Effects of Tropical Climate on Reproduction of Cross- and Purebred Friesian Cattle in Northern Thailand

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ABSTRACT : In the first part of the study, rates of estrus occurrence and success of A.I. service in the Thai-native and Friesian crossbred, and purebred Friesian cows fed in the National Dairy Training and Applied Research Institute in Chiang Mai, Thailand were traced monthly throughout a year. An electric fan and a water sprinkler cooled the stall for the purebred cows during the hot season (March-September). Both rates in pure Friesians were at their highest in the cold-dry season (October- February), but they decreased steadily during the hot-dry season (March-May) and were at their lowest in the hot-wet season (June-September). Seasonal change of a similar pattern was observed in the incidence of estrus, but not in the success rate of insemination in the crossbred cows. By the use of reproductive data, compiled in the same institute, on the 75 % cross- and purebred Friesian cows, and climatological data in Chiang Mai district, effects of ambient temperature and humidity on the reproductive traits of cows were examined by regression analysis in the second half of the study. Significant relationships in the crossbred, expressed by positive-linear and parabola regressions, were found between reproductive parameters such as days to the first estrus (DTFE), A.I. service (DTFAI), and conception, the number of A.I. services required for conception and some climatic factors. However, regarding this, no consistent or intelligible results were obtained in purebred cows, perhaps because electric fans and water sprinklers were used for this breed in the hot season. Among climatic factors examined, the minimum temperature (MINT) in early lactation affected reproductive activity most conspicuously. As the temperature during one or two months prior to the first estrus and A.I. service rose, DTFE and DTFAI steadily became longer, although, when MINT depleted below 17-18°C, the reproductive interval tended to be prolonged again on some occasions. The maximum temperature also affected DTFE and DTFAI, but only in limited conditions. The effect of humidity was not clear, although the inverse relationship between DTFE and minimum humidity during 2 months before the first estrus in the crossbred seemed to be significant. Failure to detect any definite effect of climate on the reproductive traits of pure Friesians seemed to indicate that forced ventilation by electric fans and water sprinklers were effective enough to protect the reproductive ability of this breed from the adverse effects of a hot climate. ***(Asian-Aust. J. Anim. Sci. 2003. Vol 16, No. 7 :952-961)***

Key Words : Reproduction, Crossbred, Friesian, Cow, Heat Stress, Thailand

INTRODUCTION

As in other tropical areas of the world, the reproductive inferiority of European cattle breeds compared with those of native ones, and even their crossbreds with foreign breeds, is demonstrated in Thailand (Madsen and Vinther, 1975; Humbert et al., 1990; Chantarapteep and Humbert, 1993; Harinmirintaranon et al., 1994). However, questions such as what climatic factor or factors has the most profound effect on the reproduction of cows, and what reproductive events or in what reproductive stages are these factors most severe and so on have, up till now, not been answered well by these studies. The main body of dairy cattle now kept in northern Thailand is crossbreds of various degrees between Thai-native and Friesian cows. In the previous paper (Pongpiachan et al., 2000), we reported on the milk production of such crossbreds, together with that of pure Friesians. We used the database of 50% and 75% crossbred and purebred Friesian cows, fed in the National Dairy Training and Applied Research Institute (NDTARI), Livestock Department, Ministry of Agriculture, Chiang Mai, Thailand, and the effect of a tropical climate on their lactation was analyzed further. Since the stall in the institute for purebred Friesians was cooled by forced ventilation and water sprinkling in the hot season, significant effects of high temperature and humidity on lactation were detected only in the 75% crossbred. Despite this limitation still being present, a similar research on the reproductive performance of cows by the use of the same data files was subsequently planned.

Although it is widely believed among dairymen in Thailand that the success rate of artificial insemination (A.I.) service is worse in the hot rather than cold season, especially in a dairy breed of Western origin, no concrete study has been carried out on this subject so far. Therefore, in order to confirm this fact and simultaneously understand the effects of a tropical climate on the reproduction of Thailand's dairy cattle, monthly changes in the incidence of estrus and the success rate of A.I. service in cross- and purebred Friesian cows were checked throughout a one year

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period from October, 1998 to September, 1999, as the first step of this study.

Due to the definite effect of season on reproductive records being proved by this survey, more detailed analysis of the effect of climate on the reproduction of cross- and purebred Friesian cattle was carried out in the second step. We noticed quickly, and beyond our expectation, that the reproductive activity of dairy cattle was related closely to the magnitude of their milk production as well as receiving climatic influence. This may mean that tropical climate possibly influences the reproductive performance of dairy cows by two routes, directly and indirectly through its effect on milk production, and, therefore, the effects of lactation and climate on reproduction may have to be analyzed simultaneously. However, it was feared that such an analysis would make the problem too complicated and difficult to understand readily. In addition, our previous work (Pongpiachan et al., 2000) revealed that a hot climate affected milk production adversely only in the 75% crossbred cows. No significant effects were found in the purebred cows, which produced more milk, but were protected considerably from heat stress by forced ventilation and water sprinkling. Regarding this, we decided to deal with the problem separately. Results of the analysis on the relationship between lactational and reproductive performances in cross- and purebred Friesian cows were summarized in the accompanying paper and the effect of tropical climate on reproduction was examined in the second part of the present study. Because the 75% crossbred and purebred cows in these papers were exactly the same in number, summary of raw data and results of simple comparison of them between breeds were presented in the accompanying paper (Pongpiachan et al., 2003) and omitted from the present paper. In addition, the data on the 50% crossbred were not used for analysis in the present study because of their small number.

MATERIALS AND METHODS

Animals

On the farm of the National Dairy Training and Applied Research Institute (NDTARI), the crossbred between Friesian and natives and the pure Friesian cattle were maintained in different herds. Although the contribution of Friesian gene in the gene constitution of the crossbred varied from 50% to 93.75%, the 75% crossbred was the most (66%), followed by the 87.5% (25%), and the average contribution of Friesian gene was around 78% of the total population. Details of these animals and their feeding systems have been described in the previous paper (Pongpiachan et al., 2000). In brief, crossbred cows were kept the whole day in a yard or pasture with small sheds and fed with fresh grass or silage and mineral mix. In addition, a concentrate mixture of ingredients, in accordance with the basic NRC standard (1988) for dairy cows, was given twice daily at the time of milking (04:30 and 16:00 h) at a proportion of 1 kg diet to 3 kg milk produced. On the other hand, purebred cows were kept in a free stall with stockyard. Large and small fans were set on the ceiling of the central feed passageway in the stall and operated in the hot-dry and hot-wet seasons (March-May, June-September). Water sprinklers were also set along the passageway at one-meter intervals and worked 10 minutes in each 30 to 60 minutes from 08:00 to 23:00 h in hot seasons. The animals were fed with corn silage and concentrate formulated in accordance with the 1988 NRC standard, and a supplementary amount of the concentrate was also given twice daily at the time of milking.

Milking records were started from 5 days after calving and stopped 45 to 60 days before the expected day of the next parturition in pregnant-lactating cows or at a time when the daily milk yield decreased to below 5 kg. The total milk production during a lactation period (TMP) and the duration of lactation (DUR), as the number of days from the start to the end of milking, were recorded.

The estrous behavior of cows such as bellowing and mounting were monitored by daily routine observation throughout the lactation and subsequent dry periods, and animals suspected of being estrous received further detailed observations on vulva and cervical secretion (Rodtian et al., 1996). Conception was confirmed by rectal palpation at around 60 days after the last estrus.

Experimental

Onset of estrus and artificial insemination (Experiment 1): The estrus of cross- and purebred non-pregnant lactating cows on the farm was checked and all cows judged as being estrous, even at the first postpartum estrus, received the A.I. service during a one year period from October, 1998 to September, 1999. Data were collected monthly and rates of estrus occurrence and the success of A.I. were obtained in 63 to 71 crossbred and 37 to 45 purebred cows in each month.

Climatic effect on reproduction (Experiment 2): The data collected from NDTARI data files from 1989 to 1995 and used to analyze the effect of lactation in the accompanying paper, were also used to record reproductive traits for the present analysis. The data comprised the numbers of days from current calving to the first estrus (DTFE), A. I. service (DTFAI) and conception, i.e., the last A. I. service (DTC) and the number of times of A. I. services required to make the cow conceived (NAIS), of the 75% cross- and purebred Friesian cows. The data used, therefore, were those collected in 52 and 70 lactations in twenty one 75% crossbred and fifty two purebred cows, respectively.

For each crossbred and purebred cow, daily records of maximum and minimum temperature, relative humidity (MAXT, MINT, MAXH and MINH) and temperature-humidity index (THI) in the farm district were collected throughout its lactation period from the climatological datafiles described in the next section. They were averaged respectively at intervals of 30 days over a period from 1 day after calving to the end of lactation (post-parturient dating, Series A) and from 1 to 60 days before or 1 to 30 days after the cow's reproductive events; that is to say, the first estrus (FE), the first A.I. service (FAI) and conception (the last A.I. service, LAI) (peri-event dating, Series B), and regressions of reproductive parameters on respective climatic averages were checked in each 30 day period in the manner described below. Among reproductive parameters, the interval between the first estrus and A.I. service (ETAI) and the average interval of A.I. service until fertile insemination (IOAI) were subjected to the analysis of the accompanying paper, but omitted from the subject of regression analysis in the present work. This was because the period in which climatic change might affect the length of these intervals could not be specified clearly.

Data on climate

Daily records on the highest, average and lowest values of ambient temperature (°C) and relative humidity (%) in Chiang Mai district from 1989 to 1995 and in 1998 and 1999 were supplied from the Department of Soil Science and Conservation, Faculty of Agriculture, Chiang Mai University. The THI of each day was calculated by using the average daily temperature and humidity, and the equation of Curtis (1983); i.e., $THI=\{0.4\times(DBT+WBT)\}+4.8$, where DBT is the dry bulb temperature (°C) and WBT is wet bulb temperature (°C) obtained from DBT with relative humidity (%) given. Average values of climatic factors throughout the years of observation were 20.2±3.7 (SD) °C for MINT, 32.6±3.0 °C for MAXT, 56.4±13.2% for MINH, 88.0±5.7% for MAXH and 23.8±2.2 for THI.

Statistical analysis

Analyses were performed by the use of SAS (1985) computer programs as far as proper programs were available. GLM and REG procedures were mainly employed. All statistical significance was judged basically at a 5% level. The first, second and third order regressions were checked by the REG procedure. When all partial regression coefficients as well as the coefficient to the model were significant and the adjusted R square value increased as the order of regression progressed, the regression of the highest order obtained was adopted. Regressions with positive and negative coefficients of the highest order were noted as positive- and negative-first, second and third order regressions, respectively. In the second and third order regressions, turning points of regression equations (y=f(x)), i.e., x values for maximum or minimum value in parabolic and maximum and minimum values in cubic curves, were also calculated.

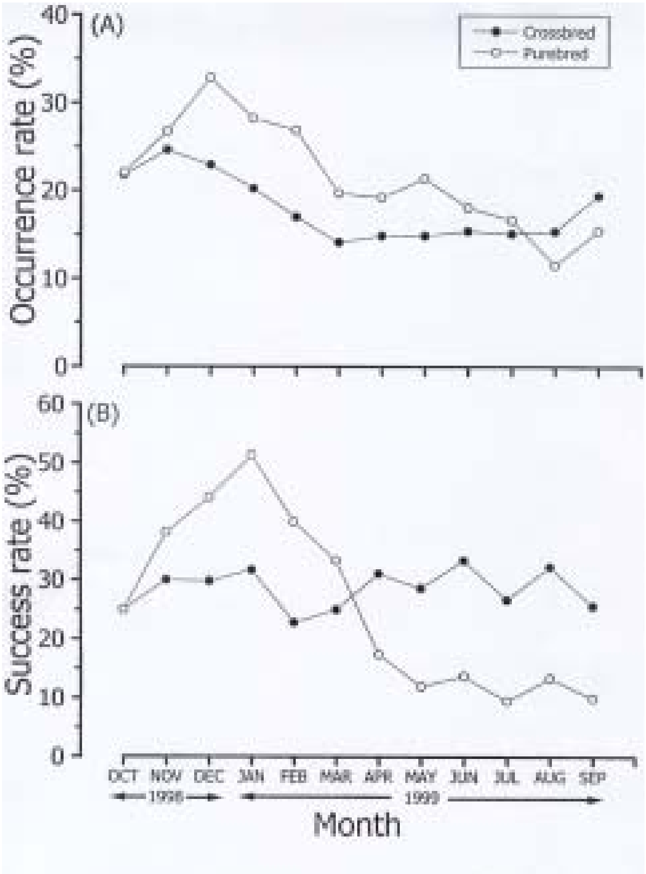

Figure 1. Monthly changes in rates of estrus occurrence (A) and success of A.I. insemination (B) throughout one year between October, 1998 and September, 1999 in crossbred and purebred Friesian cows, expressed in terms of moving average over 3 months. Crossbred cows had between 50 % and 93.75 % (78.0 % average) of Friesian gene in their gene constitution.

RESULTS

Onset of estrus and artificial insemination (Experiment 1): In order to show the general trend of change in reproduction throughout one year clearly by eliminating the effect of monthly fluctuation, changes in the rates of estrus occurrence and success of A.I. service are shown in the form of moving averages over 3 months in Figure 1. The incidence of estrus was high from November to January or February, decreased rapidly thereafter and was kept low from March to September in both crossbreds and purebreds. On the other hand, a similar pattern was observed in the change of success rate of A.I. service in the purebred, but not in crossbred cattle. In order to reveal the cyclic nature of changes in these rates, their regressions to the sine curve

Table 1. Rates of estrus occurrence and success of A.I service in crossbred and purebred Friesian cows in 3 seasons during one year between October, 1998 and September, 1999

Breed	Crossbred[1]			Purebred		
(A) Rate of estrus occurrence						
Season[2]	No. of observations[3]	No. of estrus observed	Occurrence of estrus (%)	No. of observations	No. of estrus observed	Occurrence of estrus (%)
Cold–Dry	338	74	21.9[ab 4]	214	61	28.5[a]
Hot–Dry	195	29	14.9[c]	120	23	19.2[abc]
Hot–Wet	265	41	15.5[c]	170	25	14.7[bc]
Throughout year	798	144	18.1[x]	504	109	21.6[x]
(B) Rate of success of A.I. service						
Season	No. of A.I. Served[5]	No. of A.I. succeeded	Success rate of A.I. (%)	No. of A.I. served	No. of A.I. succeeded	Success rate of A.I. (%)
Cold–Dry	74	21	28.4[ab]	61	25	41.0[a]
Hot–Dry	29	9	31.0[ab]	23	4	17.4[b]
Hot–Wet	41	11	26.8[ab]	25	3	12.0[b]
Throughout year	144	41	28.5[x]	109	32	29.4[x]

[1] Consisting of cows having 50% to 93.75% (78.0% average) of Friesian gene in their gene constitutions. [2] Cold–Dry: October-February, Hot–Dry: March–May, Hot–Wet: June–September. [3] Sum of number of cows kept on the farm in each month during the season. [4] All cows at estrus were inseminated during the period of observation.

[a-c] There was no significant difference between percentages in all breed-season combinations in (A) and (B) having the common alphabet in their superscripts. Summation of results of chi-square test or Fisher's exact probability test in each pair of season-breed combinations. [x] Similarly, no significant differences were found in the percentage throughout one year between breeds in both (A) and (B).

Table 2. Summary of reproductive data used for the regression analysis (Cited from Table 1 of Pongpiachan et al., in submitting)

Item[1]	Breed	
	75% Crossbred	Purebred
N	52	70
DTFE (day)	68.2±4.9[a2]	83.7±5.9[a]
DTFAI (day)	86.7±4.2[a]	110.1±5.3[b]
DTC (day)	139.5±11.0[a]	233.4±15.0[b]
NAIS	2.3±0.2[a]	3.6±0.3[b]

N=number of lactations, in which reproductive data were recorded. Records from the same cow at different parities are included. DTFE=days to the first estrus postpartum, DTFAI=days to the first A.I. service postpartum, DTC=days to the conception, NAIS=number of A.I. services required for conception. Mean±SE.

[a, b] There was no significant difference between means in the same line when they have the same alphabet in their superscripts ($p<0.05$; GLM-MEANS/T test).

were examined. Significant regression was found in the rate of estrus occurrence in the crossbred and that of successful insemination in the purebred, and the regression was nearly significant (p=ca.0.06) in the incidence of estrus in the purebred.

Years in Thailand are usually classified into three seasons, the cold-dry season from October to February, the hot-dry from March to May and the hot-wet from June to September. Therefore, the incidence of estrus and success rate of A.I. were compared statistically among seasons and between breeds (Table 1). There were no significant differences in the rates between breeds in any season and also throughout the year. On the other hand, differences in rates except for those of A.I. success in the crossbred were significant between cold and hot seasons or at least between cold-dry and hot-wet seasons.

Climatic effect on reproduction (Experiment 2): Summaries of reproductive data used for the regression analysis are cited from Table 1 of the accompanying paper (Pongpiachan et al., in submitting) and shown again for convenience as Table 2 of the present paper. Regression equations of reproductive parameters on climatic factors, which were proved as significant by the above noted criteria in the post-parturient (Series A) and peri-event (Series B) dating systems, are summarized in Tables 3 and 4, respectively. The turning points of the second and third order regression equations are also shown, i.e., maximum or minimum value in parabolic and maximum and minimum values in cubic curves, and range of variation of climatic factors during the 30-day testing period.

Analysis in the post-parturient dating system (Series A): In the crossbred cows, significant effects of MINT and THI on DTFE and those on DTC were observed in the periods before 60 days postpartum (pp) and between 61 and 150 days pp, respectively (Table 3). In addition, MINT had a significant effect on DTFAI in the period between 61 and 90 days and MAXT in 30 days pp also did on DTFE. Most of regressions in these cases were of the positive-first order. This indicated that the intervals from calving to FE, FAI and LAI increased along with the rise of climatic factors during periods that slightly preceded and/or almost corresponded to the time of occurrence in respective reproductive events shown in Table 2. MINT, in the period between 61 and 90 days pp, affected DTFAI and DTC in a positive-parabolic fashion. This expressed that these intervals were long in the condition of low MINT. They became shorter as it rose, but when the temperature elevated to over 17-18 °C, they began to become longer again, which

Table 3. Results of regression analysis on the effects of climate during different days after calving on reproductive traits in 75 % crossbred and purebred Friesian cows (Series A)

Reproductive trait[1] (Y)	Climatic factor		Days after calving	Regression equation			
	Item[2] (X)	Range		N[3]	Y = f (X)	p	Turning point[4]
75% Crossbred							
DTFE	MINT	12.2-24.0	1-30	52	$Y= 4.15X-14.34$	0.003	-
	MINT	12.3-24.1	31-60	46	$Y= 3.68X-1.68$	0.004	-
	MAXT	28.4-38.3	1-30	52	$Y= 5.61X-116.43$	0.007	-
	THI	19.0-26.1	1-30	52	$Y= 7.25X-103.54$	0.002	-
	THI	19.0-26.2	31-60	46	$Y= 5.92X-68.58$	0.006	-
DTFAI	MINT	12.3-24.2	61-90	44	$Y= 1.36X^2-50.74X+543.44$	0.036	18.7
DTC	MINT	12.2-24.2	61-90	48	$Y= 2.60X^2-91.98X+905.92$	0.022	17.7
	MINT	11.8-24.1	91-120	35	$Y= 8.21X+2.03$	0.023	-
	MINT	12.7-24.3	121-150	25	$Y= 11.43X-42.77$	0.025	-
	MINH	28.3-80.3	61-90	48	$Y=-1.20\times10^{-2}X^3+2.09X^2-115.88X+2177.08$	0.020	45.8, 70.3
	MINH	29.0-81.0	121-150	25	$Y= 2.59X+52.51$	0.007	-
	MINH	28.3-81.0	241-270	6	$Y=-3.95X+537.09$	0.045	-
	THI	18.9-26.2	61-90	48	$Y= 9.57X-80.55$	0.047	-
	THI	18.9-26.1	91-120	35	$Y= 14.86X-187.64$	0.023	-
	THI	19.3-26.1	121-150	25	$Y= 17.95X-238.01$	0.040	-
NAIS[5]	MINH	28.3-80.3	61-90	48	$Y=-1.96\times10^{-4}X^3+3.44\times10^{-2}X^2-1.91X+35.96$	0.013	45.3, 71.1
	MAXH	67.3-96.2	151-180	18	$Y= 7.42\times10^{-3}X^3-1.97X^2+174.57X-5141.28$	0.027	85.6, 91.7
Purebred							
DTFE	MINT	12.3-24.1	31-60	64	$Y= 1.55X^2-57.30X+593.25$	0.028	18.5
	MINT	12.2-24.2	61-90	41	$Y= 2.05X^2-77.63X+813.99$	<0.001	18.9
	MINT	11.1-24.1	91-120	26	$Y=-4.82X+233.87$	0.018	-
	MINT	12.4-24.3	151-180	9	$Y= 6.34X+49.38$	0.041	-
	MAXT	24.4-38.3	1-30	68	$Y=-1.10X^3+111.19X^2-3722.85X+41498.33$	<0.001	31.7, 36.4
	MAXT	28.6-38.3	61-90	41	$Y=-6.44X+323.88$	0.032	-
	MAXT	28.5-38.4	121-150	15	$Y= 9.45X-153.62$	0.005	-
	MAXT	28.6-38.4	151-180	9	$Y= 6.30X-33.04$	0.044	-
	MINH	28.4-80.9	91-120	26	$Y= 9.64\times10^{-2}X^2-11.71X+475.73$	0.006	60.8
	MINH	29.0-81.0	121-150	15	$Y=-1.28X+228.33$	0.045	-
	MAXH	66.8-95.7	121-150	15	$Y=-2.55X+379.14$	0.019	-
	THI	19.0-26.1	1-30	68	$Y= 4.39X^2-202.87X+2406.35$	0.017	23.1
	THI	19.0-26.2	31-60	64	$Y= 4.06X^2-184.68X+2166.99$	0.037	22.8
	THI	18.9-26.2	61-90	41	$Y= 5.08X^2-233.88X+2777.73$	0.001	23.0
	THI	18.9-26.1	91-120	26	$Y=-7.81X+322.77$	0.031	-
	THI	19.3-26.3	151-180	9	$Y= 10.12X-63.86$	0.032	-
DTFAI	MINT	12.3-24.1	31-60	70	$Y= 1.64X^2-61.42X+659.79$	0.005	18.7
	MINT	12.2-24.2	61-90	65	$Y= 1.60X^2-60.41X+658.12$	0.002	18.9
	MINT	12.4-24.3	151-180	14	$Y= 4.96X+77.52$	0.036	-
	MAXT	28.4-38.3	1-30	70	$Y=-1.03X^3+104.15X^2-3505.27X+39265.29$	<0.001	31.6, 36.0
	MAXT	28.4-38.1	31-60	70	$Y= 3.17X^2-206.12X+3449.50$	0.017	32.5
	MAXT	28.6-37.5	91-120	40	$Y=-1.83X^3+179.61X^2-5864.53X+63768.47$	0.037	30.9, 34.6
	MAXT	28.5-36.4	121-150	26	$Y= 6.40X-55.37$	0.036	-
	MAXT	28.6-38.4	151-180	14	$Y= 6.07X-20.24$	0.031	-
	THI	19.0-26.1	1-30	70	$Y= 3.68X^2-171.04X+2080.92$	0.019	23.2
	THI	19.0-26.2	31-60	70	$Y= 4.26X^2-195.30X+2324.38$	0.008	22.9
	THI	18.9-26.2	61-90	65	$Y= 3.97X^2-182.90X+2200.88$	0.004	23.1
	THI	19.3-26.3	151-180	14	$Y= 7.92X-10.85$	0.030	-
DTC	MINT	12.2-24.0	1-30	70	$Y=-10.73X+445.08$	0.005	-
	MINT	11.8-24.3	211-240	39	$Y= 16.14X-23.99$	0.002	-
	MINT	11.6-24.0	241-270	33	$Y= 10.81X+113.97$	0.010	-
	MINT	12.3-24.2	271-300	25	$Y= 11.10X+135.49$	0.026	-
	MAXT	28.5-38.4	121-150	56	$Y=-4.35X^3+436.75X^2-14548.48X+161207.61$	0.001	31.4, 35.5
	MAXT	28.6-38.4	151-180	50	$Y= 15.87X-234.53$	0.012	-
	MAXT	28.2-38.1	271-300	25	$Y= 36.09X-786.54$	0.014	-
	MINH	29.0-79.0	1- 30	70	$Y= 1.67\times10^{-2}X^3-2.64X^2+131.55X-1812.53$	0.022	40.3, 65.1
	MINH	29.7-80.3	31- 60	70	$Y=-2.28X+360.24$	0.044	-
	MINH	28.3-80.3	61- 90	68	$Y=-2.58X+376.27$	0.026	-
	MINH	28.4-80.9	91-120	60	$Y=-2.42X+389.61$	0.036	-
	MAXH	67.5-96.1	61- 90	68	$Y=-208\times10^{-1}X^3+53.25X^2-4544.28X+129207.00$	0.015	81.6, 89.5
	MAXH	71.7-94.5	91-120	60	$Y=2.00\times10^{-1}X^3-51.80X^2+4447.87X-126452.65$	0.008	80.5, 92.7
	MAXH	65.6-95.8	241-270	33	$Y=3.89\times10^{-1}X^3-101.31X^2+8768.58X-251963.40$	0.042	82.1, 92.0
	THI	19.0-26.1	1-30	70	$Y=-17.14X+635.76$	0.009	-
	THI	19.3-26.3	151-180	50	$Y= 13.62X-39.23$	0.047	-
	THI	19.1-26.1	241-270	33	$Y= 18.83X-115.43$	0.008	-
	THI	19.2-26.1	271-300	25	$Y= 18.98X-90.40$	0.026	-
NAIS[5]	MAXT	28.5-39.4	121-150	56	$Y=-8.28\times10^{-2}X^3+8.33X^2-278.61X+3101.19$	0.017	31.8, 35.3
	MAXH	67.5-96.1	61-90	68	$Y=-5.03\times10^{-3}X^3+1.29X^2-109.91X+3115.63$	0.009	80.9, 89.9
	MAXH	65.6-95.8	241-270	33	$Y= 8.99\times10^{-3}X^3-2.33X^2+200.44X-5728.49$	0.036	81.6, 91.1
	MAXH	69.7-96.2	271-300	25	$Y= 1.22\times10^{-1}X^2-21.94X+991.47$	0.033	90.0

[1] DTFE=days to the first estrus, DTFAI=days to the first A.I. service, DTC=days to conception, NAIS=number of A.I. services required for conception.

[2] MINT=minimum temperature (°C), MAXT=maximum temperature (°C), MINH=minimum humidity (%), MAXH=maximum humidity (%), THI=temperature-humidity index.

[3] N=number of lactations subjected to the analysis in each period (see footnote 1 of Table 2). Cows for which days to occurrence of respective reproductive events were shorter than the period appointed were excluded from the analysis.

[4] Minimum or maximum point of parabolic and minimum and maximum points of cubic curves. They were calculated by using full digits of figures of partial regression coefficients obtained by regression analysis. The values, therefore, are slightly different in some cases from the values obtained by the regression equations shown in the table, because only figures of a somewhat restricted number of digits are shown in the equations.

[5] Cows subjected to the analysis were the same as those used for the analysis of DTC.

Table 4. Results of regression analysis on the effects of climate during months before and after the occurrence of reproductive events on reproductive traits in 75 % crossbred and purebred Friesian cows (series B)

Reproductive trait[1] (Y)	Climatic factor		Days before or after event[5]	Regression equation			
	Item[2] (X)	Range		N[3]	Y = f (X)	p	Turning point[4]
75 % Crossbred							
DTFE	MINT	11.0-24.4	60-31 before	46	$Y= 5.32X-36.11$	<0.001	-
	MINT	13.1-24.2	30-1 before	52	$Y= 4.37X-19.67$	0.001	
	MAXT	28.7-39.0	30-1 before	52	$Y=-1.88X^2+125.82X-2024.24$	0.049	33.5
	MINH	28.8-88.7	60-31 before	46	$Y= 0.75X+31.45$	0.017	-
	MINH	30.3-82.0	30-1 before	52	$Y= 1.23X-1.45$	0.001	-
	THI	18.1-26.3	60-31 before	46	$Y= 1.96X^2-80.82X+876.86$	0.001	20.6
	THI	19.7-26.1	30-1 before	52	$Y= 7.42X-108.89$	0.001	-
DTFAI	MINT	12.7-24.4	60-31 before	52	$Y= 1.08X^2-39.22X+425.13$	0.008	18.2
	THI	18.1-26.3	60-31 before	52	$Y= 3.24X^2-146.00X+1714.16$	0.004	22.6
DTC	MINH	28.3-81.2	1-30 after	52	$Y= 1.57\times10^{-1}X^2-17.82X+616.48$	0.048	56.9
	MAXH	73.7-96.1	60-31 before	52	$Y= -7.26\times10^{-1}X^2+127.35X-5419.38$	0.031	87.7
Purebred							
DTFE	MINT	13.1-24.2	30-1 before	70	$Y= 5.32X-22.27$	0.005	-
	MAXT	28.7-39.0	30-1 before	70	$Y=-2.29X^2+157.37X-2605.28$	0.019	34.4
	THI	19.7-26.1	30-1 before	70	$Y= 7.31X-88.55$	0.019	-
DTFAI	MINT	12.4-24.1	30-1 before	70	$Y= 4.69X+16.59$	0.001	-
	MAXT	28.5-37.5	60-31 before	70	$Y= 7.09X-122.25$	0.018	-
	THI	19.2-26.2	60-31 before	70	$Y= 5.78X-27.65$	0.034	-
	THI	19.2-26.1	30-1 before	70	$Y= 6.91X-52.96$	0.005	-

[1-4] See the corresponding number of footnotes in Table 3 for abbreviations and/or explanations.
[5] Days before the first estrus and A.I. service, and days before or after the last A.I. service.

occurred at the turning point of the graph and when temperature were a little lower than the annual average. The effect of humidity, MINH and MAXH, was also observed on DTC and NAIS. However, the period of affect, especially that on DTC, could not be specified in relation to the occurrence of the reproductive event. In addition, patterns of regression were not uniform, including the positive- and negative-third order ones.

In comparison with relatively simple relationships between reproductive traits and climate in the crossbred, those observed in the purebred were much more complicated; significant regressions were obtained in various post-parturient periods over a wide range and the pattern of regressions were also diverse. The positive-second order regressions of DTFE and DTFAI on MINT and THI during the periods between 31 and 90 days pp and the positive-first order ones of DTC on the same climatic factors between 151 and 300 days pp, could resemble the relationships between the same reproductive and climatic parameters in the crossbred. This might be because these periods of affect were preceding a little or almost corresponding to the average time of occurrence of respective reproductive events in this breed. However, in the purebred, significant regressions of reproductive traits on climatic factors also appeared in the periods which were quite apart from the time of FE, FAI or LAI and seemed not to relate to them. For example, regressions of DTFE and DTFAI on MINT, MAXT and THI in periods after 150 days pp, DTC on MINT and THI between 1 and 30 days pp and on MINH and MAXH before 120 days pp, and NAIS on MAXT and MAXH before 150 days pp. In addition, patterns of these regressions are more complicated than those observed in due time as a whole and sometimes positive- and negative-third order regressions were observed in them. Negative-first order regression was observed only in DTFE and DTC. Besides the regression of DTC on MINT, MINH and THI in very early periods after calving, it is noteworthy to some extent that DTFE regressed by this pattern on MINT, MAXT and THI in periods between 61 and 120 days pp and on MINH and MAXH between 121 and 150 days pp, because these periods almost corresponded to the time of FE and to the time just after FE, respectively, in the purebreds.

Analysis in the peri-event dating system (Series B): In order to check the time causal relationship of the climatic effect on reproductive traits more precisely, regressions of reproductive parameters on climatic factors in the periods one and two months before and one month after FE, FAI and LAI, respectively, were investigated (Table 4). Results obtained were relatively simple in both crossbreds and purebreds. Regressions of the positive-first order were obtained the most frequently and those of positive- and negative-second orders were only seen in a small number of cases for MINT and THI, and MAXT and MAXH, respectively. Negative-first order and the third order regressions were no longer found in this dating system. The rise in MINT and THI during one or two months before FE and FAI caused prolongation of DTFE and DTFAI, respectively. In the case of linear regression on MINT, the intervals were lengthened by about 5 days in response to the rise in MINT by 1.0°C. Regressions of DTFE on THI and DTFAI on MINT and THI, during 31-60 days before events, were the positive-second order in the crossbred. Turning points of these parabolic regressions were 18.2°C for MINT and 20.6 and 22.6 for THI. The increase in MAXT also brought about the prolongation of DTFE and DTFAI, although temperatures higher than 33-34°C tended to shorten the intervals rather than lengthen them further. Significant effects of MINT, MAXT and THI on DTC were not detected in the periods examined, while significant positive- and negative-second order regressions of DTC were observed in MINH during 30 days after, and MAXH between 60 and 31 days before LAI, respectively, in the crossbred. No significant effects of humidity were found in any reproductive trait of the purebred cows.

DISCUSSION

By cooling specifically pure Friesians in the NDTARI by electric fan and water sprinkling in the hot season, and feeding them higher quality rations, their heat susceptibility has been covered and their good productive and reproductive abilities displayed as much as possible. The fact observed in Experiment 1; that there were no differences in rates of estrus occurrence and success of A.I. service throughout one year between crossbred and purebred cows, may evidence the effectiveness of measures adopted by the institution for hot climate conditions. However, big differences between breeds were found in the pattern of seasonal change in these rates. The influence of season appeared more eminently in the purebred than crossbred in either estrus incidence or success rate of A.I. service. That is to say, although there was a tendency for both rates to be a little higher in the purebred than crossbred in the cold-dry season, the rates dropped markedly in purebred cows in the hot season. This was in spite of special care being given to the purebred in order to overcome the hard season. The seasonal effect in the rate of estrus occurrence, but not in the success rate of A.I. was observed in the crossbred. These results confirmed the general feeling of dairymen in Thailand on seasonal effects on the reproduction of their cows.

As we demonstrated in the adjoining paper, the reproductive performance of cows became worse as their milk production increased, and the extent of such an adverse effect of lactation appeared more largely in the purebred than the crossbred because of the greater amount of milk produced in the former. In addition to the use of electric fans and water sprinklers for purebreds only in the hot season, this fact might also contribute to making the relationship between ambient climate and reproductive traits very complicated in pure Friesians. When relationships between climatic and reproductive parameters were examined in this breed, along with the date after calving, significant regressions were often obtained in periods far distant from or even after the time of occurrence of subjected reproductive events. Patterns of regression obtained in these cases were apt to be very complicated such as positive- and negative-third orders or as unlikely as the negative-linear. It was difficult to explain these patterns as expressions of the natural physiological responses of cows to various climatic conditions. On the other hand, in the case of the crossbred, significant regressions of reproductive parameters on climatic changes were found in simpler form and only in the periods a little preceding or almost coinciding with the time of occurrence of respective reproductive events. The exception was for those of DTC and NAIS on MINH and MAXH. The most conspicuous effects were those of MINT and THI during the first 2 months after calving on DTFE and those during the period from the 3rd to the 5th month pp. on DTC. Therefore, in order to examine the effect of climate more precisely during the period just preceding reproductive events, the analysis on the peri-event dating system was carried out. Then, it was surely proved that MINT and THI affected DTFE during one or two months before FE and, in addition, those before FAI affected DFAI. It was also revealed that these climatic effects could be observed similarly in the purebred as well as in the crossbred. The climatic effect on DTC could not be found in the peri-event dating system, except for the effects of MINH during the period after and MAXH two months before the day of conception. Integration of climate over a long period from calving to successful fertilization might affect DTC, and then the effect of climate during a relatively short period before the last estrus might not be discovered so readily in this reproductive trait.

Except for responses of a very complicated form in pure Friesians in Series A, reproductive parameters responded to changes in climatic factors in the form of positive-linear regression in most cases and in the positive-parabolic fashion in several cases. Positive-linear regression indicates that respective reproductive intervals lengthened as temperature, humidity and/or the THI value rose, i.e., reproductive performance of cows became worse as climate became hotter and/or wetter. On the other hand, in the cases of DTFAI and DTC on MINT in Series A and DTFE on THI, DTFAI on MINT and THI and DTC on MINH in Series B in the crossbred, respective intervals shortened once temperature, humidity and THI elevated from low values, but they again lengthened as the climatic parameters rose beyond respective turning points, 17.7-18.9°C for MINT, 56.9% for MINH and 20.6-22.6 for THI. There seem to be two possible explanations for these biphasic responses of reproductive parameters of crossbred cows. The first is that an ambient temperature and humidity at around these turning points are the best for crossbred cows in keeping their body condition. Then, when the temperature and/or humidity become either higher or lower than these points, the body condition of cows is lowered, restoration of estrous cycle is delayed and then reproductive intervals become longer. In other words, a depression of ambient temperature below the turning point may be received as a kind of stress by animals that are well adapted to a tropically hot climate. Cold stress in contrast to heat stress. Another explanation is that the biphasic response was brought about by the result of a combination of effects of climate on reproduction and milk production. We found previously, in crossbred cows, that milk production was significantly affected by the change in MINT, MINH and THI in a negative-linear fashion; i.e., the production increased or decreased as temperature and humidity decreased or increased (Pongpiachan et al., 2000). As we have already reported (Pongpiachan et al., 2003), greater milk production impairs the reproductive activity of cows and makes reproductive intervals longer. Therefore, as climate becomes cooler and drier, both milk production and reproduction of cows become better. However, when a decrease in temperature and/or humidity proceeds further, the increase in milk production and its ill effect on reproductive function may exceed the benefit of a cool climate and reproductive intervals become longer again as the climatic changes proceed. We cannot decide at present which explanation is more plausible. More elaborate studies including direct observations of physiological and behavioral responses of cows to climatic change may be required in order to solve this problem.

The effect of MAXT on reproductive performance was not so eminent, except for the purebred in Series A, in which the effect was expressed by very diverse forms of regression. In this case, it can be easily imagined how cows took to strange behavior in order to escape from the intolerable heat of a hot season day, e.g., standing still for a long time under a water sprinkler or in front of an electric fan. Such diversity in the behavior of individual animals, together with the difference in their milk yield, seems to make the response of reproductive parameters to the change in MAXT very complicated as a whole. On the other hand, in cases of the crossbred in Series A and crossbreds and purebreds in Series B, the effects of MAXT were observed only in a few cases. They were on DTFE at the first 30 days after calving in the crossbred in Series A and on DTFE during 30 days before FE in the crossbred and DTFE during the same period and DTFAI during 2 months before FAI in the purebred in Series B. Regressions in these cases were of the positive-linear in the effect on DTFE of the crossbred in Series A and those on DTFAI of the purebred in Series B. However, they were of the negative-second order in 2 other cases with turning points on the graph being 33.5 and 34.4°C, respectively. It may be possible to explain this biphasic response by the combination of the effect on milk production as in the case of MINT. That is to say, when an ambient temperature rose above these turning points, milk production was decreased by the effect of such a high temperature, and, as a result, its suppressing effect on reproduction decreased, although no significant effect of MAXT on lactation was detected in the previous work. Effects of humidity on reproduction were obscure as a whole. Significant effects of MINH and MAXH were found mostly on DTC and NAIS, and on DTFE only the effect of MINH was found between 90 and 150 days pp. The effects of MAXH were found between 120 and 150 days pp in the purebred, and those of MINH found during the 60 days before FE in the crossbred were significant. Neither MINH nor MAXH affected DTFAI anymore. Clear time causal relationships between periods, in which significant relationships were observed and reproductive events occurred, cannot be considered, other than the effect of MINH during 2 months before the first estrus on DTFE in the crossbred. It, therefore, seems pointless in holding discussions on the physiological meaning of the results obtained so far on humidity.

Among the climatic factors examined, the effect of MINT was the most eminent. Although THI followed MINT, its effect is considered to be mostly a reflection of the effect of MINT, because the affect of the change in humidity was not obvious except for the effect of MINH during 2 months before FE on DTFE. It was revealed in our previous paper (Pongpiachan et al., 2000) that MINT also affected milk production the most profoundly among climatic factors examined in the crossbred cows, which were not given any protection against the hot climate. MINT may be a nighttime temperature that varies more widely than MAXT, which is a daytime temperature, throughout the year in Thailand. The rise in ambient temperature during the night may affect the body condition of cows most severely and cause a depression of milk production and fertility.

Heat stress has been proved to reduce the conception rate of lactating cows by impairing the ovarian follicular development during an estrous cycle (Wolfenson et al., 1995; Trout et al., 1998; Wilson et al., 1998) and increasing the rate of early embryo death due to the elevation of body temperature (Putney et al., 1988). The ill effect of the rise in MINT during one or two months after calving or during 30 or 60 days before the first estrus on DTFE observed in the present study, is considered to be a result of the delay in follicular growth. This is caused by heat stress directly and/or the depression of body condition due to hot nights. In the latter case, high MINH during the same period, combining with high MINT, may make the condition worse and act to prolong DTFE. Inverse relationship between MINT/THI and DTFAI seems to provide a similar explanation. On the other hand, no definite climatic effects were found on DTC in the present study. Hot climate can be considered to prolong DTC by two routes; one is to disturb the recurrence of the estrous cycle through the same mechanism, as affecting DTFE and DTFAI, and the other is to raise the embryo mortality by causing hyperthermia in mothers. Positive correlations between MINT/THI and DTC, observed during 60-50 days pp in the crossbred in Series A, may be evidence of the first probable mechanism. Qureshi et al. (2000) reported in dairy buffalo an inverse relationship between milk progesterone levels and atmospheric temperature and also that fertility was the lowest during summer associated with the lowest progesterone levels and the highest incidence of silent ovulations. Disturbance of the function of hypothalamo-hypophysial-gonadal system due to the elevated air temperature may be the cause of depression of low fertility also in this case. However, a similar relationship could not be detected in Series B, in which the period of climate effect was restricted to two months before the final A.I. service. In order to check the latter probability, the effect of climate during one month after the last insemination on DTC was examined, but no significant result, except for the effect of MINH in the crossbred, was obtained. Gwazdauskas et al. (1973) demonstrated, in dairy cows kept in Florida, that there were significant inverse relationships between conception rate and uterine temperature on the day of insemination, and between the rate and ambient (maximum, minimum and average) temperature on the day after insemination. If a high ambient temperature during only one or two days after the insemination could induce embryo death enough, the duration of one month after the A.I., used in the present study to calculate averages of MINT and MAXT, would be too long. Thus, the effect of high temperature during a short period such as one or two days might be overlooked.

Eminent seasonal changes in the rates of estrus occurrence and successful insemination in the purebred indicate the presence of definite effects of hot climate on the reproductive activity of this breed, even under the protection of electric fans and water sprinklers. However, there were no significant differences in the above noted rates throughout one year between crossbreds and purebreds. The fact that neither a consistent nor an intelligible relationship could be detected between reproductive and climatic parameters in the purebred, may indicate inversely the effectiveness of such facilities for protecting the reproductive performance of Friesians from tropically hot climates as a whole.

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