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The effect of temperature and humidity on daily milk production and milk composition for four breeds of dairy cattle at Darwin

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Abstract

The influence of components of the environment on daily production of milk and milk constituents in a tropical monsoonal climate has been investigated. The components relative humidity, maximum temperature, and derived joint estimates of those two variables; namely, a direct interaction term, and a temperature-humidity index (THI) have been studied.

Daily milk yield and composition parameters for individual animals of four breed groups: Australian Milking Zebu (AMZ), Australian Friesian Sahiwal (AFS), Holstein-Friesian (HF) and Illawarra (IL) have been measured. These breeds represent varying degrees of *Bos indicus* content from 50% (AFS) to 0% (Holstein-Friesian and Illawarra).

The influence of individual components of the environment, maximum daily temperature and relative humidity, on a cow's daily milk production and composition is assessed with linear models of the form:

$$Y = L + D + TO + H2 + Z3$$

where Y = daily milk yield per cow;

L = a constant dependent on level of production class;

D = stage of lactation in days;

TO = max temp on day of recording;

H2 = relative humidity at 1500 hours on day prior to recording; and

Z3 = a TO × H2 interaction term.

In fitting these models, it was found that the humidity at 1500 hours on the day preceding recording asserted the major influence on subsequent yield traits. The maximum temperature on recording day and the interaction between this temperature and humidity (TO×H2) were secondary but significant considerations.

Cows of the HF, AMZ and AFS breeds respond to the same temperature and humidity factors, but with a difference in the magnitude of the response: that is, cows with nil *Bos indicus* content (HF) are more influenced by humidity and temperature than those with half *Bos indicus* (AFS). The AMZ cows (25 to 30% *Bos indicus*) exhibit an intermediate response.

This difference in the magnitude of the response to the environment, influences the daily production of each breed in a stressful environment. The major effect of humidity and temperature is shown to be a reduction in daily milk yield, with fat yield and protein yield following a similar, but smaller, trend.

INTRODUCTION

One of the major challenges in dairy cattle breeding in the last half of the twentieth century has been the development of a breed of dairy cattle adapted to the tropical environment and capable of achieving reasonable levels of production.

Animal geneticists have at their disposal a range of techniques to improve the precision of selection of superior animals, and the ability to rapidly exploit those desirable characteristics by spreading them throughout the population. The success of artificial insemination, embryo transfer, and multiple ovulation and embryo transfer (MOET) techniques for accelerating the rate of genetic improvement is dependent on the accuracy of the selection process.

Milk production and composition can be accurately measured. This information is often used as a guide to selection for adaptation to a particular environment. It is now appropriate to further develop this selection process by measuring the animal's response to each component of the environment, rather than it's performance in a particular environment. This should allow more efficient and rapid identification and selection of animals with superior adaptive characteristics.

This paper reports the performance of Australian Friesian Sahiwal (Alexander *et al.* 1985), Australian Milking Zebu (Hayman 1974), Holstein Friesian and Illawarra dairy cows in the tropical monsoonal climate at Darwin over the period October 1980 to August 1983. In particular, the response of individual animals to the readily measured climatic factors of temperature and humidity in terms of milk yield and milk composition has been measured.

An understanding of those components of the environment which exert significant influences over daily, and hence total lactation, milk yield and milk composition, should provide the basis for the refinement of selection programmes. This technique can then be used to assess environmental adaptation instead of the lengthy process of measuring lactation milk production over a number of lactations.

This paper reports a preliminary investigation of dairy cows' performance as affected by those criteria which form a part of the tropical environment.

MATERIALS AND METHODS

Dairy farming in the Northern Territory has been a high risk enterprise since the area was settled. The major population centre, Darwin (Latitude 12° 28′S , Longitude 130° 50′E), has a tropical monsoonal climate and represents the most stressful dairy cattle production environment for a major population centre in Australia.

Bos taurus dairy cattle genotypes were imported to Darwin from Perth by sea and from South Australia by road. In the 1970s, Queensland became an attractive source of dairy cattle due to work in developing *Bos indicus* × *Bos taurus* crossbred cattle which were better adapted to the stressful environment. In 1980, a farmer at Elizabeth River near Darwin introduced into his herd, cows from the AMZ and the AFS breeds.

Initially, 46 AMZ and 5 AFS cows were added to the herd of Holstein-Friesian (HF), Illawarra (IL) and assorted other *Bos taurus* breeds. A further 9 AFS cows entered the herd in 1981, and an additional 12 in 1983.

All cows grazed native grass species and pangola grass (*Digitaria decumbens*). Supplements including 4kg per day brewer's grain, 1.5kg per day sorghum grain and a mineral premix were fed to each cow during milking.

Data collected

Milk yields were recorded for a morning and evening milking at 25 to 40 day intervals (mean 33.5± 6.3 days) over the period October 1980 to August 1983. Milk samples were taken at each recording using the method described by Reason and Legg (1978) for the estimation of milk composition. Fat and protein test percentages were determined using a Foss Electric Milkoscan 203 instrument.

Meteorological data on maximum air temperature,and relative humidities at 0900 hours and 1500 hours were obtained from the Darwin Weather Bureau. These data are collected routinely, and were made available on request, for the specific dates on which milk recordings were taken, and for the day prior to recording.

From the known date of calving and the date of recording, each cow's stage of lactation was calculated as days since calving. Twenty-four-hour yields of fat and protein were also calculated from the recording data using the milk yield and the appropriate percentage.

Data from 100 cows (11 IL, 15 AFS, 26 HF and 48 AMZ) were used in this analysis. Only cows in the period 80 to 220 days post-partum were included in the analysis. The limitation on the stage of lactation was selected because it represents a section of the lactation curve which exhibits a consistent and, if not influenced by environmental effects, predictable rate of decline with advancing stage of lactation (Wood 1972).

There is some evidence to suggest that high yielding cows show greatest sensitivity to heat stress due to their higher heat load (Flatt *et al.* 1969). To remove some of the variation occurring between recordings of different cows, four levels of production were defined and each cow was allocated to one of these levels on the basis of milk yield at the first recording after 80 days postpartum. These four levels were arbitrarily defined as:

Level 1 <5.0 litres milk per day;
2 5.0 to 9.9 litres milk per day;
3 10.0 to 14.9 litres milk per day; and
4 >15.0 litres milk per day.

These production classes can be likened to production potential groupings. The milk recording used to allocate cows to the production classes was then omitted from further analyses.

Environmental data

Environmental conditions were assessed using data on daily maximum temperature and the relative humidities at 0900 hours and 1500 hours for the recording day, and the day before recording. Temperature-humidity indices (THI's), were computed using the formula of Johnson (1965) to describe a combined temperature and humidity condition. In addition to these THI's, interaction terms were derived as the product of a temperature and a corresponding humidity. The specific temperature and humidity combinations used are given below. Their selection was based on a subjective assessment of possible combined influences.

Meteorological variables used were:

Maximum daily temperature — TO
0900 hours relative humidity — HO
1500 hours relative humidity — H4
} on recording day

Maximum daily temperature — TM
0900 hours relative humidity — H1
1500 hours relative humidity — H2
} on day preceding recording

Derived meteorological variables used were:

Z1 — TO × HO interaction

Z2 — TO × H1 interaction

Z3 — TO × H2 interaction

Z4 — TM × HO interaction

Z5 — TM × H1 interaction

Z6 — TM × H2 interaction

I1 — a THI including TO and HO values

I2 — a THI including TM and H1 values

I3 — a THI including TM and H2 values

THI's as used by Johnson (1965) were calculated using the formula of Oliver (1973) where:

$$THI = T - (0.55 - 0.55 \times RH)(T - 58)$$

where T = dry bulb temperature reading (°F);

RH = relative humidity.

The temperature-humidity indices (THI's) were developed initially for human climatology studies. However, the underlying principles of a combined effect of both factors as joint influences on an animal's heat load regulatory system led to their being used by Johnson (1965) and his co-workers in cattle response studies.

Statistical analyses

Linear models including as a factor, level of production, the variable, days in lactation, together with various combinations of the variables temperature and humidity, and their interactions or indices were fitted to the data. These models were fitted using the GLIM statistical package (Baker and Nelder 1978). Models were fitted for milk yield, fat yield, protein yield, fat test percentage and protein test percentage parameters.

Initially, models including individual cows (C) as a factor rather than production levels (L) were fitted to assess the validity of using the production level to account for between cow variability. Reason (1986) showed that in the majority of cases, the production level models resulted in a residual variation not significantly different ($P < 0.01$) from that obtained when the cow term was included. Models involving only a production level term allow greater generalisation than do models including a specific cow term.

A separate set of models was fitted for each breed, as it was anticipated that the responses to the environment would differ for each breed.

A total of 26 models was fitted for each breed in addition to a basic level of production plus stage of lactation effects model. These 26 models included the individual observed temperature and humidity data either singly or in conjunction with each other, the effect of an interaction between temperature and humidity in addition to temperature and humidity, the use of the THI index as described by Johnson (1965), and the use of a (T×H) interaction term alone as an alternative to a derived THI index.

In interpreting the results of fitting these models, the significance of the overall model (F-test) was calculated. For models which significantly reduced the estimate of natural variation, an F-test was undertaken on the terms in addition to level of production (L) and stage of lactation (D), to test whether these additional terms significantly improved the reduction in natural variation over the reduction due to the base model of L + D.

Models which satisfied both these criteria were listed with their R^2 values, and the best-fit significant models determined as the significant models with the highest R^2 value. The best-fit models for each breed and production parameter were determined, and the co-efficients for each term in the model were extracted and tested against zero using at-test. Whilst the selection of a best-fit model was based on the maximum R^2 value, in most cases the selected model was also statistically superior to the remaining models. In those cases where an alternative model may have given an equivalent fit, the difference lay in the inclusion of TM rather than TO, except for the protein test for AFS where H1 replaced HO (Reason 1986). It is felt that the use of the maximum R^2 is justified to obtain an initial comparison between breeds, providing care is taken in interpreting which temperature is of major importance.

RESULTS

The results of fitting each of the 26 models for each breed and each production parameter have been summarised and only the best-fit models (those with the highest R^2) for each breed and parameter are reported in Tables 1 to 5. These tables give details of the overall goodness of fit (R^2) for each model, the overall reduction in variation over L + D due to the temperature and/or humidity terms in each model, and the coefficients of the terms included in the models.

Table 1. Best-fit models for milk yield for each breed

		R^2(%)		Coefficients for variables in the model			
Breed	Terms in model	Full model	Addit terms to L+D	D	T	H	Z
IL	L+D+Z1	67.7	2.7	0.0012	—	—	0.001*
HF	L+D+TO+H2+Z3	33.8	8.5	−0.014*	−0.72	−0.55*	0.018*
AMZ	L+D+TO+H2+Z3	53.1	3.7	−0.022*	−1.33*	−0.82*	0.026*
AFS	L+D+TO+H2+Z3	60.8	2.9	−0.36*	−2.16*	−1.26*	0.040*

* co-efficient significantly different from zero ($P < 0.05$).

Table 2. Best-fit models for fat test percentage for each breed

		R^2(%)		Coefficients for variables in the model			
Breed	Terms in model	Full model	Addit terms to L+D	D	T	H	Z
IL	L+D+TO+H1+Z2	17.3	13.0	0.006*	−2.015*	−0.899*	0.030*
HF	L+D+TM+HO	12.5	5.3	0.005*	0.108*	0.017*	
AMZ	L+D+TO+H2+Z3	6.6	4.3	0.003*	0.435*	0.288*	−0.009*
AFS	L+D	1.0	—	−0.014			

* co-efficient significantly different from zero ($P < 0.05$).

Table 3. Best-fit models for fat yield for each breed

Breed	Terms in model	R^2(%)		Coefficients for variables in the model			
		Full model	Addit terms to L+D	D	T	H	Z/I
IL	L+D+IO	45.8	4.4	−0.048*			0.72*
HF	L+D+TO+H2+Z3	16.0	6.5	0.001	0.0915	−0.326	0.015
AMZ	L+D+TO+H2+Z3	32.7	2.6	−0.080*	−3.706	−2.14*	0.071*
AFS	L+D	3.7	—	0.299			

* co-efficent significantly different from zero ($P < 0.05$).

Table 4. Best-fit models for protein percentage for each breed

Breed	Terms in model	R^2(%)		Coefficients for variables in the model			
		Full model	Addit terms to L+D	D	T	H	Z
IL	L+D+TM+H1+Z5	29.6	24.6	0.003*	−1.36*	−0.54*	0.018*
HF	L+D+TM+HO+Z4	17.6	6.9	0.002*	−0.331*	−0.12*	0.004*
AMZ	L+D+TM+HO+Z4	17.6	8.1	0.002*	−0.701*	−0.28*	0.009*
AFS	L+D+TO+HO+Z1	20.0	15.3	0.003*	1.931*	0.76*	−0.023*

* co-efficient significantly different from zero ($P < 0.05$).

Table 5. Best-fit models for protein yield for each breed

Breed	Terms in model	R^2(%)		Coefficients for variables in the model			
		Full model	Addit terms to L+D	D	T	H	Z
IL	L+D+TM+HO+Z4	68.2	6.1	−0.05*	−8.33*	−3.29*	0.105*
HF	L+D+TO+HX+Z3	29.8	6.5	−0.017	−2.00	−1.40	0.047
AMZ	L+D+TO+H2+Z3	41.6	4.2	−0.054*	−2.45*	−1.74*	0.057
AFS	L+D+TO+H2	59.1	4.8	−0.085*	2.50*	0.20*	

* co-efficient significantly different from zero ($P < 0.05$).

DISCUSSION

The inclusion of stage of lactation (days post-partum) to the model gave a significant reduction in the residual variance for the estimate of milk yield in all breeds, fat test in HF and AMZ cows, fat yield in Illawarra and AMZ cows, protein test in HF and AMZ cows and protein yield in Illawarra, AMZ and AFS cows (Reason 1986). A general trend for milk yield, fat yield and protein yield to decline with increasing days post-partum was maintained, while fat test percent and protein test percent generally increased with increasing days post-partum and a decline in milk yield.

Yield traits

The best fit models which resulted in a significant improvement over L + D for milk yield are presented in Table 1. The best-fit model common to HF, AMZ and AFS cows was:

Yield= L + D + TO + H2 + Z3
Where L= a constant dependent on level of production class;
D= stage of lactation in days;
TO= maximum temperature on day of recording;
H2= relative humidity at 1500 hours on day prior to recording; and
Z3= a TO x H2 interaction term.

This model contributed to an additional reduction in variation over the L + D model of 8.5 %, 3.7 % and 2.9 % respectively for those 3 breeds. Milk yield was sensitive to temperature on recording day, and relative humidity at 1500 hours on the day preceding recording. Daily milk yield estimates in Illawarra cows were improved when the interaction Z1 was included in the L + D model. The term Z1 includes the components of TO (maximum temperature on recording day), and HO (humidity at 0900 hours on recording day) and indicates a parallel with the other three breeds in that TO had a common effect on all four breeds.

It is of interest to note that of the 10 models (in addition to L + D) which significantly reduced the unexplained variations in daily milk yield in the four breeds, six were common to the HF and AMZ breeds (L+D+TM+H2, L+D+TO+H2+Z3, L+D+TM+H2+Z6, L+D+Z3, L+D+Z6, and L+D+I2). This is possibly the reason the lactation milk performance is similar for these two breeds at Darwin (Reason 1986). The high variation (66.2%) not explained by the L+D+TO+H2+Z3 model for Holstein-Friesian cows appears to be due to higher between cow variation in performance in the tropical environment. The comparisons of models including individual cows (C) as opposed to level of production group (L) as a factor in the model resulted in an improvement in explained variation of 35.5 % for Holstein-Friesian (comparing L+D+TO+H2+Z3 with C+D+TO+H2+Z3). Comparable figures for AFS, Illawarra and AMZ breeds were 0.5% , 8.0 % , and 17.0 % respectively.

Best-fit models for fat yield (Table 3) and protein yield (Table 5) closely parallelled those for milk yield, with L+D+TO+H2+Z3 being the best-fit model for protein yield in HF, AFS and AMZ breeds, and fat yield in the HF and AMZ breed.

Percent composition traits

Best fit models which resulted in a significant improvement over L + D for fat test percentage are reported in Table 2. There is no consistent trend across breeds in the response to a particular temperature and/or humidity variable. In AFS cows, there was no significant reduction in unexplained variation by the inclusion of temperature or humidity in the model.

The best-fit models which resulted in significant improvement over L + D for protein test percentage are presented in Table 4. The best fit models for protein test accounted for approximately 20 % of the total variation, and resulted in significant improvements over L + D of 24.6 % for Illawarra, 6.9 % for HF, 8.1 % for AMZ and 15.3 % for AFS. Rodriguez *et al.* (1985) reported mprovements in R^2 of 6.3 % in HF and 16.46 % in Jersey cows. These results support the conclusion that the higher testing breeds, or those with the higher 'potential' protein test are more susceptible to environmental stress, and react accordingly. The most commonly occurring parameters in the models were TM (maximum temperature on the day before recording) and HO (0900 hours humidity on day of recording).

Practical implications

Yield traits are the most important consideration in dairy situations, as farmers are ultimately paid on yield of milk and/or yield of milk constituents. Yield traits in Holstein-

Friesian, AMZ and AFS are related to the best fit models for milk yield (Y = L + D + TO + H2 + Z3), and this model provides the best fit for milk yield and protein yield in the three breeds, and fat yield in Holstein-Friesian and AMZ cows.

The common nature of this response to temperature and humidity in Holstein-Friesian and AMZ cattle is of note because of the parallels in milk production in this herd (Reason 1986), in Malaysia (Sivasupramanian *et al.* 1983) and the differences between AMZ and Holstein-Friesian reported by Donegan *et al.* (1984). The differences reported by these later authors related to the performance of cattle in a hot-room study where relative humidity was held constant at approximately 40% and the temperature was varied from 21° C. to 38.5° C. However, in our study, the major environmental effect on milk yield, fat yield and protein yield appears to be humidity on the afternoon prior to recording day, with temperature on the day of recording being a secondary though still significant factor. The interaction between temperature and humidity is also significant, and suggests that further work in a hot-room situation should also consider a range of humidity levels in addition to temperature. This would preclude the measurement of sweating rates of cattle in the hot-room studies, as sweating rate cannot be measured at high humidities.

The relative effects of TO+H2+Z3 in reducing residual variation in yield traits decrease as the percentage of *Bos indicus* inthe animals increases. This indicates that the relative effects of temperature and humidity decrease as the *Bos indicus* content increases. The observed variability in response within each breed group also decreased as the *Bos indicus* content increased.

The performance of Illawarra cattle in relation to environmental parameters generally differed from that of the other three breeds, and in the case of milk yield, fat yield and protein yield, appears to be a more 'instantaneous' or direct response. That is, HO rather than H2 appears to have the predominant effect. This study does not, however, allow measurement of the duration of the effect of environmental stress. The Illawarra animals, while reacting directly to changes in humidity, may also exhibit a different recovery pattern as a part of their response to environmental stress.

CONCLUSIONS

When data on individual components of the environment are used, linear models including the effect of a level of production index and stage of lactation can account for approximately 50% of the observed variation in daily milk yield of cows in the tropics. The inclusion of temperature and humidity data allows a significant improvement in the explanation of this residual variation, with up to an additional 8.5% of observed variation being explained.

The definition of a common best-fit equation for the explanation of variation in milk yield and protein yield for three breeds (HF,AMZ and AFS) and its application to two breeds (HF and AMZ) in the analysis of fat yield, has provided information to help understand the way in which temperature and humidity influence dairy cow productivity on a day to day basis. For these yield traits, the relative humidity on the day prior to recording had the major effect, followed by temperature on the day of recording and the interaction between these two terms.

Milk composition traits increased as milk yield declined. There was no consistent trend in fat test response to temperature or humidity across breeds. Protein test percentage was sensitive to maximum temperature on the day before recording, and to humidity on the day of recording. The maximum temperature on the day preceding recording was the major factor influencing protein test percentage.

These results suggest that the measurement of the response in daily milk yield to changes in humidity and temperature can provide an alternative method for assessing environmental adaptation.

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