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# Response of Friesian Cows to Microclimate on Small Farms in Warm Tropical Climates

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**Abstract:** In order to know whether heat stress associated with the warm tropical environment in Central Uganda has a direct effect on the physiology of imported temperate Friesian cows, physiological responses of 81 Friesian animals grouped into Zero Grazed (ZG), n = 28 and Open Grazed (OG), n = 53 cows to heat stress were measured. The responses examined included Hair Coat Temperature (HCT), Breathing Rate (BR) and Rectal Temperature (RT). Cow responses were measured repeatedly every 7-9 days during 4 seasons, between 1200 and 1700 h, simultaneously with spot measurement of microclimatic parameters, i.e. ambient Temperature ($T_A$), Relative Humidity (RH), Solar Radiation (SR), Wind Speed (WS) and black globe Temperature ($T_{BG}$). Statistical analyses of physiological responses were done using the SAS 6.12 statistical package and included FREQ procedure, TTEST and GLM. Results indicated that animals responded to changes in the microclimate and temperature, relative humidity and solar radiation were directly causing heat stress to a proportion of cows at the smallholder farms. These climatic parameters had stronger effects on animal responses in OG than ZG cows accounting for up to 24 and 36% of variation in physiological the parameters, respectively. Wind movements were important in reducing hyperthermia in both systems.

**Key words:** Heat stress, THI, ambient temperature, environment, microclimate, Friesian cows

## INTRODUCTION

Animals are known to respond to thermal stress by an increase in body temperature, breathing rate, incidence of mastitis and change in behaviour (Ansell, 1976). These responses inevitably will translate into reduced feed intake (Maust *et al*., 1972), reduced fertility (Ingraham *et al*., 1974) and milk production (West *et al*., 2003). Comparison of the physiological responses with known normal standards can give an indication as to whether animals are heat stressed or not. Measurement of hair coat temperature gives an indication of the radiant heat load that an animal experiences at a given time and comparison of hair coat temperature of cows in shaded and non-shaded micro-environments, gives a judgement of the extent of radiation non-shaded cows may be receiving over that which shaded cows may be receiving (Hansen, 1990). In a related research by the author, it was found that cows in this environment are exposed to stress for at least a third of the time everyday with minimal seasonal variation. It hypothesised that cows in are heat stressed. The objective of the study, was to determine the effects of various microclimatic parameters and indices on the physiology of cows. This will help to understand their interaction in influencing cow thermal comfort and will allows us propose management techniques that promote cooling and or prevent elevation of heat stress in small holder farms in the warm tropics.

## MATERIALS AND METHODS

A total of 81 animals Friesian cows on 6 farms comprising of pregnant and non-pregnant cows from the 1st-6th parity, studied in 4 seasons from July 1999 to July 2000. Cows were grouped zero grazed (n = 28) and open grazed (n = 53) management system. In each management system, cows were unequally distributed to three different farms. The 3 ZG were distributed in a ratio of 14:10:4 and OG cows in ratio of 27:23:3 cows. Cows were identified by numbered ear tags and names. Animal attributes, viz stage of lactation, milk quality and quantity, stage in reproductive cycle, parity, Body Condition Score (BCS) and Body Weight (BW) were used to define the status of a cow on the day of farm visit. Cows on a farm in different stages of lactation, reproductive status, parity, body condition score or body weight were measured at the same time so that animal status was not confounded

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with day of measurement. This provided a basis for separating effects of day and of animal attribute in the analysis of animal responses. Reproductive status was divided into six categories: Puerperal cows were those that had calved less than 60 days before the day of visit. Anoestrous-lactating cows were those that had gone beyond 60 days after calving and had not yet been seen in heat. Cycling-lactating cows had been seen on heat less than 21 days before the day of the farm visit and had or had not been served. Pregnant milking cows were those that were pregnant and in milk on the day of the farm visit. Pregnant dry cows were those that were in an advanced stage of pregnancy and had been dried off. Non-pregnant dry cows were neither pregnant nor lactating. Parities ranged from 1, 2, 3, 4, 5 and 6 or above and were used in place of age for all analyses that required age as an influencing factor. Body condition score was estimated subjectively on a scale of 1.0 for very poor body condition through 4.0 for very good body condition (Edmondson *et al.*, 1989). Scaling was done once at the beginning of a data collection season and once on the last day of a season. The mean of the two measurements was recorded to represent the body condition of the cow during that season.

Body weight (kg) was estimated using a weighing tape (Medvet Laboratories, Kampala, Uganda). Measurement was done once at the beginning of a season and once on the last day of a season. The mean of the 2 measurements was recorded to represent the body weight of the cow during that season.

Cow responses of a cow were measured repeatedly every 7-9 days during a season. The same cows were observed on each visit within a farm-season but the cows observed during different seasons in a farm were not necessarily the same. Breathing Rate (BR), Rectal Temperature (RT) and Hair Coat Temperature (HCT) were measured between 1200 and 1700 h when climatic parameters were expected to be high enough to elicit clear physiological responses in the cows (Román-Ponce *et al.*, 1977). Breathing rate was estimated by counting the flank movements (Román-Ponce *et al.*, 1977) for 6 sec. The observation was repeated four times and the mean of the four countings was multiplied by ten to get the mean respirations per minute. Rectal temperature was determined by inserting a digital thermometer (Kruuse MT-900-1CDK-5290 Marslev range 32-43.9°C) into the rectum. Hair coat temperature was measured using a hand-held digital infrared thermometer (Raytek. Raynger ST2L, Calex, Model RAYR ST2LG Birchington Road, Northants NN17 9RS). on the left and right side of each cow at the pin bone at a distance of 2.5 cm away from the hair. The average of the two readings was taken to represent the overall hair coat temperature.

Simultaneous measurement of, microclimatic parameters (spot climatic measurements) was done. This included ambient temperature, relative humidity, solar radiation and wind speed, The blackglobe temperature reading in the shade and no shade taken closest to the time of measuring a cow's physiological parameters was used to estimate the total radiant heat that a cow was receiving at that particular moment and was related to the physiological responses of zero and open grazed cows, respectively. THI was calculated for each cow at the time of measuring its physiological parameters using the temperature and relative humidity. The variations in climatic parameters and indices between systems or seasons were the basis for comparing the effect of environment on the animal parameters.

Statistical analyses of physiological parameters were done using the SAS 6.12 statistical package (SAS Institute Inc 1989, Cary, NC, USA). To test the hypothesis that "cows are heat stressed", frequencies of observations for elevated RT, BR and HCT were calculated using the FREQ procedure. Cows were classified under the normal RT group if they had a RT less or equal to 39.1°C. Cows with RT between 39.1-39.5°C were in danger of hyperthermia, those with RT from 39.6-40°C were hyperthermic and those 40°C were extremely hyperthermic (Bianca, 1968; Radostitis *et al.*, 1994). Differences between subclasses of any class were tested with the chi-square test ($p<0.05$). Differences in means of HCT, BR and RT of the cows in two different management systems, or parities were tested by comparing the least squares mean using Student's t-test. Significant fixed and continuous effects of animal attributes on cow responses were tested using a completely randomised GLM procedure according to Imtiaz Hussain *et al.*( 1992). An f-test was used to test whether there was significant variation of the dependent variable among the different sub-classes or levels of the independent variable. Significant differences in the least squares means of two levels of an independent variable that had an affect on the dependent variable were tested using the t-test. The combination of animal attributes that resulted in the best model (one with the highest r-square) was referred to as the "base model" for that particular response. To test the relationship between climatic parameters and cow responses, a stepwise correlation procedure was first done. This showed the magnitude and direction of relationships and identified the most influential single climatic parameter on the animal responses. Adding individual climatic parameters as continuous effects to the base model, in which HCT, BR and RT were dependent variables, tested the effect of climatic parameters on the variation in cow responses. Any improvements in r-square were attributed to the introduced climatic variable and tested the hypothesis that climate caused heat stress.

The general linear model used to analyse HCT BR and RT in open and zero grazed lactating cows is shown below as:

$$Y_{ijkomn} = \mu+R_i+P_j+L_k+S_o+b_M.M(L)_k+E(C)_{mn}+e_{ijkomn}$$

Where,

$Y_{ijkomn}$ = Observed hair coat temperature, breathing rate or rectal temperature

$\mu$ = Overall mean of the hair coat temperature, breathing rate or rectal temperature

$R_i$ = Fixed effect of the reproductive status I: (1 = not pregnant), (2 = pregnant)

$P_j$ = Fixed effect of the parity j: (1 = parities1, 2), (2 = parities 3, 4, 5), (3 = parities $\geq$ 6)

$S_o$ = Fixed effect of Body Condition Score BCS o: (1 = BCS $\leq$ 3.7), (2 = BCS > 3.7)

$L_k$ = Fixed effect of stage of lactation k: (1 = 0-200 days), (2 = > 200 days)

$M(L)_k$ = Milk yield of the cow within k$^{th}$ stage of lactation

$C_m$ = Fixed effect of the m$^{th}$ coat colour m: (1 = > 50% black), (2 = $\leq$ 50% black)

$E(C)_{mn}$ = Random effect of the n$^{th}$ cow within the and m$^{th}$ coat colour (n = 1-58)

$b_M$ = Partial regression of hair coat temperature or breathing rate or rectal temperature on milk yield within stage of lactation

$e_{ijkomn}$ = Residual deviation [$N(0,\delta^2 e)$]

## RESULTS

**Hair coat temperature:** The overall mean HCT was 33.9°C (SD = 3.5). Open grazed cows had a higher mean HCT of 34.6°C than ZG cows with 33.5°C (t-test, p = 0.0101). There was an interaction of coat colour and management system, whereby coat colour was only significant in the OG but not in the ZG system. Dark coloured OG cows had a significantly higher HCT than light coloured open grazed cows. The HCT of light coloured OG cows was not different from that of dark and light coloured ZG cows (Table 1).

A Pearson correlation between climatic parameters and HCT indicated that climatic parameters had stronger correlations with HCT in open grazed than zero grazed cows (Table 2). Sky temperature was negatively correlated with HCT at the open grazing farms, while roof temperature was positively correlated with HCT inside the zero grazing units.

The influence of single or combined climatic parameters and indices on the variation of HCT is shown in Table 3. Climate accounted for up to 36 and 24% of the variation in HCT in OG and ZG cows, respectively.

Table 1: Least square means of hair coat temperature (°C) of dark and light coloured Friesian cows in the zero and open grazing systems in peri urban Kampala

| System | Coat colour | Number of observations | Mean | Standard error |
|---|---|---|---|---|
| Zero | Light | 58 | 33.6$^a$ | 0.4 |
| | Dark | 144 | 33.3$^a$ | 0.7 |
| Open | Light | 58 | 33.5$^a$ | 0.7 |
| | Dark | 256 | 35.7$^b$ | 0.4 |

Different superscripts in a column indicate significant differences (t-test, p<0.001)

Table 2: Correlations of climatic parameters and THI with hair coat temperature in open and zero grazed lactating Friesians around Kampala

| Climatic parameter | Open grazed cows (n = 450) Coefficient | p-value | Zero grazed cows (n = 300) Co-efficient | p-value |
|---|---|---|---|---|
| Solar radiation | 0.65 | 0.0001 | 0.47 | 0.0001 |
| Sky/roof temperature | -0.57 | 0.0001 | 0.60 | 0.0001 |
| Air temperature | 0.51 | 0.0001 | 0.45 | 0.0001 |
| THI | 0.51 | 0.0001 | 0.37 | 0.0001 |
| Spot wind speed | -0.31 | 0.0001 | 0.003 | 0.9657 |

**Breathing rate:** Overall, cows were hyperthermic 13% of the time and extremely hyperthermic 2% of the time. Open grazed cows were hyperthermic 16% of the time compared to 8% for zero grazed cows. After correcting for animal attributes, open-grazed cows were found to have a significantly higher mean BR of 43 breaths per minute than ZG cows, which had 35 breaths per minute (p = 0.0007) as summarised in Table 4.

Whereas air temperature, THI, sky temperature, solar radiation and wind speed, were significantly correlated with BR in the OG cows, only air temperature, THI and roof temperature were significantly correlated with BR in ZG cows. Breathing rate increased as roof temperature increased in the zero grazing units but it reduced as sky temperature increased at the open grazing farms. Minimum air temperature was correlated to BR only in the ZG system (Table 5).

Using the GLM procedure, animal attributes that affected breathing rates in the OG system (p<0.01) were parity, stage of lactation, milk yield and random effect of the cow, while in zero grazed cows only milk yield and random effect of the cow affected BR. The animal attributes, accounting for 40 and 39% of the variation in BR, constituted the base models in the OG and ZG systems, respectively. The influence of the climatic parameters (singly or in combination) on the variability of BR was tested by their improvement of the base model. In the open grazing system, climate accounted for up to 26% of the variation in BR, with temperature and solar radiation increasing BR and wind speed reducing it. The best model describing BR in OG cows was:

$$BR = -21.3 - 0.1WN+2.3T_A,$$

Table 3: Effect of climatic parameters and THI on hair coat temperature of all the cows

| | Open grazing system (n = 300) | | | Zero grazing system ( n = 162) | | |
|---|---|---|---|---|---|---|
| Model | R-square | Partial coefficient | p-value | R-square | Partial coefficient | p-value |
| Base | 0.24 | - | - | 0.29 | | |
| Base+solar radiation | 0.60 | | | NA | | |
| solar radiation | | 0.01 | 0.0001 | | | |
| Base+air temp | 0.51 | | | 0.53 | | |
| Air temp | | 0.73 | 0.0001 | | 0.35 | 0.0001 |
| Base+RH | 0.47 | | | 0.49 | | |
| RH | | -0.14 | 0.0001 | | -0.06 | 0.0001 |
| Base+air temp+RH | 0.54 | | | NA | | |
| Air temp | | 0.79 | 0.0001 | | | |
| RH | | 0.02 | 0.5651 | | | |
| Base+THI | 0.55 | | | 0.47 | | |
| THI | | 0.70 | 0.0001 | | 0.27 | 0.0001 |
| Base+solar radiation+wind | 0.60 | | | NA | | |
| Solar radiation | | 0.01 | 0.0001 | | | |
| Wind speed | | -0.10 | 0.4398 | | | |
| Base+air temp+wind speed | 0.53 | | | NA | | |
| Air temp | | 0.71 | 0.0001 | | | |
| Wind speed | | -0.38 | 0.0167 | | | |
| Base+RH+wind speed | 0.51 | | | NA | | |
| RH | | -0.14 | 0.0001 | | | |
| Wind speed | | -0.64 | 0.0002 | | | |
| Base+THI+wind speed | 0.58 | | | NA | | |
| THI | | 0.67 | 0.0001 | | | |
| Wind speed | | -0.58 | 0.0002 | | | |

NA = The combination of climatic parameters or THI was not applicable to the model in explaining the variation in HCT

Table 4: Percentages of cows within systems under different classes of breathing rates in lactating Friesians around Kampala

| | | Breathing rate (cycles per minute) class | | |
|---|---|---|---|---|
| System | Number of observations | Normal (≤59) | Moderate hyperthermia (60-79) | Extremely hyperthermic (>80) |
| Open | 706 | 84.1 | 13.6 | 2.3 |
| Zero | 421 | 91.9 | 7.4 | 0.7 |
| Overall | 1127 | 87.0 | 11.3 | 1.7 |

Table 5: Correlations of climatic parameters with BR in open and zero grazed lactating cows

| | Open grazed cows (n = 500) | | Zero grazed cows (n = 260) | |
|---|---|---|---|---|
| Climatic parameter | Coefficient | p-value | Co-efficient | p-value |
| Solar radiation | 0.36 | 0.0001 | 0.01 | 0.8448 |
| Air temperature | 0.32 | 0.0001 | 0.34 | 0.0001 |
| Sky/roof temperature | -0.28 | 0.0001 | 0.28 | 0.0001 |
| Spot wind speed | -0.16 | 0.0004 | 0.12 | 0.0561 |
| Minimum temperature | 0.15 | 0.0012 | 0.13 | 0.0382 |
| Spot THI | 0.34 | 0.0001 | 0.31 | 0.0001 |
| Minimum THI | 0.23 | 0.0001 | 0.12 | 0.0574 |

Where BR = breaths per minute, WN = wind run (km) from 1700-0900 h and $T_A$ = air temperature (°C).

In the ZG system, climate accounted for up to 10% of the variation in BR with air temperature and solar radiation increasing BR and wind speed reducing it. Although solar radiation increased BR in ZG cows, it was not significant. The best model describing BR in ZG cows was:

$$BR = -86.8+2.49T_{min}+1.12THI$$

Where; BR = Breaths per minute and $T_{min}$ = minimum temperature (°C) before counting the BR. Table 6 shows the contributions of climatic parameters and indices to the variation in BR in open and ZG systems.

**Rectal temperature:** In the afternoons, 17% of the cows had temperatures above normal, 10% were hyperthermic and 3% were extremely hyperthermic. As many as 35.1% of the OG cows had above the normal body temperature i.e., in danger or actual hyperthermia, compared to only 14.5% for zero grazed cows. The proportion of hyperthermic cows (12.5%) in the OG system was more than double the proportion of hyperthermic cows (5.3%). in the ZG system (chi-square- test, p = 0.001). The proportions of different classes of RT are shown in Table 7.

Open grazed cows had a higher mean RT of 39.0°C than ZG cows, with 38.6°C (t-test, p = 0.0001). In the OG system, the RT of darker coloured cows was 0.2°C higher than that of lighter coloured cows (t-test, p = 0.0404) but in the zero grazing units, coat colour had no effect on RT. Pearson correlation indicated small but significant correlations between climatic parameters and RT (Table 8). In the ZG units,

Table 6: Effect of climatic parameters and THI on breathing rates of lactating Friesians

| | Open grazing system (n = 350) | | | Zero grazing system ( n = 120) | | |
|---|---|---|---|---|---|---|
| Model | R-square | Partial coefficient | p-value | R-square | Partial coefficient | p-value |
| Base (ß) | 0.41 | | | 0.39 | | |
| ß+spot wind | 0.42 | | | 0.37 | | |
| Spot wind | | -1.70 | 0.0074 | | 1.60 | 0.51 |
| ß+spot temp | 0.53 | | | 0.42 | | |
| Spot temp | | 2.30 | 0.0001 | | 0.96 | 0.0051 |
| ß+spot temp+spot wind | 0.54 | | | 0.43 | | |
| Spot temp | | 2.20 | 0.0001 | | 1.42 | 0.0046 |
| Spot wind | | -0.77 | 0.2132 | | -0.20 | 0.39 |
| ß+spot RH | 0.47 | | | 0.40 | | |
| Spot RH | | -0.37 | 0.0001 | | -0.11 | 0.211 |
| ß+spot RH+spot wind | 0.48 | | | NA | | |
| Spot RH | | -0.95 | 0.0001 | | | |
| Spot wind | | -1.42 | 0.4090 | | | |
| ß+spot radiation | 0.52 | | | 0.43 | | |
| Spot radiation | | 0.03 | 0.0001 | | 0.57 | 0.31 |
| ß+spot RH+spot temp | 0.55 | | | 0.44 | | |
| Spot RH | | 3.73 | 0.0001 | | 0.20 | 0.1174 |
| Spot temp | | 0.36 | 0.0061 | | 1.60 | 0.0029 |
| ß+spot THI | 0.56 | | | 0.44 | | |
| Spot THI | | 2.40 | 0.0001 | | 0.94 | 0.0019 |
| ß+spot THI+spot wind | 0.56 | | | 0.44 | | |
| Spot THI | | 2.45 | 0.0001 | | 1.27 | 0.003 |
| Spot wind | | -0.31 | 0.0605 | | -2.29 | 0.398 |
| ß+mini temp | 0.40 | | | 0.41 | | |
| Mini temp | | 0.43 | 0.5629 | | 1.66 | 0.0583 |
| ß+mini temp+spot temp | 0.53 | | | 0.48 | | |
| Mini temp | | -0.16 | 0.8240 | | 2.66 | 0.0023 |
| Spot temp | | 2.39 | 0.0001 | | 1.24 | 0.003 |
| ß+mini temp+spot THI | 0.56 | | | 0.49 | | |
| Mini temp | | -0.38 | 0.6151 | | 2.49 | 0.0036 |
| Spot THI | | 2.51 | 0.0001 | | 1.12 | 0.0002 |
| ß+mini temp+spot temp+RH+spot wind | 0.56 | | | 0.48 | | |
| Mini temp | | -0.76 | 0.3322 | | 2.63 | 0.0085 |
| Spot temp | | 3.81 | 0.0001 | | 1.88 | 0.0032 |
| Spot RH | | 0.37 | 0.0101 | | 0.03 | 0.8617 |
| Spot wind | | -1.61 | 0.0283 | | -4.42 | 0.1157 |
| ß+mini temp+spot THI+spot wind | 0.57 | | | 0.48 | | |
| Mini temp | | -0.85 | 0.2710 | | 2.47 | 0.0103 |
| Spot THI | | 2.46 | 0.0001 | | 1.53 | 0.004 |
| Spot wind | | -1.55 | 0.0345 | | -4.01 | 0.1383 |
| ß+night wind run | 0.51 | | | NA | | |
| Night wind run | | -0.13 | 0.0538 | | | |
| ß+night wind run+spot temp | 0.61 | | | NA | | |
| Night wind run | | -0.09 | 0.1298 | | | |
| Spot temp | | 2.26 | 0.0001 | | | |

Table 7: Percentages of lactating Friesians within systems under different classes of rectal temperatures measured between 1200 and 1700 h

| | | Rectal temperature (°C) class | | | |
|---|---|---|---|---|---|
| System | Number of observations | Normal ≤39.1 | Danger of hyperthermia 39.1-39.5 | Hyperthermic 39.6-40.0 | Extremely hyperthermic >40.0 |
| Open | 726 | 64.9 | 22.6 | 9.2 | 3.3 |
| Zero | 457 | 85.6 | 9.2 | 3.3 | 2.0 |
| Overall | 1183 | 72.9 | 17.4 | 6.9 | 2.8 |

Table 8: Correlations of climatic parameters with RT of open and zero grazed lactating cows

| | Open grazed cows (n = 600) | | Zero grazed cows (n = 280) | |
|---|---|---|---|---|
| Climatic parameter | Coefficient | p-value | Co-efficient | p-value |
| Sky/roof temperature | -0.29 | 0.0001 | 0.02 | 0.7298 |
| Night wind | -0.23 | 0.0001 | | |
| Minimum RH | -0.05 | 0.2851 | 0.16 | 0.0086 |
| Spot wind speed | -0.14 | 0.0003 | -0.005 | 0.9286 |
| Air temperature | 0.13 | 0.0023 | 0.14 | 0.0229 |
| Solar radiation | 0.09 | 0.0336 | -0.08 | 0.1541 |
| Minimum temperature | 0.09 | 0.0271 | 0.13 | 0.036 |
| Minimum THI | 0.15 | 0.0013 | 0.14 | 0.0156 |
| Spot THI | 0.14 | 0.0017 | 0.12 | 0.0653 |

roof temperature was not correlated to RT but at the OG, RT increased as sky temperature decreased.

The variation in the observed RT in lactating cows was tested with the GLM procedure. Animal attributes that significantly affected rectal temperature in the OG system ($p<0.05$) were parity, hair coat colour, milk yield and random effect of the cow, while in ZG cows only the random effect of the cow was significant. Animal attributes accounted for 32 and 29% of the variation in RT and constituted the base models for the OG and ZG systems, respectively.

Table 9: Effect of climatic parameters on rectal temperature of lactating Friesians in OG and ZG systems

| | Open grazing system (n = 355) | | | Zero grazing system ( n = 120) | | |
|---|---|---|---|---|---|---|
| Model | R-square | Partial coefficient | p-value | R-square | Partial coefficient | p-value |
| Base (ß) | 0.32 | | | 0.29 | | |
| ß+spot wind | 0.36 | | | 0.45 | | |
| Spot wind | | -0.04 | 0.0113 | | -0.10 | 0.35 |
| ß+spot radiation | 0.35 | | | NA | | |
| Spot radiation | | 0.01 | 0.0024 | | | |
| ß+spot temp | 0.36 | | | 0.31 | | |
| Spot temp | | 0.03 | 0.0001 | | | |
| ß+spot temp+spot wind | 0.38 | | | 0.45 | | |
| Spot temp | | 0.03 | 0.0002 | | 0.0044 | 0.87 |
| Spot wind | | -0.01 | 0.0333 | | -0.1067 | 0.36 |
| ß+spot RH | 0.36 | | | 0.31 | | |
| Spot RH | | -0.01 | 0.0179 | | -0.0051 | 0.1594 |
| ß+spot RH+spot temp | 0.38 | | | 0.31 | | |
| Spot RH | | 0.01 | 0.2553 | | -0.01 | 0.5575 |
| Spot temp | | 0.05 | 0.0076 | | 0.01 | 0.5287 |
| ß+spot THI | 0.38 | | | 0.30 | | |
| Spot THI | | 0.04 | 0.0001 | | 0.01 | 0.4126 |
| ß+spot THI+spot wind | 0.39 | | | 0.47 | | |
| Spot TH | | 0.04 | 0.0002 | | 0.03 | 0.1621 |
| Spot wind | | -0.04 | 0.0602 | | -0.17 | 0.1518 |
| ß+mini temp | 0.34 | | | 0.31 | | |
| Mini temp | | 0.05 | 0.0185 | | 0.06 | 0.1010 |
| ß+mini temp+spot wind | 0.38 | | | 0.50 | | |
| Mini temp | | 0.05 | 0.0202 | | 0.10 | 0.0122 |
| Spot wind | | -0.04 | 0.0227 | | -0.13 | 0.1990 |
| ß+mini temp+spot temp | 0.38 | 0.06 | 0.0288 | 0.35 | | |
| Mini temp | | | | | 0.10 | 0.0225 |
| Spot temp | | | | | 0.04 | 0.0368 |
| ß+mini temp+spot temp+spot RH | 0.39 | | | 0.35 | | |
| Mini temp | | 0.06 | 0.0408 | | 0.11 | 0.0142 |
| Spot temp | | 0.04 | 0.031 | | 0.02 | 0.3216 |
| Spot RH | | 0.01 | 0.3655 | | -0.01 | 0.2713 |
| ß+mini temp+spot THI | 0.40 | | | 0.33 | - | |
| Mini temp | | 0.06 | 0.0456 | | 0.08 | 0.051 |
| Spot THI | | 0.03 | 0.0009 | | 0.02 | 0.1808 |
| ß+mini temp+spot temp+spot wind | 0.39 | | | NA | | |
| Mini temp | | 0.05 | 0.0613 | | | |
| Spot temp | | 0.03 | 0.001 | | | |
| Spot wind | | -0.04 | 0.0671 | | | |
| ß+night wind run | 0.44 | | | NA | | |
| Night wind run | | -0.01 | 0.0001 | | | |
| ß+night wind run+spot temp | 0.52 | | | NA | | |
| Night wind run | | -0.0069 | 0.0037 | | | |
| Spot temp | | | | | | |
| ß+mini THI | 0.42 | | | NA | | |
| Mini THI | | 0.057 | 0.0004 | | | |

The influence of the climatic parameters on the variability of RT was tested by their contribution to the base model. In both OG and ZG systems, climate accounted for up to 20% of the variation in RT. Night wind run had the highest single influence on variation in RT for OG and a combination of night wind run and spot air temperature had the best model for rectal temperature, with the equation:

$$RT\ (°C) = 38.4+0.05T_A-0.007WR$$

Where $T_A$ is air temperature (°C) at the time of taking rectal temperature and WR = Wind Run (km) from 1700-0900 h.

In the ZG, minimum temperature combined with spot wind speed gave the best model for predicting RT. The equation can be written as:

$$RT\ (°C) = 37.1+0.1T_{min} - 0.13WS,$$

Where $T_{min}$ is minimum air temperature (°C) before measurement of the RT and WS = Wind Speed ($ms^{-1}$)

at the time of RT measurement. Table 9 shows the contributions of climatic parameters and indices to the variation in RT.

## DISCUSSION

The animal responses have shown that a moderate proportion of cows at the smallholder farms are heat stressed. The results have also shown that temperature, relative humidity and solar radiation are directly causing heat stress in the animals and climate influenced up to 24 and 36% of variation in physiological parameters in zero and open grazed cows, respectively.

Sky temperature had a negative correlation with HCT of open grazed cows while roof temperature had a positive correlation with HCT of zero grazed cows implying that as the sky became clear of clouds, the sky temperature fell but more direct solar radiation reached the cows so raising the HCT. In agreement with earlier research (Johnson *et al*., 1962; Bianca, 1965; McDowell, 1972; Ingraham *et al*., 1974) THI explained the variation in animal responses more than air temperature or relative humidity alone or the two put together in the same model but not integrated into an index. Relative humidity had a negative effect on animal responses because it increased whenever air temperature decreased. This means that in this environment, air temperature plays the greater role in eliciting responses than relative humidity. The strategic measurement of both climatic parameters and physiological response between 1200 and 1700 when cows are most responsive to heat stress has demonstrated the high magnitude of animal responses to THI and other climatic parameters.

The finding that spot wind speed was negatively correlated with all animal responses on the open grazing farms, but was not in the zero grazing units was not unexpected because of the very low wind speed inside the units. However, the finding that in combination with other climatic factors, wind speed had a coolant effect on both open and zero grazed cows emphasizes the need for the planning of zero grazing structures in such a way that wind, which plays a significant heat ameliorative role, can have free access and movement through the zero grazing units.

Similarly, solar radiation was positively correlated with all animal responses on the open grazing farms, but was not in the zero grazing units, because of the minimal amount of solar radiation received inside the zerograzing units. In the open grazing system, the effect of spot solar radiation was strongest in increasing hair coat temperature and breathing rate but was minimal in increasing rectal temperature implying that rectal temperature response is delayed.

The importance of inherent animal factors in increasing the vulnerability of animals to stressful microenvironments as opposed to moderate microenvironments (Hahn, 1999) was demonstrated by the finding that hair coat colour, parity and stage of lactation affected breathing rate and rectal temperature in open grazed cows, but they did not do so in zero grazed cows. Open grazed cows in the first half of lactation had higher BR than cows in the second half of lactation cows because cows in late lactation are less affected by hot weather since they are reducing in milk production (Wood, 1967). Because of the low demand, they are expected to consume less dry matter and therefore generate less heat increment of feeding and internal body heat (Maust *et al*., 1972; West *et al*., 2003). Open grazed cows with darker hair coat colour had higher rectal temperatures than lighter coloured cows because dark colours absorb more radiant heat which contributes to a higher net heat gain than light colours (Riemerschmid, 1943; Finch *et al*., 1984; King *et al*., 1988; Hansen, 1990). Since direct solar radiation was eliminated from zero grazing units and animals received only diffuse radiation, the lack of response to solar radiation amongst zero grazed cows was expected.

## CONCLUSION

Thus the major determining factor for heat stress of the cows was the management system. Individual animal attributes per se played a lesser role in eliciting heat stress responses. The proportion of stressed cows (hyperthermic) in non-housed cows were double that of housed cows. This has implications in the subsequent productivity of the non-housed cows which are managed in such a way that they feed during the day only. The heat stress is likely to force them to reduce on the hours of daytime grazing and/or to reduce the efficiency with which they can convert feed energy into useful products such as milk and meat. Zero grazed cows were less heat stressed than open grazed cows, mainly because they were exposed to less solar radiation as manifested by the hair coat temperature, which was 1.5°C lower. It was interesting to see cows grazing under the open sun in a hot early afternoon. This need to satisfy metabolic needs forces cows to go out in the sun to feed, getting exposed to the sun and heat stress in the process, whereas other observers might conclude that heat stress is not a problem for them. Zero grazed cows are at an advantage because they are continuously fed under the shade. The continuous daytime shade helps to reduce the severity of stress and therefore, proportion of heat stressed cows.

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