, T.J., Schultz, L.H. and Harde, A.R. 1980. Effect of dry period overconditioning on subsequent metabolic disorders and performance of dairy cows. *J. Dairy Sci.* 63: 1080-1090.

Garnsworthy, P.C. and Topps, J.H. 1982. The effects of body condition at calving, food intake and performance in early lactation on blood composition of dairy cows given complete rations. *Anim. Prod.* 35: 121-125.

Gomila, L.F., Roussel, J.D. and Beatty, J.F. 1977. Effect of zone cooling on milk yield, thyroid activity and stress indicators. *J. Dairy Sci.* 60: 129-132.

Hart, I.C., Bines, J.A., Morant, S.V. and Ridley, J.L. 1978. Endocrine control of energy metabolism in the cow: comparison of the levels of hormones (prolactin, growth hormone, insulin and thyroxine) and metabolites in the plasma of high- and low-yielding cattle at various stages of lactation. *J. Endocr.* 77: 333-345.

Jones, S.D.M. 1983. Tissue growth in young and mature cull Holstein cows fed a high energy diet. *J. Anim. Sci.* 56: 64-70.

Kunz, P.L., Blum, J.W., Hart, I.C., Bickel, H. and Landis, J. 1985. Effects of different energy intakes before and after calving on food intake, performance and blood hormones and metabolites in dairy cows. *Anim. Prod.* 40: 219-231.

Kunz, P.L. and Blum, J.W. 1985. Relationships between energy balances and blood levels of hormones and metabolites in dairy cows during late pregnancy and early lactation. *Z. Tierphysiol., Tierernähr. u. Futtermittelkde.* 54: 239-248.

Reid, I.M., Roberts, C.J., Treacher, R.J. and Williams, L.A. 1986. Effect of body condition at calving on tissue mobilization, development of fatty liver and blood chemistry of dairy cows. *Anim. Prod.* 43: 7-15.

Russel, A.J.F. and Wright, I.A. 1983. The use of blood metabolites in the determination of energy status in beef cows. *Anim. Prod.* 37: 335-343.

Schwalm, J.W. and Schultz, L.H. 1976. Relationship of insulin concentration to blood metabolites in the dairy cow. *J. Dairy Sci.* 59: 255-261.

Treacher, R.J., Reid, I.M. and Roberts, C.J. 1986. Effect of body condition at calving on health and performance of dairy cows. *Anim. Prod.* 43: 1-6.

Wright, I.A. and Russel, A.J. 1984. Partition of fat, body composition and body condition score in mature cows. Anim. Prod. 38:25-32.