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LXXV.

Productive Adaptability of Holstein Cows to Environmental Heat

Part I.

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Abstract

Fifty-one Holstein cows, producing more than 20 kilograms of milk per day during a three-year study at three stages of lactation, were exposed to short-term heat (three days at 32 C) to measure adaptive and productive responses and the time necessary for recovery following exposure. Early-stage animals had higher rectal temperatures than mid- or late-stage animals. Heat exposure reduced milk yields and feed intake, increased rectal temperature and water intake at all stages. Four days after being exposed to the heat, milk yields and feed intake had not recovered whereas rectal temperature and water intake recovered significantly. Nine or 10 days were needed to recover thermoneutral milk levels for early or mid and late stage, respectively. Early-stage cows had a greater conversion ratio of feed to milk (milk/feed, Mcal) than mid or late stages during thermoneutral conditions and heat increased this ratio. A review of the frequency distributions for average individual cow responses to heat (all three stages) for rectal temperature, milk yield and feed intake suggested the development of a heat tolerance (positive productive adaptability) and heat sensitivity (negative productive adaptability) index. These data and the index reemphasized the dependency of lactation during heat stress on maintenance of thermoneutral core body temperature and the ability of the animal to maintain homeothermy and continue adequate feed intake.

Introduction

Heat adaptability of an animal reflects its ability to balance metabolic heat production against environmental heat gains and heat losses. Consequently, traditional heat tolerance indices have been based on the stability of body temperature (2, 3, 6, 7, 11, 29, 33). Rectal temperature is an index of heat adaptability, but it continues to be controversial for numerous reasons such as differences in response time to rising ambient temperature due to body size (4, 13). To add practical significance to a heat adaptability index, a production factor such as milk yield or growth rate must be equated with the level of thermal balance or imbalance.

The adaptability of lactating Holstein cows to environmental heat stress presumably varies with lactation level and individual animal phenotypic differences. But precise documentation is lacking. Acclimation and acclimatization affects (20, 22, 27, 30, 35) productive adaptability measures (17, 20, 25), and related post-stress recovery responses are of major importance in assessing the adaptability of an animal. Productive adaptability is an excellent concept for utilizing the thermal and productive response to more accurately predict a relative level of production potential in an adverse hot climate. Thermal imbalance of the animals negates the production goals of dairy enterprises, primarily because of economic losses associated withthe decline in feed intake (20), milk production and poor reproductive performance (27, 35).

Seasonal extremes (15, 34) in all climatic zones of the world present environmental limitations to high milk yields. Such limitations are particularly important during hot conditions in humid tropical, subtropical and temperate zones which inhibit evaporative heat losses. The overall limitations may be heat and humidity (5, 6), feed quality and quantity (21, 28), disease and pastures (12), general dairy management practices or a combination of these factors. An interaction of several factors may be responsible for suboptimal performance of lactation (8), reproduction (14, 19, 26) and growth (1, 9, 32). Data presented in this report are focused on acclimation responses of relatively high-producing lactating Holstein cattle to short-term (three day) heat exposure and post-heat response. Heat-induced effects in controlled-environment chambers were the sole limiting environmental factor with nutritional quality, disease and management factors being eliminated or minimized as variables. Rectal temperature, feed intake, water intake, body weight and milk yield measures were used to provide an integrated approach to assessment of productive adaptability, which included acclimation trends. A subsequent publication will describe responses of selected endocrine functions to assess relative productive adaptability.

Specifically, objectives of this investigation were to:

--Measure the effects of short-term heat exposure in the laboratory on the milk yields, rectal temperature and feed intake on fifty-one lactating Holstein cows at three stages of each cow's lactation, and to measure the time necessary to return to the preheat (prelaboratory and preheat) exposure production levels after return to the herd;

--Measure the stage of lactation effects on the above responses for high-producing cows (22 kg/day); and

--Estimate the relative individual heat adaptability capacity based on these measured responses and derived indices.

Materials and Methods

Table 1 describes the number of cows used, their stage of lactation, dates and season of entry into the Missouri Climatic Laboratory. Holstein cows from the University of Missouri herd were the source of experimental animals. About every three or four months, six cows were selected for testing using as criteria a lactation level greater than 22 kg/day at 60 to 100 days post-calving. This interval permitted testing of the cows during all seasons of the year (Table 1). After initial selection, the same cows were returned to the laboratory every 90-100 days as representative of mid- and late-lactation cows. As the experiment progressed, six early, six mid and six late-stage animals were tested during each season of the year. A total of nine groups of six animals were tested at each stage of their lactation. A total of 51 animals were used, including some that calved and were then used during a subsequent lactation. The procedure for testing at each stage of lactation was to record milk yields for nine days at the farm prior to transfer, to transfer animals by trailer to the Climatic Laboratory, and to start the schedule of measurements after overnight rest in the laboratory. Conditions in the laboratory were controlled as follows: four days thermoneutral (TN_1) conditions, constant 18 C and 60% RH; three days heat exposure (HS), constant 32 C and 50% RH; and four days post-heat thermoneutral exposure at constant 18 C and 60% RH (TN_2). Following the four days at TN_2, the animals were returned to the farm where milk production records were collected for 30 days to determine time of post-heat recovery. Daily yields throughout their lactation were obtained on as many of the cows used as possible in order to provide an estimate of the persistency of decline. In the laboratory, daily measures were made on individual feed intake, milk yields and water intake. Blood samples for hormonal analyses were taken at 10 a.m. and 10 p.m., and energy metabolism at 1 p.m. daily. Body weights were measured at 2 p.m. during the adjustment and last day of each treatment period.

Feed

Cows were fed just prior to morning and evening milkings at 6 a.m. and 6 p.m. Concentrate (UMC ration, HO-23; see Table 2 for composition and analysis) and long stem alfalfa hay were fed at fixed levels of 10.0 and 3.6 kg/cow/day, respectively. Corn silage was fed ad libitum daily. Any uneaten concentrate, hay and corn silage was weighed and recorded daily to obtain ad libitum intake. Cows were fed just prior to morning and evening milkings. Crude protein was measured by the Kjeldahl method and fiber by the acid detergent fiber procedure, which measures mainly cellulose, lignin, and energy (expressed as Mcal) by the bomb calorimeter.

Rectal Temperature

Rectal temperature for each cow was measured twice daily at 8 a.m. and 4 p.m. throughout the experiment using 13 cm clinical veterinary thermometers.

Water Consumption

Water was available ad libitum throughout the experiment from individual animal water bowls. Water meters (Kent, Model PSM 190) were read at 7 a.m. to measure the total volume of water consumed per day per cow. Water temperature was about 20 C.

Milking Procedure

Animals were milked with a Surge milking system (bucket-type) twice daily. Sanitary milk procedures included udder wash and use of strip cups.

Experimental Design

Cows entered the study at early, mid and late stages of lactation. Animals at each of the stages were tested at the various seasons of the year, to minimize any seasonal bias. Individual animal sensitivity or tolerance to the heat stress, recovery time and magnitude of response was also examined. Six animals at midstage of lactation were used as a partial sham control to assess any treatment, handling or duration of chamber effects during TN and heat exposure. Responses were sorted into early, mid and late categories and mean values were obtained for each cow at the three stages. Mean values for each lactational stage and each thermal exposure (TN_1, HS, TN_2) were tested for significance.

Statistical Analysis

Sample mean total milk production and other parameters were compared by stage of lactation and day of trial, with environmental treatments imposed as day differences. Analysis of variance, using sources of "stage of lactation", "day of test" and interaction was computed and least square means generated. Sample means were compared by day and stage to the production of days -9 (farm) and +3 (TN_1; as shown in Table 3). This permitted an evaluation of the effects of the three-day heat stress (days 4-6) and recovery during the post-heat thermal neutral period (days 7-10).

Results and Discussion

Effects on Milk Yield, Rectal Temperature and Water Intake

Figure 1 describes the average daily milk yield at each stage of lactation for all cows used in the study. The average daily milk yield trend for the nine days preceding transfer to the laboratory was extrapolated linearally as an expected milk yield during the laboratory and post-laboratory periods.

Milk yields for cows at all stages of lactation declined immediately upon transfer to TN_1 in the laboratory (Figure 1). The decline is ascribed to the transport and the new management and environmental conditions associated with stanchion housing, since feed quality and type was the same as received at the farm. Milk yield of all groups declined significantly during the three-day heat exposure with rapid recovery by day 10 (four days post-heat), although still significantly less than day 3 TN conditions. Percentage recoveries (day 3 vs day 10) were 84%, 87% and 88% for early, mid and late stages, respectively. The amount of milk lost as a result of the experimental treatments, the ability of the cows to recover in milk yield and the time for recovery at each stage of their lactation, were estimated using the average persistency decline (expected milk yield) shown in Figure 1. There was considerable individual cow variation in the slope of persistency decline. Cows were sorted into three lactation levels, even though all animals entered the experiment as good producers (22 or more kilograms of milk per day) in their early stage of lactation. Animals with less than 25 kg/day milk yields had an average persistency decline (M) of -0.019. Cows with milk yields of 25-30 kg/day had an M value of .031 and higher producers (30 kg/day) had an M value of -.059. The average persistency decline was 0.03%/day.

The total milk loss/cow/day due to environmental heat (TN day +3) compared with "expected" milk yields may be observed graphically in Figure 1. The dotted line (.....) in Figure 1 was used to calculate the heat effect and parallels the calculated persistency line described previously. The deviation or losses in milk yield from the farm levels (farm days -9 to -1) and subsequent persistency (—) line are also shown in Figure 1.

Table 3 provides a daily record of the mean milk yields for all cows at each stage together with the actual differences from farm (-1) and TN_2 (+3) days due to heat treatment. With no corrections for persistency decline, milk yields recovered so that no significant differences were detectable between pre-experimental production at the farm (day-1) and post-experimental production at the farm by day 15 for early, day 22 for mid, and day 15 for late stage cows. Early and mid stage cows returned to laboratory TN_1 production levels (day +3) by day 12 and 13 and by day 15 for late stage cows. That is four days post-heat for full recovery by early, six for mid stage cows and seven days for late stage cows. The stage of lactation and all environmental treatment conditions during periods 0, 1, 2, 3, 4 (Table 4) significantly ($P<.05$ or better) affected daily milk yields. The interactions of stage of lactation and environment at treatment were also significant.

Table 5 provides estimates of the total milk yield losses/cow/day resulting from heat and the losses of transportation and adjustment to laboratory and heat. The total milk losses/cow for the heat effects for early, mid and late stage cows were 20, 38 and 22 kg, respectively, for the nine- to 12-day periods. At $12.50/cwt for milk this would average about $748 for a 100-cow herd. The total losses in milk yield/cow for the 14-21 day heat plus transportation effects would average about $15/cow or $1500 for a 100-cow herd.

To estimate the ability of lactating cows to possibly compensate for heat-induced milk yield losses subsequent to the heat-stress period (after days 15 or 22, depending on stage of lactation) to day 40, average daily milk yields above or below the persistency line were calculated (Table 6). The net difference did indicate a possible slight recovery of lost production. But even if the effect is real, the value of the recovered yield would only be about $53.00 for 100 cows over a 19- to 23-day period. If milk yields were depressed by heat for more than three days, conceivably the compensation effects or recovery of milk yield may be much greater.

A sham trial was conducted in which all conditions of transport, laboratory management and measurements in the laboratory were identical to the schedule in Table 1; the only difference was that temperature during the HS period (days 4-6) was maintained at 18 C, 60% RH. Neither milk yields nor rectal temperature were significantly different ($P<.05$) for TN_1, sham heat or TN_2 conditions (Figure 2).

Table 7 presents the treatment period mean values for milk yields, rectal temperature and water intake at each of the three stages of lactation. Milk yields were significantly ($P<.05$) depressed for all lactation stages after transport and exposure to the laboratory conditions (TN_1). The heat treatment significantly decreased yields for all lactation stages. Recovery of milk yields during TN_2 to previous TN_1 levels did not occur for any stage of lactation. Mean 30 day values uncorrected for persistency decline for the post-laboratory exposure (farm) were significantly lower ($P<.05$) than the prior farm milk yields. A comparison among the three lactation stages at each of the environmental treatments (Table 7) showed all milk values to be different. Rectal temperatures were significantly increased by the heat exposure for cows at all lactation stages, but returned to prior TN_1 levels during TN_2. Rectal temperatures were slightly, but significantly ($P<.05$), higher for early stage cows during heat exposure than mid or late stage cows. Water intake significantly ($P<.05$) increased during the heat exposure, but returned to pre-heat levels (TN_1) during the TN_2 period for all lactation stages. However, late stage cows were significantly lower than early or mid lactation cows during TN_2 conditions.

Table 8 provides mean daily milk yield, rectal temperature and water intake during the TN_1, heat and TN_2 treatments. These values permit an assessment of the response time after exposure to the 30 C, 50% RH conditions; i.e., the day on which values differ significantly from day 3 of TN_1. Recovery responses to values after the TN_2 period begins can also be evaluated. Milk yields declined significantly ($P<.05$) on day 6 (third day of heat exposure) for early stage cows; mid and late-stage cows declined significantly ($P<.05$) by day five. Recovery of milk yields to the TN_1 (day three) values did not occur by the end of the TN_2 period (day 10) for cows at any lactation stage. Rectal temperatures increased significantly ($P<.05$) on day 4 (first day of heat) for early and day 5 for mid and late-lactation stage cows. For all stages of lactation, the cows returned to TN_1 levels on the second day of the TN_2 period (day 8).

Energetic Responses

Figure 3 illustrates energetic responses for milk and feed (Mcal/day) together with rectal temperatures (C) during heat exposure and subsequent post-heat trends compared to pre-heat values for all cows in early, mid and late-lactation stages. Increased body temperatures during the heat exposure provided a signal for decreased voluntary feed intake. Feed intake energy declined relatively greater than milk yield energy during the exposure time. By the third day of heat exposure, relatively fewer Mcal of feed were consumed per Mcal of milk produced. Rectal temperatures progressively increased during this period. As rectal temperatures declined during the post-heat period, feed intake energy recovered relatively faster than milk yields, energy and the milk/feed energy ratios and returned to pre-stress values during TN_2 treatment. The ratios of milk/feed energy increased progressively during heat exposure from days four through seven (Table 9), indicating less feed intake per unit of milk yield. A quite consistent increase in the ratio of milk/feed energy occurred during heat exposure for all lactation stages. The ratio during early lactation was 0.58 to 0.68, while it was 0.47 to 0.57 during midstage lactation. The ratio was 0.38 to 0.48 during late-stage lactation. Considering body weight loss during heat exposure as an energy input for milk synthesis, the milk/feed plus equivalent body weight energy declined slightly during heat exposure and continued to decline until day 8 (second day of TN_2 period). The decline indicated reduced efficiency during this period of reduced feed intake.

The milk/feed energy ratio declined as lactation progressed from 0.58, 0.47 to 0.38 during TN_1. During heat exposure the values similarly declined through E, M and L stages, (0.68, 0.57, 0.48) respectively. The mean declines for TN_2 were 0.57, 0.42 and 0.36., respectively. These data generally indicated that more feed was required per unit of milk as lactation progressed and thus resulted in less efficient conversion of feed to milk.

The comparative responses of milk yields, feed intake and rectal temperatures are illustrated in Figure 3. The relative declines in milk yield and feed intake were similar for each stage of lactation. However, the increase in rectal temperature was slightly higher at the early stage of lactation.

Feed energy intake and body weight as affected by environmental temperature for each stage of lactation are given in Table 10. Energy intake expressed as Mcal/day decreased significantly upon heat expo-

exposure for all stages and did not return to TN_1 levels during the four days post-heat TN_2 period. For an unknown reason, the early-stage lactating cows had a significantly lower intake (27.2 Mcal/day) during TN_1 than mid (28.4 Mcal/day) or late-stage cows (29.8 Mcal/day). There also was significantly less recovery after heat stress by early lactation stage cows than by mid and late stage cows. However, there was no difference in feed energy intake among the three lactation stage cows during heat exposure. Table 11 indicates that stage of lactation had no effect on rectal temperatures though early vs mid and late stage was shown earlier to be significant (Table 1). Other measures -- water, net energy intake and body weight -- were significantly affected by environmental heat.

Analysis of Adaptability

Since these experimental animals were selected at random from a herd all having a level of production greater than 22 kg/day at the early lactation stage, this experiment afforded an opportunity to assess relative phenotypic differences in heat tolerance at each stage of lactation. Milk yield and feed intake data were combined with rectal temperature in terms of a productivity index. Criteria used to establish negative or positive heat adaptability were the milk yield declines, the magnitude of rectal temperature increase and the decline in feed intake by day three of heat exposure.

To further understand the individual animal characteristics in animal productive adaptability in differences of TN_1 (day three) at each lactation stage vs heat (day six) measures were calculated for rectal temperature, milk yield and feed energy intake. These differences for the three stages for each cow were averaged and distributed into categories (Table 12). Differences in rectal temperature (R) (day three vs day six) ranged from 0.3 C to 2.8 C. The extremes of the population were designated as positive heat adaptable if rectal temperature changes were less than 1.2 C and those cows with 2.4 C or greater as negative heat adaptable. The designation was based on the average individual response at all three stages. For comparison, similar distributions were developed for the productive characteristics of milk yield (M) and feed energy intake (F). Because of stage of lactation differences in volume of milk yield, percentages were used in these comparisons. The percentage decline in milk yield during heat (day six) ranged from zero (100% of normal production level for TN_1 on day three) to 55% (45% of the TN_1 level). Individuals producing 92% or more of day three yields were designated as positive heat adaptable and those producing 72% or less designated as negative heat adaptable. Feed energy intake includes the average intake of concentrate, silage and hay expressed as Mcal/day. These feed intake data confirm the earlier work of Johnson et al. (25) which served as the basis for relationships developed and used by Osburn and Hahn (32). Table 12 also showed the derived index values for RM (Rectal Temperature increases x Milk Yield % decline) and for RMF, which includes a decline in feed intake as a multiple factor.

Of the 51 total cows, four (4, 91, 857 and 984) met all of the designated criteria for the rectal temperature (R), milk production (M) and feed intake (F) classifications. They also met the criteria for the calculated R x M or "RM" productive adaptability and the R x (M + F) RMF index as (+) productive adaptability. Similarly, three cows (75, 44, 925) met all of the criteria for a negative (-) productive adaptability index.

Six other cows which satisfied the criteria for (+) RM or RMF but exceeded the limits for some of the classifications (R, M, or F) are also shown in Table 12. Cows 90, 16, 686 met the (+) classification for R but did not meet the M and F (+) classification range. They presumably declined more in milk yield and feed intake to minimize an increase in rectal temperature. Two other cows exceeded the rectal temperature (R) limits but did not decline in milk (M). These examples illustrate the variation among animals in the relative compromises made for thermostability or maintenance of milk yields and feed intake.

At the other extremes of this randomly selected group of cows with genetic potential to produce greater than 22 kg/day in early stage of lactation are heat sensitive and negative animals based on R, M and F classification and which have negative RM or RMF indices. Included in this listing are eight animals that only exceeded the limits of one classification (R, M or F). The negative (-) productive indices (RM or RMF) were marginal for cows 796, 844, 7 and 53, though all cows far exceeded the greater than 28% milk decline except cow 7.

Table 12 lists the remainder of the cows which were intermediates in most index classifications, with the exception of cow 26. All of these cows were within the derived RMF range of 17.4 to 97.2. Only four of the cows were slightly outside of the RM range (9.6 to 67.2).

Regarding the merits of using more than one primary measure or derived index to select the most or least productively adaptable animals, it is apparent that for four cows only one measure (R, M or F) would be satisfactory, but would eliminate two cows (100 and 989) that can produce well under heat stress. Conversely, cows 90, 16, and 686 would be selected on the basis of R but declined somewhat more than desired for M. The RM or RMF index would retain all of these animals as the top 20% of the cow group. Appendix I lists the body weights of each cow at each stage of lactation. The data may be useful in future evaluation of the productive index. Figure 5 shows frequency distributions for the three primary measures, the two derived indices and a combination of all classifications for cows that fully met all criteria.

These classifications demonstrate the response of a herd to extreme stressors of heat and the relative changes in body temperature, milk yields and feed intake.

These curves illustrate the median and range of values at 18 C and 32 C. Environmental heat not only increases the median rectal temperature to 40.5 C or greater, but there was a wide range of rectal temperatures. Milk production, though decreased at 32 C for all stages, showed a similar characteristic for early and midstages. But late-stage curves were spread over a much wider range (5-30 kg/day). A greater number of early-stage cows showed feed intake around 18 Mcal/day at 32 C and about 28 Mcal/day at 18 C. Values were similar at midstage but at the late stage more of the animals' feed intake was around 30 Mcal/day at TN and 18 Mcal/day at 32 C with a wider distribution.

Discussion

Quantitative data on responses of a relatively large number of experimental cows to the same environmental temperature and humidity as developed in this study are especially useful since they also include the post-heat recovery changes which are quite limited in the literature. These data provide information on the temperature-time effects of body temperature, feed intake, milk yield and body weight changes which are the key factors in short or long-term adaptation. Data were further analyzed in terms of "productive-adaptability", the ability to maintain the prestress physiological and productive state, and measures of any compensating gains in lactation and related functions.

Responses to environmental heat and post-heat recovery did not differ greatly as a result of stage of lactation. The ability of early-lactation cows to recover milk yields following heat stress and to compensate was somewhat greater than for mid or late-lactation cows. The average post-heat recovery time required around 9-12 days depending on stage of lactation when compared to TN_1 levels. A longer stress period presumably would require a longer recovery time period. Whether more or less compensation in milk production would result is a matter of conjecture. Environmental heat reduces feed intake, milk production and the body reserves in lactating cows. But in growing animals, depression of feed energy intake and growth only involves the depression of body weight and/or energy reserves which can be more readily compensated (16). Late-stage animals had a lower ratio of feed/milk energy decline.

Though the cows had similar milk potential and production levels, there were considerable individual heat adaptability differences as measured by the various parameters. Heat tolerance or the ability to maintain thermal balance, especially when changes in milk yields and voluntary feed intake are combined for a "productive adaptability" index, can provide a scientific basis for the establishment of improved strains for adverse climatic zones. As long ago as 1932, Edwards described the problems of adaptability of temperate cattle which were transferred to tropical climates, but to date no major international scientific effort to resolve or minimize these problems has been initiated.

Of special significance in this study was the simultaneous measures of a spectrum of parameters on 51 cows at three stages of their lactation, with the cows selected at random from a group (herd) having production levels greater than 22 kg/day in the early stage of lactation. Generally, but with some exceptions, animals which had a higher (+) productive adaptability index declined less in milk and feed intake and had relatively less increase in rectal temperature. Within the ranges of milk production, the duration of exposure and temperature stress the stage of lactation was not a major factor in the milk decline due to heat, or the post-heat recovery. The primary measures of rectal temperature (RT), milk production (MP) or feed intake (F) appeared to classify the animals similarly to the derived indices (RM, RMF) for negative or positive adaptability. This relationship of rectal temperature to performance (milk yield) describes clearly the functional significance of thermal balance and energy related or "productive" functions. Coefficients need to be developed with appropriate supportive data for other livestock to equate a relationship with milk yield. These data do provide a productivity index within a production level range and demonstrated large individual differences in productive adaptability to heat stress.

A major challenge to the successful utilization of purebred temperate-evolved cattle and their crosses in the humid tropics and subtropics of the world is to utilize selective breeding practices with the aid of a productive-adaptability index that recognizes both thermal balance and production level. Of course, the heritability of the higher productive-adaptable animals needs to be established. Ultimately, an index should incorporate the relative effects of temperature, feed and disease resistance on production, as these are important animal adaptability characteristics for the various climatic zones of the world.

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Table 1. Schedule for cows, stage of lactation and season, dates in laboratory.

Cow Numbers	Stage of Cows	Date Entered Laboratory	Season
608*, 648, 829	E	3/15/79	W
857, (844), 989	M	7/11/79	S
984	L	9/12/79	F
880*, 919, 7, 1*	E	6/20/79	S
9, 5	M	10/02/79	F
	L	1/02/80	W
856, 942*, B-11	E	10/17/79	F
B-8, B-19, B-4	M	1/16/80	W
	L	4/30/80	SP
686, 608*, B-14	E	2/06/80	W
B-26, B-27, B-33*	M	5/14/80	SP
	L	7/30/80	S
990, 44, 880*, 999	E	5/28/80	SP
994, 64	M	11/28/80	F
	L	1/28/81	W
100, 91, 90, 1*	E	12/10/80	F
16, 104	M	2/11/81	W
	L	5/13/81	SP
89, B-33*, 95	E	2/25/81	W
	M	5/27/81	SP
942*, 93, 925, (B-20)	L	9/16/81	F
116, 34, 38, 101	E	6/10/81	S
106, 109	M	10/07/81	F
(Sham) 28, 92, 984 916, 75, 122	M	1/27/82 to 2/08/82	W

Season: Spring (SP), March 21-June 19; Summer (S), June 20-September 19; Fall (F), September 20-December 20; Winter (W) December 21-March 20

*Cows used in two laboratory series (608, 880, 1,33, 942)

Table 2. Composition of UMC Ration HO-23 and analysis of grain, silage, and hay.

Grain Concentrate Composition	Percentage
Ingredients:	
Ground Corn	78.2
Soybean Meal	13.4
Molasses	5.0
Dicalcium Phosphate	1.2
Urea	1.0
Salt	1.0
Phosphorous & Sulphur (Dynamate)	0.4
Magnesium	0.2
Vitamins A & D	0.2

	Chemical Analysis of the Feed		
	Protein D.M.%	Fiber(ADF) D.M.%	E.N.E. Mcal/kg
Grain Concentrate	20.3	4.4	1.9
Corn Silage	12.4	30.6	1.4
Alfalfa Hay	17.3	37.1	1.2

Table 3. Mean daily milk production, kg/day at farm, TN_1, Heat, TN_2 and farm.

		EARLY			MID			LATE		
			Diff Day			Diff Day			Diff Day	
Period	Day	Milk Prod	-9	+3	Milk Prod	-9	+3	Milk Prod	-9	+3
Farm (0)	-9	25.6 ± .59			23.0 ± .49			18.5 ± .87		
	-8	26.4 ± .55			23.5 ± .56			19.2 ± .75		
	-7	26.5 ± .55			23.0 ± .43			18.7 ± .77		
	-6	26.3 ± .59			22.4 ± .51			18.8 ± .78		
	-5	26.7 ± .59			23.2 ± .59			18.5 ± .73		
	-4	26.4 ± .54			22.4 ± .56			18.4 ± .78		
	-3	26.3 ± .50			21.7 ± .66			18.6 ± .73		
	-2	25.6 ± .44			22.2 ± .66			18.1 ± .78		
	-1	25.3 ± .53			21.1 ± .69			18.5 ± .84		
TN_1 (1)	1	23.3 ± .53			19.2 ± .68			16.5 ± .77		
	2	23.4 ± .50			19.6 ± .57			16.8 ± .71		
	3	23.4 ± .48			19.8 ± .61			16.7 ± .72		
Heat (2)	4	23.6 ± .43			20.4 ± .50			16.8 ± .68		
	5	22.0 ± .45			18.3 ± .53			15.3 ± .71		
	6	19.9 ± .43			16.4 ± .46			13.6 ± .77		
TN_2 (3)	7	18.0 ± .54			13.1 ± .53			11.7 ± .72		
	8	19.0 ± .51			14.3 ± .55			12.5 ± .76		
	9	20.3 ± .42			16.2 ± .46			14.1 ± .70		
	10	20.8 ± .53			17.4 ± .44			14.5 ± .72		
Farm (4)	12	21.7 ± .57	-3.9*	-1.65*	21.6 ± .42	-1.4	-1.83*	16.2 ± .74	-2.4*	- .55
	13	23.3 ± .46	-2.3*	- .05	19.6 ± .51	-3.3*	- .11	15.9 ± .73	-2.6*	- .76
	14	23.8 ± .36	-1.9*	.42	19.5 ± .52	-3.5*	.28	15.9 ± .82	-2.6*	- .18
	15	24.3 ± .47	-1.4	.90	20.3 ± .54	-2.6*	.58	17.0 ± .81	-1.5	.28
	16	24.6 ± .44	-1.1	1.22	20.2 ± .50	-2.7*	.48	17.4 ± .83	-1.1	.68
	17	24.6 ± .43	-1.0	1.23	20.1 ± .66	-2.9*	.32	17.2 ± .87	-1.3	.49
	18	25.1 ± .43	-0.5	1.77*	20.0 ± .76	-3.0*	.58	17.7 ± .81	- .8	1.04
	19	25.2 ± .44	-0.4	1.86*	20.36± .59	-2.6*	.62	17.2 ± .86	-1.3	.54
	20	25.6 ± .41	-0.1	2.21*	20.6 ± .52	-2.4*	.84	17.2 ± .90	-1.3	.54
	21	25.6 ± .53	-0.1	2.2*	21.0 ± .56	-1.9*	1.3	17.9 ± .93	- .6	1.24
	22	24.8 ± .65	-0.8	1.48	21.6 ± .58	-1.4	1.82*	17.6 ± .85	- .9	.92
	23	25.1 ± .68	- .6	1.7*	21.5 ± .59	-1.5	1.76*	17.8 ± .88	- .8	1.07
	24	25.4 ± .56	- .3	2.01*	21.2 ± .60	-1.8*	1.41	17.0 ± .89	-1.5	.33
	25	25.7 ± .60	- .1	2.35*	20.8 ± .57	-2.1*	1.1	16.9 ± .94	-1.6	.24
	26	25.1 ± .55	- .6	1.72*	20.2 ± .81	-2.8*	.43	17.1 ± .85	-1.4	.38
	27	25.4 ± .46	- .2	2.05*	21.4 ± .60	-1.5	1.69*	17.6 ± .89	- .9	.9
	28	25.2 ± .53	- .5	1.8*	21.2 ± .54	-1.7*	1.5	17.6 ± .93	-1.0	.85
	29	25.0 ± .60	- .7	1.6*	21.1 ± .57	-1.9*	1.37	17.4 ± .93	-1.2	.65
	30	25.1 ± .60	- .6	1.72*	21.3 ± .51	-1.7*	1.54	17.3 ± .94	-1.2	.63
	31	24.4 ± .58	-1.3	1.00	21.1 ± .55	-1.8*	1.39	17.8 ± .97	-2.0	1.05
	32	24.4 ± .56	-1.3	1.99	21.2 ± .57	-1.7*	1.5	17.6 ± 1.1	- .9	.88
	33	23.4 ± .58	-1.7	.58	21.3 ± .59	-1.7*	1.56	17.2 ± 1.1	-1.3	.54
	34	24.1 ± .62	-1.5	.74	21.0 ± .57	-1.9*	1.3	17.1 ± 1.1	-1.5	.36
	35	24.9 ± .62	- .8	1.51	21.1 ± .56	-1.8*	1.4	16.7 ± 1.0	-1.9	.03
	36	23.8 ± .58	-1.8 *	.45	21.0 ± .60	-1.9*	1.29	17.5 ± 1.0	-1.1	.75
	37	24.1 ± .56	-1.6	.7	21.1 ± .61	-1.8*	1.36	17.4 ± 1.0	-1.1	.72
	38	24.1 ± .56	-1.6	.69	20.3 ± .72	-2.7*	.54	17.7 ± 1.0	- .8	.98
	39	24.4 ± .78	-1.3	1.00	21.1 ± .61	-1.9*	1.36	17.5 ± 1.0	-1.0	.80
	40	24.5 ± .69	-1.2	1.11	21.2 ± .61	-1.8*	1.45	17.6 ± 1.0	- .9	.88
	41	23.8 ± .56	-1.8 *	.46	20.4 ± .58	-2.5*	.69	16.9 ± 1.0	-1.6	.23

[1]The "difference from day" indicated is used as the basis for comparing milk production laboratory study to milk yields before entering the laboratory (-9) and on last day of TN (+3).

*Refer to significance $P < .05$.

Table 4. ANOVA table for environmental temperature and stage of lactation effects on daily (am plus pm) milk production.

	D.F.	Sum of Squares	F	Significance
Stage of lactation	2	26298.1054	592.50	.0001
Environmental treatment	4	18618.0501	209.76	.0001
Stage X Environment	8	358.2584	2.02	.0405

Table 5. Total milk loss kg/day/cow due to environmental heat (TN day +3) to date of return to expected milk yields and milk loss and due to combination of transportation-laboratory and heat (farm day -1) to return to expected milk yield (data taken from Figure 1).

Stage of Lactation	Heat Effect			Heat + Transportation - Lab		
	days	kg/milk	value, $	days	kg/milk	value, $
Early	3-12	20.6	$ 5.66	1-15	58.7	16.18
Mid	3-13	38.6	10.61	1-22	58.8	16.20
Late	3-15	22.5	6.19	1-15	47.1	12.98
Average		27.2	$ 7.48		54.9	$15.12

Table 6. Post-treatment recovery of yield (kg/cow) above or below the expected persistency line.

Stage	Day	E Above	E Below	Net Difference	Value $*
E	17-40	5.0	1.5	3.5	.95
M	21-40	2.7	1.5	1.2	.32
L	17-40	2.7	1.5	1.2	.32
Average		3.4	1.5	1.9	.53

An estimation of post-heat compensatory gain in milk yield may be calculated by summation of milk yield above or below the persistency line (from figure 1).

*Based on 12.50/cwt.

Table 7. Comparisons of treatment effects within each stage and between stages on milk yield, rectal temperature and water intake.

Stage	Environmental Treatments	Milk Production kg/day				Rectal Temperature °C				Water Intake l/day			
		x	SE	(1)	(2)	x	SE	(1)	(2)	x	SE	(1)	(2)
Early	Farm	26.11	.18	A	a								
	TN_1	23.44	.28	B	a	38.5	.10	A	a	59.8	1.3	A	a
	Heat	21.76	.29	C	a	40.1	.07	B	a	70.6	1.8	B	a
	TN_2	19.57	.26	D	a	38.8	.04	A	a	57.5	1.2	A	a
	Farm	24.58	.10	E	a								
Mid	Farm	22.50	.19	A	b								
	TN_1	19.52	.35	B	b	38.8	.02	A	a	57.3	1.3	A	a
	Heat	18.33	.32	C	b	39.8	.09	B	b	71.9	1.9	B	a
	TN_2	15.38	.27	D	b	38.9	.08	A	a	56.5	1.3	A	a
	Farm	20.81	.13	E	b								
Late	Farm	18.59	.26	A	c								
	TN_1	16.88	.41	B	c	38.5	.15	A	a	52.3	1.3	A	a
	Heat	15.39	.43	C	c	39.7	.14	B	b	71.2	2.1	B	a
	TN_2	13.2	.37	D	c	38.8	.04	A	a	53.2	1.3	A	b
	Farm	16.19	.17	B	c								

(1)^{A,B,C,D,E}Indicates significance of each treatment within each stage of lactation. Values with different superscripts are significant (<.05).

(2)^{a,b,c}Compares significance of each specific treatment among E, M, or L stage. Significant at P .05. Values with different superscripts are significant (<.05).

Table 8. Mean daily values and treatment values for milk yield, rectal temperature and water intake.

		Milk Yield kg/day						Rectal Temperature, °C						Water Intake, l/day					
		Early		Middle		Late		Early		Mid		Late		Early		Mid		Late	
Treatment SE	Days	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE	x	
TN_1	1	23.6	.53	19.8	.68	16.6	.77	38.4	.034	38.7	.037	38.5	.030	62.4	2.38	58.7	2.43	51.0	2.73
	2	23.2	.50	19.0	.57	16.9	.71	38.3	.038	38.7	.038	38.6	.033	60.5	2.23	60.0	2.11	52.1	1.88
	3	23.4[a]	.48	19.7[a]	.61	16.7[a]	.72	38.8[a]	.036	38.8[a]	.036	38.7[a]	.032	55.8[a]	2.46	58.7[a]	2.15	54.5[a]	2.80
	Avg.	23.4		19.5		16.8		38.5		38.8		38.5		59.8		57.5		52.3	
Heat	4	23.6[a]	.43	20.4[a]	.50	16.8[a]	.68	39.5[b]	.090	39.2[a]	.061	38.9[a]	.085	76.7[b]	2.63	79.1[b]	2.99	77.9[b]	3.64
	5	22.0[a]	.45	18.3[b]	.53	15.9[b]	.71	40.3[b]	.100	40.1[b]	.091	39.8[b]	.120	72.9[b]	2.56	66.8[b]	3.00	69.5[b]	3.63
	6	19.9[b]	.43	16.4[b]	.46	13.6[b]	.77	40.6[b]	.106	40.0[b]	.121	40.3[b]	.111	67.9[b]	3.16	70.3[b]	3.58	66.9[b]	3.81
	Avg.	21.7		18.3		15.4		40.1		39.8		39.7		70.6		71.9		71.2	
TN_2	7	18.0[b]	.54	13.1[b]	.53	11.7[b]	.72	39.6[b]	.119	39.8[b]	.062	39.7[b]	.082	60.3[a]	2.23	54.9[a]	2.65	51.8[a]	2.4
	8	19.0[b]	.51	14.3[b]	.55	12.4[b]	.76	38.4[a]	.076	38.5[a]	.051	38.4[a]	.042	53.5[a]	2.30	54.4[a]	2.43	53.0[a]	2.02
	9	20.3[b]	.42	16.2[b]	.46	14.1[b]	.20	38.7[a]	.081	38.5[a]	.042	38.5[a]	.040	55.5[a]	2.60	57.5[a]	2.51	55.3[a]	3.03
	10	20.8[b]	.53	17.4[b]	.44	14.5[b]	.72	38.7[a]	.063	38.6[a]	.043	38.6[a]	.039	57.8[a]	2.40	60.1[a]	2.58	49.2[a]	2.57
	Avg.	19.5		15.4		13.3		38.8		38.9		38.8		57.5		56.5		53.2	

[a,b]Compares significance of day 3 with days 4 thru 11.

Values with different superscripts are significant ($P<.05$).

Table 9. Feed, milk and milk/feed energy during TN and heat conditions[1].

Treatment	Day	Stage of Lactation								
		Early			Mid			Late		
		Feed Mcal/day	Milk Mcal/day	Milk/ Feed	Feed Mcal/day	Milk Mcal/day	Milk/ Feed	Feed Mcal/day	Milk Mcal/day	Milk/ Feed
TN_1:	1	26.7	15.9	.59	28.7	13.1	.45	29.8	11.3	.38
	2	27.6	26.9	.58	28.6	13.4	.48	29.8	11.4	.39
	3	27.9	15.9	.57	28.6	13.5	.47	29.7	11.4	.38
	Ave.	27.4	19.9	.58	28.6	13.3	.47	29.8	11.4	.38
HS:	4	25.9 (56.1)	16.1	.62 (.29)	26.4 (49.9)	13.9	.53 (.28)	26.0 49.5	11.4	.44 (.23)
	5	21.2 (51.4)	15.0	.71 (.29)	22.5 (46.0)	12.5	.56 (.27)	22.0 45.5	10.9	.50 (.24)
	6	19.1 (49.3)	13.6	.71 (.28)	18.2 (41.7)	11.2	.62 (.26)	18.8 42.3	9.3	.49 (.22)
	Ave.	22.1 (56.6)	14.9	.68 (.28)	23.4 (45.8)	12.5	.57 (.27)	22.2 45.7	10.5	.48 (.23)
TN_2	7	22.7 (52.9)	12.3	.54 (.23)	22.0 (45.5)	8.9	.40 (.20)	21.2 44.7	8.0	.38 (.18)
	8	22.3 (52.5)	12.98	.58 (.25)	24.5 (48.0)	9.7	.40 (.20)	25.4 48.9	8.5	.33 (.17)
	9	23.4	13.8	.59	25.9	11.0	.42	26.3	9.6	.37
	10	25.8	14.2	.55	26.7	11.8	.44	27.0	9.9	.37
	Ave.	23.5	13.4	.57	24.8	10.4	.42	25.0	9.1	.36

[1]() Data in parentheses refer to Total Mcal/day including feed intake and body weight loss. Body weight loss during days (4-8) in terms of Mcal was estimated using: 2.1 x lb loss/5 days x 1.814 Mcal (Brody, 1945, p.53, 840).

Table 10. Comparison of temperature effects within each stage and between stages of lactation on feed energy intake and body weight.

Stage Lactation	Environmental Temperature	Energy Intake Mcal/day x	SE	(1)	(2)	Body Weight kg x	SE	(1)	(2)
Early (E)	TN_1	27.2	.47	A	a	515.6	7.6	A	a
	Heat	22.4	.58	B	a	505.8	7.7	A	a
	TN_2	23.7	.41	C	a	498.0	7.2	A	a
Mid (M)	TN_1	28.4	.48	A	b	535.8	7.0	A	b
	Heat	22.3	.46	B	a	525.0	7.2	A	b
	TN_2	24.9	.28	C	b	522.5	7.1	A	b
Late (L)	TN_1	29.8	.30	A	c	574.8	7.6	A	c
	Heat	22.2	.58	B	a	573.7	7.8	A	c
	TN_2	25.0	.32	C	b	561.6	7.1	A	c

(1) ^{A,B,C}Compares significance of each environmental temperature condition within each stage of lactation. Values with different superscripts are significant ($P<.05$).

(2) ^{a,b,c}Compares significance of each environmental condition at E, M or L stage. Values with different superscripts are significant ($P<.05$).

Table 11. ANOVA table for rectal temperature, water intake, net energy intake and body weight as affected by stage of lactation, environmental treatment and interaction.

		Rectal Temperature		Water Intake		Net Energy Intake		Body Weight	
	D.F.	Sum of Squares	F	Sum of Squares	F	Sum of Squares	F	Sum of Squares	F
Stage of lactation	2	9.3246	1.94	3645.1605	4.93*	365.6535	6.34*	233360.5168	21.43*
Environmental Temperature	2	414.6619	86.12*	70309.8024	95.11*	8325.5221	144.24*	32370.7098	2.97*
Stage x Temperature	4	19.7228	2.05	2391.5779	1.62	287.2434	2.49*	5427.1967	.25

*P<.05

Table 12 Grouping of all cows by the various classifications or indices (R, M, F, RM and RMF).

Classification		PRODUCTIVE-ADAPTABILITY INDICES (+)					(Interm.)					(-)				
Cows	Bd. Wt.	R	M	F	RM	RMF	R	M	F	RM	RMF	R	M	F	RM	RMF
	(Avg. - Wgt. in kg)	0-1.2	0-8	0-6.5	0-9.6	0-17.4	1.2-2.4	8-28%	6.5-12.5	9.6-67.2	17.4-97.2	2.4 or >	28 or >	12.5 or >	67.2 or >	97.2 or >
4	522	1.2	.01	1.6	.01	2.0										
91	435	1.1	000	4.5	000	4.9										
857	577	.35	000	3.1	000	1.1										
984	523	1.05	000	6.3	000	6.9										
90	556	.84	---	6.5	9.2	14.7		11								
16	642	.73	---	---	6.5	12.6		9	8.3							
686	666	.8	---	---	8.8	16.5		11	9.7							
100	476	---	000	3	---	5.7	1.9									
989	555	---	000	---	000	16.7	1.5		11.2							
1	484						1.8	---	8.9	55.5	71.5		31			
8	443		6		8.6		1.4	---	7.9	---	19.9					
9	520						2.0	8	12.5	16.4	42.1					
11	436						1.7	25	12.5	42.5	63.7					
14	512						1.7	9	8.2	15.3	29.2					
19	482						2.1	25	11.2	52.5	76.0					
20	552			5			1.8	9	---	16.6	25.7					
26	534	1.1	6		6.6		---	---	10.1		17.9					
27	546						2.3	20	11.2	46.2	72.1					
33	528						1.5	13	11.5	19.7	37.3					
34	585						---	26	8.9	---	91.5	2.6			68.1	
38	605						2.0	23	12.5	47.1	72.9					
53	462						2.3	28	---	63.8	93.2			12.9		
58	490			5.8			2.4	17	---	41.6	55.6					
64	521			5.6			2.3	18	---	40.7	53.3					
89	496						2.3	13	7.5	29.6	46.6					
93	535						1.9	19	---	36.1	61.5			13.4		
95	537						2.4	12	9.5	28.5	51.3					
101	482						1.5	17	8.5	25.5	38.2					
104	541			4.6			2.2	16	---	34.8	45.0					
106	427		4		7.6		1.9	---	6.8	---	20.5					
109	440			5.1			2.0	21	---	43.0	53.5					
116	528						2.2	16	10.7	35.2	58.0					
608	626						1.5	19	12.5	29.4	49.0					
648	575						1.4	17	--	24.6	46.7				15.2	
829	738	0.9					---	19	--	16.3	29.7				15.5	
856	592						1.7	27	11.6	46.2	65.6					
880	578						1.8	13	10.1	23.8	42.2					
919	522	0.9		5.9			---	16	--	15.0	20.6					
942	662						1.7	9	11.5	15.0	34.2					
966	593			6.0			1.2	10	--	12.3	19.7					
990	627						1.5	14	10.3	21.7	37.6					
796	689						2.05	--	--	65.6	92.7	--	32	13.3	---	---
5	526								11.0			2.6	33	--	85.8	116.2
999	528								11.5			2.6	37	--	96.2	126.2
844	599						1.6			64.0			40	20.7	---	97.2
994	606						2.1					--	41	16.3	88.2	123.0
7	492							27		64.3		2.4	--	16.2	---	98.1
53	462									63.8	93.2	2.4	28	12.9	---	---
65	428								6.4			2.8	35	---	98.7	116.0
75	472											2.4	34	12.5	82.6	111.6
44	457											2.8	29	12.7	81.2	116.0
925	625											2.6	45	16.5	119.0	163.0

R = Rectal temperature increase (C), day 3 (TN) vs day 6 (Heat).
M = Milk yield decline (%), day 3 vs day 6.
F = Feed energy intake decrease (Mcal/day), day 3 vs day 6.
RM = Productive adaptability (R X M).
RMF = Productive adaptability (R X M + F).

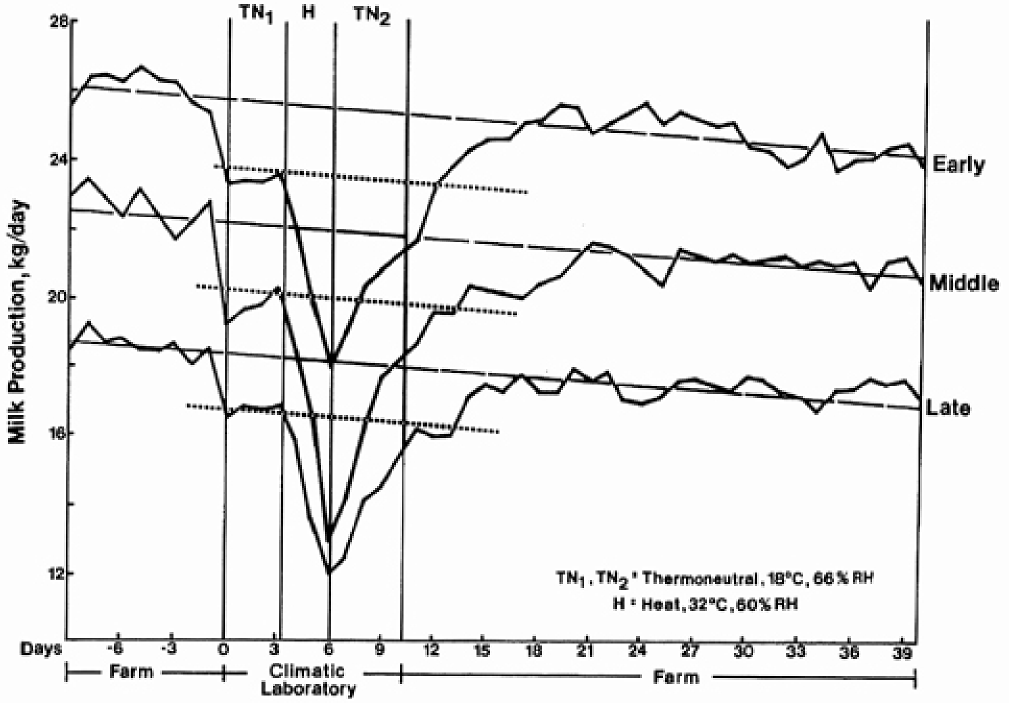

Figure 1. Average daily milk production for each stage of lactation group compared with expected milk yields. Expected milk yields (---) were based on average persistency decline of cows during lactation in which cows were on experiment. Expected milk yields (.....) using TN_1 levels as bases of post-heat (TN_2) recovery.

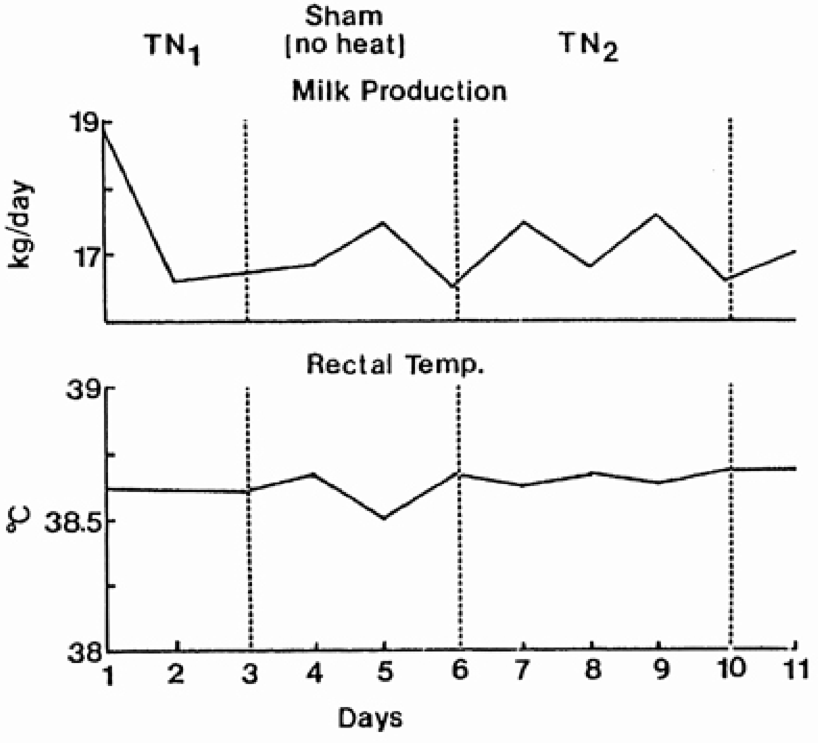

Figure 2. Sham environmental heat period effects on milk production and rectal temperatures for 6 cows. Conditions during the sham "no heat" period were 18°C, 60% RH. This trial was designed to distinguish the heat-stressing effects from other environmental factors.

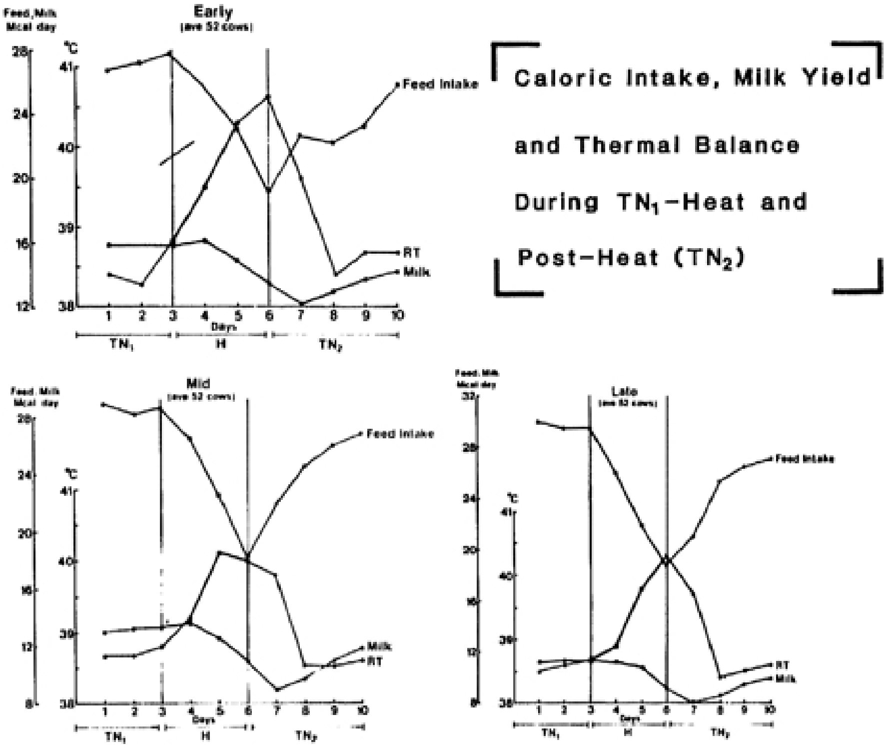

Figure 3: Comparative energy responses of daily feed intake and milk yield and associated rectal temperatures during TN_1, Heat and TN_2 exposures for Early, Mid and Late stages of lactation.

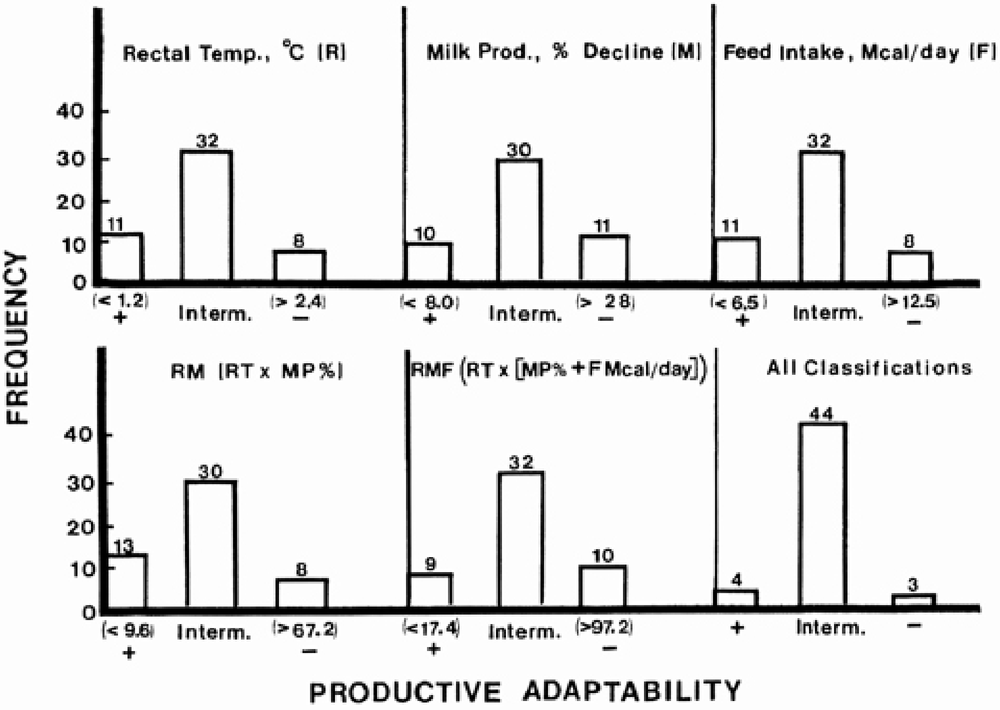

Figure 4. Frequency designations (--), (+) or intermediate for productive adaptability indices (R, M, F, RM and RMF). Individual values were based on Day 3 (TN) versus Day 6 (3rd day heat) differences.

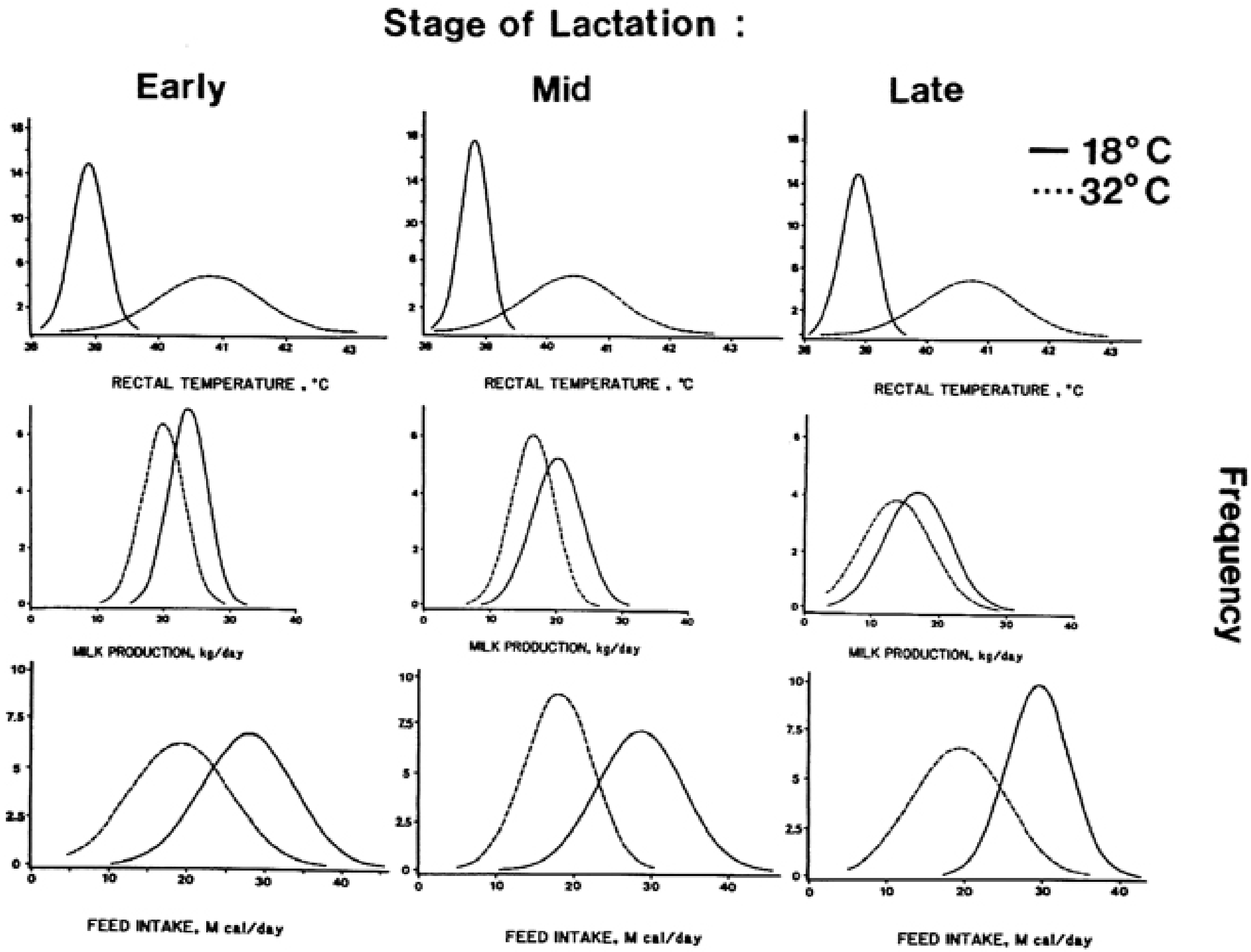

Figure 5. Distribution curves for Rectal Temperatures, Milk Production, and Feed Intake at 18°C and 32°C for Holstein Cows at Early, Mid and Late Stages of Their Lactation.

USDA Study
Body Weights (kg)

Cow #	Early	Mid	Late	Average
608	613	610	716	646
648	525	610	592	575
829	675	773	767	738
857	572			572
989	549	555	562	555
984	497	515	528	513
880		524	632	578
919		467	556	511
7		458	526	492
1		461	506	484
9		507	533	520
5		524	528	526
844		608	589	599
19	459	504		481
11	426	446		436
856	561	582	633	592
942	470	558	559	529
8	443	423	463	443
4	510	545	559	583
14	511	518	535	512
27	527	551	560	546
26	528	541	533	534
33	492	529	533	518
608	609	627	643	626
686	650	662	687	666
990	584	606	662	617
44	437	446	487	457
880	590	606	675	624
999	494	506	554	518
984	571	585	662	606
53	429	456	498	461
796	677	690	700	689
64	490	518	555	521
58	454	510	505	490
75	423	490	505	472
966	546	596	637	593
100	493	460	476	476
91	431	427	447	435
90	533	556	578	556
* 1	533	553	583	557
16	600	650	675	642
104	525	524	573	541

Cow #	Early	Mid	Late	Average
89	491	490	507	496
33	596	614	660	623
95	508	556	546	537
942	640	656	690	662
93	514	546	544	535
925	614	615		615
20			551	551
106	395	428	429	417
101	450	506	591	482
116	509	532	514	518
109	407	465	447	440
34	583	600	571	585
38	597	630	589	605