Journal of Animal and Veterinary Advances 6 (7): 907-911, 2007
ISSN: 1680-5593

SMicroclimate Dynamics in Smallholder Friesian Dairies of the Tropical Warm-Humid Central Uganda

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Abstract: To examine the influence of farm management system of Open Grazing (OG) and Zero Grazing (ZG) on the microclimate ambience of the cow, spot measurements of ground and air temperatures, solar-radiation, Temperature Humidity Indices (THI) and wind speed were measured on three OG and three ZG farms over a 12 months period at weekly intervals in the afternoons. The spot-readings were backed up by continuous recording of on-farm ambient Temperature (T_A) and humidity using a data-logger, plus standard weather recordings at a Met-station 12 km away at the Kawanda Agricultural Research Institute. Data was analysed using SAS general linear models. Results show that mean temperature maxima were > in OG than ZG farms ($p = 0.0001$), with AT of 30 and 28°C, respectively. Mean ground temperatures were 27.4°C for OG and 24.0°C for ZG ($p = 0.018$). Mean THIs were 77.9 for OG and 75.1 for ZG ($p = 0.0001$). Mean spot solar-radiation was 462 Watts m^{-2} and 12.2 Watts m^{-2} ($p = 0.0001$) for OG and ZG, respectively. Climatic parameters and indices known to reduce heat stress were better in OG than ZG farms. Mean minimum AT was (OG 16.2°C, ZG 18.4°C, $p = 0.0001$), Diurnal Temperature Variation (DTV) was (OG 13.7°C, ZG 9.7°C, $p = 0.0001$), while spot wind speed was (OG 1.23 m s^{-1}, ZG 0.23 m s^{-1}, $p = 0.0001$). Thus, climatic heat stress was more on OG than ZG farms. However, cows under both management systems experience afternoon heat load above the comfort zone (THI<72; T_A 5°-21° C) throughout the year at levels that depress milk production of lactating Friesians. Although parameters known to reduce heat stress were better on OG than ZG farms, wind speed under both management systems was < 2.2 m s^{-1}, the minimum required to reduce heat stress. Hence, microclimates under both systems were stressful and would contribute to depressed Friesian cow productivity.

Key words: THI, microenvironment, heat stress, microclimate dynamics, smallholder, THI, OZ, ZG

INTRODUCTION

To promote household food security and incomes, central Uganda has diversified its enterprises to include dairying of temperate Friesians. The major part of Central Uganda however, is located in the Lake Victoria basin, along the equator with a warm-humid tropical climate that may not be conducive for Friesian dairying. The mean monthly AT and RH (Fig. 1) fall within the heat stress range for Dairy Friesians (Johnson, 1987). With central Uganda at an altitude of 1144 metres above sea level, a mean total annual rainfall of 1304 mm and a relative humidity of 55%, the ambience may be altered. However, generalized climatic parameters can often be misleading when judging the suitability of an area for livestock production (Robertshaw, 1981; Johnson, 1987; Pagot, 1992; Phillips and Piggins, 1992). Animals respond to changes in the climatologic environment immediately surrounding them (Robertshaw, 1981) and its interaction with nutritional and management regimens to determine the animals' production level (Beede *et al*., 1985). Thus, Friesian dairying can be justified if the animal's immediate environment is modified by the finer details in physical

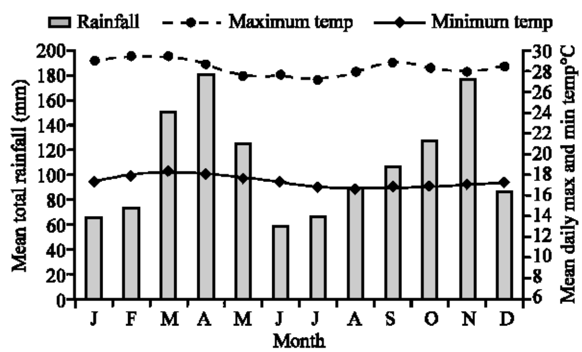

Fig. 1: Bimodal rainfall pattern with minimal temperature variation in Central Uganda (mean values 1969-1999). Rain seasons: March-May and September-November

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features such as elevation or wind strength and direction (Thompson *et al*., 1964, Beede *et al*., 1985, Johnson, 1987), or by the farmer's financial ability to adapt it to the animals' comfort (Blackshaw and Blackshaw, 1994; Buffington *et al*., 1983) and the farm management system. It is not known whether the open- and zero-grazing management systems practised in Central Uganda are sufficient to create a microclimate that ameliorates the heat stress created by the warm-humid macroclimate on the Friesians. Thus this study, investigated the microclimate dynamics at the smallholder open- and zero-grazing dairy farms using heat stress reducing or aggravating climatic parameters and indices.

MATERIALS AND METHODS

The study was done in selected villages of Kiwatule, Kiteezi, Kanyanya, Buloba and Kaliire in Wakiso District. The area long-term climate was ascertained from the Kampala meteorological department (Fig. 1).

After a survey of the smallholder system, 6 farms with good animal husbandry practices (records, vaccination regimes, feeding, general hygiene) were grouped into two management systems: Zero-Grazing (ZG; n = 3) and Open-Grazing (OG; n = 3). Under ZG, cows were permanently housed in open sided iron-roofed sheds where they were stall-fed. In the OG system, cows were not housed, but were permanently on pasture under paddock and could seek tree shade.

Measurement of microclimate parameters was done weekly, during the peak months of two rainy seasons, one dry season and one intermediate season between October 1999 and August 2000. Climatic parameters known to either aggravate or reduce heat stress were measured. Parameters taken as heat stress aggravating included ambient Temperature (T_A), Ground Temperature (GT), sky Temperature (T_S) Roof Temperature (T_R), Relative Humidity (RH) and direct/diffuse Solar Radiation (S_R). Wind speed (W_S) was taken as the heat stress reducing climatic parameter.

The T_A and RH were measured using a digital thermo-hygrometer (Digitales [Temperatur- und Feuchte-Messgerät "MD 3150"]. Beckmann +Egle GmbH, Kirchstr.30, D-71394 Kernen, Germany). Ground- roof- and sky-temperatures were measured using the Hand-held Digital Infrared Thermometer (HDIT). Ground temperature was taken by pointing the HDIT about 2 inches above the floor or grass for ZG or OG, respectively. For the roof and sky temperature, the HDIT was held 1 metre above the cow level and pointed upwards. Spot-measurements were backed up by continuous hourly recordings of AT and RH on farm using 2-channel miniature data loggers (HOBO H8; synoTECH Sensor und Messtechnik GmbH, Linnich) controlled via a computer soft ware (Boxcar-computer soft ware; synoTECH Sensor und Messtechnik GmbH, Linnich), with a range of -30 to 50°C AT and 0 to 100% RH. Solar radiation was measured using a digital solar radiometer (Skye-Handmessgerät SKS1100, Driesen+Kern GmbH Bad Bramstedt [0-2000 watts m^{-2}]). The radiometer (pyranometer) head was placed 1.3 metres (approx cow height) above the ground either inside the stall for ZG or outside for OG. Readings were repeated 4 times at 15 min intervals during a single farm visit and the mean and range of the readings recorded. The farm readings were compared with the routine climatic measurements of, maximum-, minimum- and ambient-temperature, RH, wind speed, sunshine hours and rainfall at a Met-station 12 km away at the Kawanda Agricultural Research Institute. Wind speed was measured (m s^{-1}) using a hand-held rotating vane anemometer (RS Components, Birchington Road, Northants NN17 9RS).

Two thermal stress indices, i.e. Temperature Humidity Index (THI) were derived and Diurnal Temperature Variation (DTV) were derived from the measured climatic parameters. THI, taken as a major heat stress index at the farms was determined using the formula of Johnson *et al*. (1962) and Ingraham *et al*. (1976) where:

$$THI = Tdb + 0.36Tdp + 41.2$$

Where;
Tdb = Afternoon dry bulb air temperature
Tdp = Dew point temperature

A THI > 72 and > 77 was taken as the critical level of initial drop in milk yield and of significant milk yield reduction, respectively (Johnson *et al*., 1962; Hahn and Mcquigg, 1967). In this regard, the % seasonal exposure time of cows to THI > 72 and > 77 was determined. On the other hand DTV, taken as a major heat stress amelioration index was derived by difference between the daily maximum and minimum temperatures. The proportion of days with DTV < 10°C was determined with a DTV of 10°C taken as the minimum required to elicit heat stress relief in dairy Friesians (McDowell, 1994). General Linear models of SAS 6.12 (SAS Institute INC., 1998) were used for all data analysis. A probability of $p<0.05$ was the level of significance. All results are reported with standard errors in brackets.

RESULTS

Table 1 shows that seasonal variation of climatic parameters at OG and ZG farms was minimal and Table 2 shows that the proportion of time when animals were exposed to stressful thermal environment did not vary

Table 1: Seasonal means of microclimate parameters and indices on open- and zero-grazing farms

Microclimate parameter/index	Management system	Wet season 1 (185.3 mm rain/month)	Dry season* (25.6 mm rain/month)	Wet season 2 (132 mm/month	Intermediate (60 mm rain/month)
Microclimate parameters					
Maximum temperature (°C)	Zero	27.9 (0.4)^{a}	29.3 (0.5)	27.5 (0.6)^{a}	27.4 (0.5)^{a}
	Open	30.1 (0.4)^{b}	32.9 (0.5)	30.2 (0.6)^{b}	29.7 (0.5)^{b}
Minimum temperature (°C)	Zero	18.6 (0.1)^{a}	18.5 (0.2)^{a}	19.0 (0.2)^{a}	17.7 (0.2)
	Open	16.8 (0.1)^{a}	15.7 (0.2)^{b}	16.9 (0.2)^{a}	15.8 (0.2)^{b}
Afternoon RH (%)	Zero	60.3 (1.1)^{a}	44.6 (1.5)	60.5 (1.5)^{a}	56.5 (1.3)
	Open	48.1 (1.1)^{d}	34.6 (1.5)	48.3 (1.5)^{d}	48.3 (1.4)^{d}
Spot wind speed (m sec^{-1})	Zero	0.23 (0.28)^{a}	0.24(0.32)^{a}	0.34 (0.26)^{a}	0.20 (0.27)^{a}
	Open	0.28 (0.28)	1.43 (0.30)^{b}	1.49 (0.26)^{b}	1.74 (0.25)^{b}
Spot solar (watts m^{-2})	Zero	18.7 (61.1)^{a}	8.7(61.1)^{a}	12.6 (51.6)^{a}	8.9 (51.6)^{a}
	Open	597.5 (58.2)^{a}	522.2 (61.5)^{ab}	414.4(49.9)^{bc}	314.0(48.3)^{c}
Microclimate indices					
Maximum THI	Zero	74.2 (0.4)^{c}	76.2 (0.5)^{b}	75.6 (0.5)^{b}	75.0 (0.5)^{bc}
	Open	77.7 (0.4)^{c}	79.4 (0.5)	77.9 (0.5)^{b}	77.1 (0.5)^{b}
Minimum THI	Zero	68.8 (0.2)^{c}	65.1 (0.3)	66.3 (0.3)^{c}	64.3 (0.3)
	Open	63.9 (0.2)^{c}	62.4 (0.3)^{a}	64.1 (0.3)^{c}	62.7 (0.3)^{a}
DTV (°C)	Zero	9.4 (0.5)^{ab}	10.9 (0.6)^{a}	8.6 (0.6)^{b}	10.2 (0.6)^{ab}
	Open	13.3 (0.5)^{d}	17.3 (0.6)	13.3 (0.6)^{d}	13.8 (0.6)^{d}

Similar superscripts in a row indicate no significant difference (t-test, $p<0.05$), * Area specific working definition of seasonality based on 30 years climatic data for central Uganda: Dry season < 60mm rain/month; intermediate season 60 < 100 mm rain/month; rainy season > 100 mm rain/month

Table 2: Seasonal % exposure time of cows to stressful macro THI

Exposure parameter	Rainy season 1	Dry season	Rainy season 2	Intermediate season	Overall mean
% afternoons with $THI_{max} > 72$	100	100	100	99	99.8
% time per day with THI > 72	30.0	34.2	32.2	25.4	30.5
% time per day with $THI_{max} > 77$	8.0	16.3	7.7	5.7	9.4

Similar superscripts in row indicate no significant difference (t-test, $p<0.05$), THI_{max} = Maximum Temperature Humidity Index. THI were calculated from macroclimate parameters collected at Kawanda met station in the study area

Table 3: Annual mean presentation of heat stress aggravating climatic parameters and indices on zero- and open-grazing farms in Central Uganda

Management system	Index		Parameter						
	THI_{max}	THI_{spot}	T_{max} (°C)	T_{BG} (°C)	T_G (°C)	$^{**}T_R$ / T_S (°C)	SR_{spot} (watts m^{-2})	RH_{tmin}	RH_{tmax}
Zero grazing	75.1 (4.0)	74.9 (0.5)	28.0 (4.1)	28.9 (0.2)	24.0 (0.5)	34.2 (3.0)	12.2 (28.3)	90.4(1.2)	56.2 (10.1)
Open grazing	77.9 (2.0)	75.9 (0.5)	30.0 (2.9)	34.8 (0.3)	27.4 (1.3)	4.0 (2.1)	462.0 (27.3)	94.2(1.4)	45.4 (10.6)
t-test p-value	0.0001	0.1769	0.0001	0.0001	0.0182	0.0001	0.0001	0.0419	0.0001

THI_{max} = Maximum Temperature Humidity Index; THI_{spot} = Spot Temperature Humidity Index; T_{max} = Maximum Temperature; T_{BG} = Black globe Temperature; T_G = Ground Temperature; T_R = Roof Temperature; T_S = Sky Temperature; SR = Solar Radiation; SR_{spot} = Spot Solar Radiation; RH = Relative Humidity; RH_{tmin} = Relative Humidity at minimum temperature; RH_{tmax} = Relative Humidity at Maximum temperature, * All spot climatic measurements were taken between 1200 and 1700 h (July 1999 - July 2000), ** T_R and T_S Correspond to temperatures measured from the roof of the ZG units and from the sky at the OG farms, respectively

Table 4: Annual mean presentation of heat stress ameliorating climatic parameters and indices on zero- and open-grazing farms in Central Uganda

Management system	Parameter		Index	
	Spot wind speed (m s^{-1})	Minimum temp (°C)	Minimum THI	Diurnal temp variation (°C)
Zero grazing	0.25 (0.14)	18.4 (1.1)	65.4 (1.9)	9.7 (4.5)
Open grazing	1.23 (0.14)	16.2 (1.3)	63.4 (1.7)	13.7 (3.2)
t-test p-value	0.0001	0.0001	0.0001	0.0001

* All spot climatic measurements were taken between 1200 and 1700 h (July 1999 - July 2000)

seasonally. Daytime parameters and indices associated with heat stress were significantly higher at OG than inside ZG (Table 3). Air and ground temperatures at OG were higher by 2.0 and 3.4°C, respectively while spot solar radiation was 37 times that inside the ZG. Wind speed and DTV, which are associated with amelioration of heat stress, did not reach the levels sufficient to do so. The overall, daily mean wind speed throughout the study period as measured from the met-station was only 0.54 m/sec/day. Amelioration by wind and DTV was however, higher at OG compared to ZG farms (Table 4).

DISCUSSION

Climatic thermal stress has been advanced as one of the major constraints to dairy cow productivity sub-Saharan Africa. This study demonstrated that thermal stress in central Uganda is prevalent in all the three seasons (rainy, intermediate and dry) of the year (Table 1-3). All afternoons had stressful THI (> 72). Also, 9.4% of the year had THI > 77 with the dry season doubling the duration of exposure to this severe stress. These THI levels are known to cause significant losses in milk yield and conception rates in dairy Friesians.

The finding that daily maximum temperature throughout the year did not go below 27°C has serious implications since milk yields of temperate evolved dairy cattle will drop markedly as air temperature exceeds 27°C (Ragsdale *et al.*, 1950). The benefits of evaporative cooling at a relative humidity of 45.4% at the time of maximum temperature, as observed in this study (Table 3), may be compromised by the stressful THI observed (Table 2). Thus cows would then benefit from a wind breeze that would lower the effective temperature wind movements went as high as 2.2 m sec^{-1} (McDowell, 1972; Thompson, 1973; Johnson and Hahn, 1982). However, the afternoon wind movements at the farms were too low (0.25 m s^{-1} in ZG and 1.23 m s^{-1} at OG) to help cows ameliorate heat load through evaporative and convective cooling.

The finding that Diurnal Temperature Variation (DTV) is highest at times of the year when the heat stress index (THI) is highest means that animals may get daily relief of heat stress during night cooling. This relief effect is however counter balanced by the negative physiological effects of feeding on dry poor quality forage at this time with a probable significant reduction in milk yields and fertility. Low quality feed has long been a critical limiting factor in dairy production in the tropics (Barett and Larkin, 1974).

There were clear differences in the microclimate ambience in the two management systems. The OG cows were exposed to higher heat load than ZG cows as evidenced by excess ambient temperature and THI of 2.0°C and 2.8 units, respectively and a solar radiation 38 times in OG farms (Table 3 and 4). Although the temperature radiating off the iron-roof in ZG units was 30 degrees higher than on OG farms, this heat was lost before reaching the animal, since AT and ground temperature were significantly lower inside the ZG units than out at the OG farms (Table 3). These results indicate that iron shades are important in reducing daytime climatic stress and may as well be recommended for Friesian dairy housing. On the other hand, the ZG units provided less opportunity for cooling than OG units. Whereas spot wind speed at the OG farms (1.23 m s^{-1}) was closer to the desirable speed (2.2 m s^{-1}) for cooling stressed cows, that inside the ZG units (0.25 m s^{-1}) was negligible. This suggests that ZG units need to be better planned to promote stronger wind breezes.

The finding that DTV was 4 degrees greater at the OG farms than in the ZG units suggests that this drop in night temperature may lower the body temperature of OG cows to equal or even go lower than that of ZG cows at night. This could result into restoration of thermal balance that would prevent declines in conception rates (Ingraham *et al.*, 1979). It may however, not be very helpful for milk production if the day-time heat stress prevented cows from grazing adequately for cows that do not have access to night-time grazing.

CONCLUSION

It is concluded that both OG and ZG management systems in Central Uganda expose dairy Friesians to a continuously stressful microclimate. However, ZG cows benefit from the shade, which cuts off direct and diffuse solar radiation by 38 times. Hence OG and ZG farm management systems need further modification to reduce climatic heat stress and enhance milk production and conception rates.

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