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Effect of heat stress on conception in a dairy-herd model in the Natal highlands of South Africa

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ABSTRACT

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Regression models are proposed for predicting conception rate in a dairy herd under South African and especially Natal conditions. Conception rate (CR %) was related to mean monthly temperature-humidity index (THI) by curvilinear regression equation model; CR % = –812,7 + 28,61THI – 0,2322THI^2 (P = 0,061), and by linear regression equation model; CR % = 188,0 – 1,906THI (P = 0,023). Conception rate was related to numerical month of the year (M) by: CR % = 44,34 + 6,168M – 0,428M^2 (P = 0,106). Further investigations to test the proposed regression models under various dairy-herd conditions and to improve reproduction in South African dairy herds are needed.

INTRODUCTION

An animal is never independent of the environment in which it lives: the animal and its environment form a system in which both act on and react to each other (Yousef 1985). High sensible temperature and humidity are associated with seasonal declines in the reproductive efficiency of domestic cattle (Gwazdauskas, Wilcox & Thatcher 1975; Ingraham 1974). It is clear that thermal conditions are a constraint on the performance of farm animals, particularly in high-yielding dairy cattle (Du Preez, Giesecke & Hattingh 1990; Du Preez, Giesecke, Barnard, Erasmus, Hattingh, Eisenberg, Willemse & Kruger 1992; Giesecke 1985; Hahn 1985). The effect of thermal stress on reproduction is manifest in several physiologic mechanisms and includes debilitating effects on conception rates, duration and expression of oestrus, etc. (Bianca 1970; Cavestany, El-Wishy & Foote 1985; Drost & Thatcher 1987; Fuquay 1981). At present the temperature-humidity index (THI) is the most practical means of assessing the exposure of cattle to heat stress (Yousef 1985). Warm months are more closely associated with lower conception rates than cool months (Gwazdauskas *et al.* 1975). The average THI of the second day before breeding is closely correlated with conception rate (Ingraham, Gillette & Wagner 1974).

The thermoneutral zone for cows is between 0 and 16 °C (Bianca 1970). Cows experience heat stress when the temperature rises above 23,8 °C at a relative humidity of 80 % (Nickerson 1987). A THI of 70 or less is classified as normal; values above 70 are stressful to cattle (Anonymous 1970). The Livestock

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Weather Safety Index (LWSI) indicates that in large areas of South Africa and Namibia prolonged periods of warm climatic conditions cause heat stress in food-producing animals, especially in dairy cattle, thereby hampering their performance (Du Preez & Giesecke 1990; Du Preez *et al*. 1990). Du Preez (1992) showed that the annual loss—as a result of heat stress on conception—in dairy cattle in South Africa amounts to more than thirty million rand.

The purpose of this study was to investigate the relation between the THI and conception rate in dairy cattle in the Natal highlands, a highly populated dairy area of South Africa, and to develop a model for the prediction of the conception rate of dairy cattle in that region under various THI conditions and during different periods of the year.

MATERIALS AND METHODS

Meteorological data

Meteorological data from the nearest weather station were obtained from the South African Weather Bureau Publication WB 40 (Weather Bureau, Department of Environmental Affairs 1988) and updated reports, as described by Du Preez *et al.* (1990). The THI values (Table 1) were calculated according to the methods described by Kibler (1964).

Dairy-herd model: experimental animals

The investigation was conducted during the period 1985 to 1991 on a herd of 130 Friesian cattle on the Natal highlands near Lidgetton (latitude 29°26′S, longitude 30°06′E and altitude 1204 m) in a semi-intensive system. The total number of lactations from 1985 to 1991 was 429, with an average of 3,1 per cow. The herd was machine-milked twice a day. The cows varied in age, number of lactations and daily milk yield. Breeding occurred throughout the year. The standard of management, animal husbandry and hygiene was high. All artificial inseminations were done by two qualified inseminators who used certified semen. The average milk yield per lactation per cow, over a period of 300 days, was 7041 kg. Oestrus-observation efficiency was good, and observations were always performed by the same trained personnel. The calculated mean interval between oestrus periods was 25. Cows were culled after the fifth unsuccessful insemination.

Reproduction parameters

The relationship of the mean actual monthly conception rate to heat stress in terms of the THI was investigated. Conception was verified by rectal palpation 8 weeks after insemination and by birth of live calves.

Classification of THI values

The calculated THI values were measured against the classified THI values according to the LWSI of the Livestock Conservation Institute to evaluate whether dairy cattle were heat stressed: a THI of 70 or less indicated a normal LSWI level, 70–78 an alert level, 79–83 a danger level and 83 or above an emergency level.

Statistical methods

First- and second-degree polynomials were fitted [Statgraphics (Statistic Graphics Corporation)] for the monthly mean percentage conception rate (1985 to 1991 data) on the monthly mean THI (Table 2). A second-degree polynomial was also fitted, the numerical month of the year being used as the independent variable. The regressions were compared with those obtained for the Transvaal Highveld (Du Preez, Terblanche, Giesecke, Maree & Welding 1991) by the method described by Groeneveld (1970), and the program POLKT (Agrimetrics Institute, Agricultural Research Council, Pretoria) was utilized.

Prediction of conception rates

The monthly mean conception rates for dairy cattle according to the equation: CR % = 388,3 − 4,62 THI (Ingraham 1974) and three regression models were investigated and used to predict conception rates.

RESULTS

The mean percentage conception rates, the fitted polynomials, the regression equations and the probabilities for goodness of fit are presented in Fig. 1 and 2. The relation between percentage conception rate and the THI was better described by the linear than the second-degree polynomial. The percentage variation explained (R^2 x 100) was 41,6 and 34,4 %, respectively, for the two regressions. For both the linear and curvilinear regressions on THI, the standardized residual for the conception rate for November was larger than 2 (−2,19 and −2,92, respectively). Treating this observation as an outlier and omitting it, resulted in improved goodness of fit for both regressions (P = 0,041 and 0,013, respectively; see also Fig. 1). Sample size for this conception rate was the smallest of all months (n = 25; see Table 2). The conception rate for February had the second largest standardized residual (n = 26). A somewhat poor relationship was obtained for the mean percentage conception rate on the numerical value of the months and only 25,7 % of the variation could be attributed to the latter variable. However, omitting the observation for November (outlier) improved the goodness of fit considerably and as much as 42,5 % of the variation was accounted for.

TABLE 1 The mean monthly temperature-humidity-index (THI) values applicable to the dairy-herd model at Lidgetton in Natal highlands for 1985 to 1991

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1985	71,4	69,8	68,8	68,4	65,0	63,4	62,1	66,9	66,4	69,8	69,2	68,0
1986	70,0	69,4	69,9	67,5	67,2	62,6	63,7	65,0	66,7	66,2	66,2	69,4
1987	69,7	72,6	69,0	69,0	68,1	61,5	61,7	62,7	63,2	64,6	67,2	70,6
1988	70,2	70,4	69,5	65,5	64,5	59,9	62,8	65,4	66,4	65,4	66,8	67,7
1989	69,3	66,7	69,4	65,9	64,1	59,8	60,5	67,8	66,6	65,5	65,7	69,6
1990	68,8	69,3	67,6	66,7	63,8	60,7	60,6	62,6	67,2	67,7	66,2	68,7
1991	69,7	69,8	69,0	67,2	65,3	61,2	61,7	65,0	66,1	66,6	66,8	69,2
Mean	69,9	69,7	69,0	67,2	65,4	61,3	61,9	65,1	66,1	66,5	66,9	69,0

TABLE 2 The mean monthly temperature-humidity index (THI) and corresponding actual conception rate (CR %) and predicted (P) values of CR % applicable to the dairy-herd model at Lidgetton in Natal highlands for 1985 to 1991 by means of different linear and curvilinear regression-model equations

Mean monthly data	Months by values											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
THI	69,9	69,7	69,0	67,2	65,4	61,3	61,9	65,1	66,1	66,5	66,9	69,0
CR (%)	59,6	44,8	51,9	65,6	66,2	67,1	69,4	67,9	64,2	67,3	48,6	62,3
No. of observations (n)	53	26	58	73	83	66	75	128	71	36	25	42
Predicted CR (%) on THI												
PCR (%)[a]	65,4	66,3	69,5	77,8	86,2	105,1	102,4	87,6	82,9	81,1	79,2	69,5
PCR (%)[b]	52,5	53,2	55,8	61,2	65,1	68,5	68,5	65,6	63,8	62,9	62,0	55,8
PCR (%)[c]	54,8	55,1	56,5	59,9	63,3	71,1	70,0	63,9	62,0	61,2	60,5	56,5
Predicted CR (%) on month (M)												
PCR (%)[d]	50,1	55,0	59,0	62,2	64,5	65,9	66,5	66,3	65,2	63,2	60,4	56,7

[a] According to the equation of Ingraham (1974): CR % = 388,3 – 4,62THI
[b] According to the curvilinear regression model: CR % = – 812,7 + 28,61THI – 0,2322THI^2 (SE = 7,71)
[c] According to the linear regression model: CR % = 188,0 – 1,906THI (SE = 6,64)
[d] According to the curvilinear regression model: CR %= 44,34 + 6,168M – 0,428M^2 (SE = 7,14)

The mean monthly THI values at Lidgetton for the period 1985 to 1991 are given in Table 1.

The actual and predicted quantities for all regressions and the standard error for the regressions are given in Table 2. Because the trends obtained in this study were similar to those reported by Du Preez *et al.* (1991), the regressions for the two areas were compared to determine whether common trends were present. Significant differences at P = 0,05 for the conception-rate trends were, however, evident for all comparisons for the ranges of THI values observed.

DISCUSSION

The mean actual monthly conception rate was at its lowest during the summer. A number of environmental factors may account for the fact that the predicted conception rates for November (and perhaps also for February) were too low. Apart from heat stress, poor nutrition and uterine health can also contribute to a low conception rate. The small sample sizes (non-representative) for these months may have contributed to chance selection of animals with naturally low conception rates. The conception rate was at its highest (69,4 %) in July, and the monthly THI was

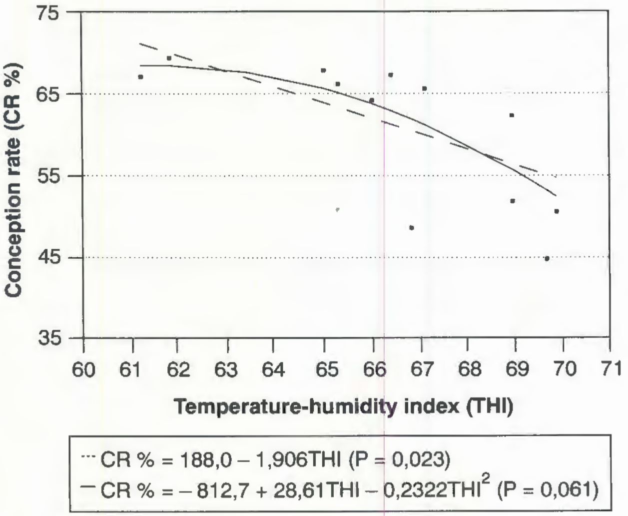

FIG. 1 The actual and predicted mean conception rates for the mean monthly THI values

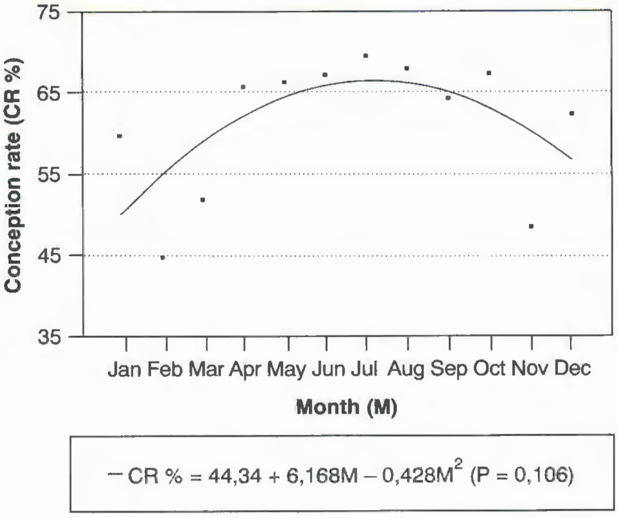

FIG. 2 The actual and predicted mean conception rates for the numerical value of the month

61,9. Generally the conception rate decreased with increasing THI values (Table 2). Although the mean monthly THI values were below 70, which is the threshold for normal performance of dairy cows, the data applicable to the dairy-herd model (Table 2) showed negative linear and curvilinear trends for the THI and conception rate (Fig. 1) and a curvilinear trend for the THI and numerical month of the year (Fig. 2). Ingraham *et al.* (1974) showed that the conception rate of 191 cows served on days with an average THI below 66 was 67 %, compared with 21 % for cows served on days with an average THI above 76.

THI values grouped according to the categories of the Livestock Weather Safety Index (Anonymous 1970) and the Livestock Weather Safety Index for lactating dairy cattle (Du Preez *et al.* 1990) suggest that within the normal range of THI values of up to 70, dairy cattle show optimal performance, experience no significant heat stress and are not adversely affected by handling (Yousef 1985). Dairy cows in the Natal highlands show sub-optimal reproduction at THI values of less than 70, because with inclining THI, although the upper limit is less than 70, conception rate declines (Fig. 1). Johnson (1985) showed that the critical THI value for milk production is 72. The THI threshold for reproduction as measured by conception rate seems to be in the region of 65 (Fig. 1). It is clear that heat stress affects the conception rate long before the THI reaches 72, at which point milk yields start to drop significantly. The predicted conception rates according to the mean monthly THI and numerical month of the year compare favourably with the actual mean monthly conception rates (Table 2). Ulberg & Burfening (1967) showed that a 1 °C increase in rectal temperature in cows within 12 h after insemination reduced the pregnancy rates from 61–45 %. Warm months were more closely associated with lower conception rate than with cool months; month effects appeared to be accounted for by the climatological measurements (Gwazdauskas, Thatcher & Wilcox 1973). Wolfenson, Flamenbaum & Berman (1988) showed that conception rate was higher in cooled than in non-cooled cows (59 v. 17 %).

Fertilization is normal in heat-stressed cattle (Drost & Thatcher 1987) and embryonic death is responsible for the decreasing conception rate of cattle in hot climates (Ulberg & Burfening 1967). Monty & Racowsky (1987) suggest that the reduced fertility of summer heat-stressed dairy cows may result from the decreased viability and developmental capacity of day-6 to day-8 embryos. The mechanisms underlying these observed adverse effects of heat-stress survivability of embryos are unknown, but may be due to a direct action of heat on the embryo or to an indirect effect that is mediated by the uterine environment. Heat stress between days 8–17 of pregnancy altered the uterine environment as well as the growth and secretory activity of the conceptus. Conceptuses weighed less, and the uterine environment was either unable to support embryo development or was toxic to the embryo (Ulberg & Burfening 1967).

The new curvilinear and linear regression models ($CR\ \% = -812{,}7 + 28{,}61THI - 0{,}2322THI^2$ and $CR\ \% = 188{,}0 - 1{,}906THI$) provided reasonable predictions of conception rates (Table 2; Fig. 1) and are recommended for Natal conditions in preference to the formula given by Ingraham (1974). The increased variation in conception-rate percentage above approximately 66,5 THI units may be attributed to differences in the effects of high stress on individual animals, while other unmeasured environmental factors, such as shade utilization and dietary factors may also have played a role.

The relatively poor fit of the second-degree polynomial for conception-rate percentage on the numerical month value is probably due mainly to the considerably larger variation in conception rate during the summer than the winter months. Predicting conception rate according to the month of the year is not recommended, as this can be used only under similar climatological conditions and is insensitive to changes in actual THI values.

Precautions against heat stress, such as shade, air movement, cooled drinking water, diet alterations and wetting (Du Preez & Giesecke 1990; Du Preez *et al.* 1990), may improve conception rates in the Natal region of South Africa. The models for the prediction of conception rates under Natal conditions can be used to implement short-, medium- and long-term precautions against heat stress in dairy cattle with low conception rates.

CONCLUSION

Preventative animal husbandry and management precautions against heat stress—which may increase conception rates—can be taken in areas in Natal, where reduced conception rates are predicted by the regression models according to the THI values. Further investigations into the effect of heat stress on the reproduction of dairy cattle in South Africa are suggested. From the results reported, the conception-rate trend may be significantly different in different regions of South Africa. Finding accurate prediction models for all the important dairy-cattle demographical regions in South Africa should have a high priority.

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