Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

THE EFFECT OF A HIGH AMBIENT TEMPERATURE ON THE PHYSIOLOGICAL RESPONSES OF FRIESIAN AND BRAHMAN X FRIESIAN CALVES FED ON TWO RATIONS

A thesis presented in partial fulfilment
of the requirements for the
Degree of Master of Agricultural Science
in Animal Science
at
Massey University

PASCAL EDWARD LAMLEMBE SAUWA

1978

ABSTRACT

Eight Friesian and eight Brahman x Friesian (F_1) steer calves were kept at 17 or 34.5°C in temperature controlled rooms and fed on hay or concentrate diets in a 2 x 2 x 2 factorial design for eight weeks. Then eight of the calves were used to study the effect of coat clipping at the higher air temperature, and later they were exposed each day to eight hours of artificial radiant heat load for two weeks.

In each trial voluntary feed and water intake, liveweight gain, rectal temperature and respiration rate were assessed. In addition dietary digestibility and hair coat cover were estimated in the factorial trial, while radiant heat load and sweating rates were measured in the radiation trial.

Data for feed and water intake, digestibility and liveweight gain are the subject of another thesis (King, 1978).

There were no significant differences between breeds at the cool ambient temperature of 17°C, but at the high air temperature (34.5°C) both breeds had reduced their voluntary feed intake and had significantly increased their rectal temperatures ($P<0.01$) and respiration rates ($P<0.005$). However, although the F_1 calves ate more feed at the high ambient temperature than the Friesians, rectal temperatures and respiration rates of Friesians (40.50°C, 100 counts per minute) were higher than those for the F_1 calves (39.80°C and 93 counts per minute respectively). Nevertheless, only rectal temperatures showed significant ($P<0.05$) interactions between the effects of breed and air temperature.

At the high ambient temperature concentrate fed calves consumed more DM and had slightly higher respiration rates but slightly lower rectal temperatures (40.11°C) than hay fed calves (40.20°C); F_1 calves fed this diet had the highest DMI and liveweight gain but lowest rectal temperature (39.63°C).

Coat cover was related to level of feeding, breed and air temperature. Generally F_1 calves consumed more of the concentrate diet and had significantly ($P<0.05$) less coat cover than the Friesians. Hay fed calves had significantly ($P<0.01$) heavier coats than concentrate fed calves. Coat weights were substantially heavier at 17°C (177 g/m^2) than at 34.5°C ambient (150 g/m^2), but this difference was not significant.

Although coat cover was positively correlated with body temperature at the high ambient temperature, clipping did not affect the DMI, body temperature or respiration rate of either of the genotypes.

Exposure to radiant heaters resulted in a net gain of radiant heat by the animals of 130 - 140 kcal/m^2 hr; this caused significant increases ($P<0.05$) in respiration rate and rectal temperature measured after 8 hours of exposure to the radiant load. However, F_1 calves were significantly ($P<0.05$) less stressed by the radiation than the Friesians.

The measured sweating rates of 153 and 60 g/m^2 hr for F_1 and Friesian calves respectively suggest that the most important cause for the genotype differences in heat tolerance is due to the superior ability of the F_1 to discharge moisture on to the skin surface for evaporative cooling.

ACKNOWLEDGEMENTS

The author wishes to express his thanks and gratitude to Dr C.W. Holmes for his supervision throughout the experimental work and guidance for the preparation of this manuscript.

Special appreciation is extended to Professors A.L. Rae and D.S. Flux for their helpful discussions regarding the experimental design and methods; the staff of the Animal Physiology Unit for their assistance in animal care and handling before and during the experimental period, Mr A.B. Pleasants for his advice and aid in statistical analysis, and Mr C.T. King for his co-operation aiding to the success of the experiment.

I am grateful to the Governments of New Zealand and Tanzania for enabling me to undertake this study.

Lastly acknowledgement is made to Mrs A.F. Barton for the typing of this manuscript.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	
LIST OF TABLES	
LIST OF FIGURES	
LIST OF PLATES	
CHAPTER ONE - INTRODUCTION	
1.1: Animal production statistics	1
1.2: Factors influencing animal production efficiency in the tropics	1
1.2.1: Nutrition	1
1.2.2: Disease	2
1.2.3: Climate; direct effect of	2
1.3: Experimental aims	3
CHAPTER TWO - LITERATURE REVIEW	
2.1: Influence of climate on heat transfer in animals	4
2.1.1: Mechanisms of heat transfer	4
2.1.1.1: Radiation	4
2.1.1.1.1: Solar radiation	5
2.1.1.1.2: Longwave radiation	5
2.1.1.2: Convective heat transfer	6
2.1.1.2.1: Free convective transfer	6
2.1.1.2.2: Forced convective transfer	6
2.1.1.2.3: Respiratory convective transfer	6
2.1.1.3: Conductive heat transfer	7
2.1.1.4: Evaporative heat transfer	7
2.1.1.4.1: Cutaneous evaporative heat loss	8
2.1.1.4.2: Respiratory evaporative heat loss	8
2.1.2: Climatic factors influencing heat transfer	9
2.1.2.1: Ambient temperature	9
2.1.2.2: Air humidity	9
2.1.2.3: Air movement	10
2.1.2.4: Rain or wetness	10
2.1.2.5: Radiation	11

Page

2.1.3: Animal influence on heat transfer 11

2.1.4: Thermal equilibrium 12

2.2: Thermoregulation in the bovine under hot conditions 13

2.2.1: Temperature sensors of the body 14

2.2.1.1: Peripheral receptors 14

2.2.1.2: Deep-body thermoreceptors 15

2.2.1.3: Integration of different thermoreceptors 16

2.2.2: Thermoregulatory effector mechanisms 17

2.2.2.1: Vasomotor control 17

2.2.2.2: Sweating 19

2.2.2.3: Panting 19

2.2.2.4: Endocrine influence on heat production 20

2.2.3: Thermoregulatory responses to climatic conditions 21

2.2.3.1: Autonomic responses 21

2.2.3.1.1: Sweating 22

2.2.3.1.2: Panting 22

2.2.3.2: Behavioural responses 23

2.2.3.2.1: Variation of habitat 23

2.2.3.2.2: Posture changes 23

2.2.3.2.3: Wallowing and saliva spreading 24

2.2.3.2.4: Activity and operative responses 24

2.2.3.2.5: Voluntary intake 24

2.3: Effect of a hot condition on metabolism 26

2.3.1: Endocrine activity and metabolism 26

2.3.2: Digestive metabolism 28

2.3.2.1: Intake 28

2.3.2.2: Rumen metabolism 28

2.3.2.3: Digestibility 28

2.3.2.4: Dietary effects on metabolism 29

2.3.3: Nitrogen metabolism 29

2.3.4: Costs in terms of animal production function of thermoregulation 30

2.4: The ability of cattle to tolerate hot conditions 32

2.4.1: Factors influencing heat production 34

2.4.1.1: Metabolic rate 34

2.4.1.2: Food intake 35

Page

2.4.2: Factors influencing heat loss 35
2.4.2.1: Coat cover 35
2.4.2.2: Coat type 37
2.4.2.3: Coat depth 38
2.4.2.4: Coat colour and skin pigmentation 38
2.4.2.5: Body size and morphology 39
2.4.2.6: Hair follicle density 40
2.4.2.7: Sweat gland population and size 40
2.4.2.8: Sweating ability 41
2.4.2.9: Fat deposition 42
2.4.2.10: Water metabolism 42
2.5: Heat stress indicators 43
2.5.1: Respiration rate 43
2.5.2: Rectal temperature 44
2.5.3: Other indicators 44
2.5.4: Heat stress indices 44

CHAPTER THREE - EXPERIMENTAL MATERIALS, DESIGN AND METHODS

3.1: Materials and methods 46
3.1.1: General information 46
3.1.2: Experimental animals 46
3.1.3: Measurements 47
3.1.3.1: Respiration rate 47
3.1.3.2: Rectal temperature 47
3.1.3.3: Food and water intake 47
3.1.3.4: Ambient temperature, black globe temperature and air humidity 48
3.1.3.5: Variation in air temperature over a 12-hour period 48
3.1.3.6: 24-hour rectal temperature 48
3.1.3.7: Hair coat cover 48
3.1.3.8: Sweating rate 48
3.1.3.9: Incident radiation 48
3.1.3.10: Net radiation 49
3.2: Specific materials and methods for each trial 49
3.2.1: Trial I 49

Page

3.2.1.1: Trial I-a: Effect of breed, ambient temperature and diet on physiological responses 49

3.2.1.1.1: Feeds and feeding 49

3.2.1.1.2: Allocation of calves into treatment groups 50

3.2.1.2: Trial I-b: Effect of clipping on respiration rate, food intake and rectal temperature 51

3.2.2: Trial II: Effect of radiant heat load on calves of two breeds 52

3.2.2.1: Animals 52

3.2.2.2: Housing 52

3.2.2.3: Feeds and feeding 52

3.3: Statistical design and analysis 52

3.3.1: Design 53

3.3.2: Statistical analysis 53

CHAPTER FOUR - RESULTS

4.1: Trial I 56

4.1.1: Environmental conditions 56

4.1.2: Treatment effects on rectal temperature and respiration rate 57

4.1.2.1: Main treatment effects 57

4.1.2.2: Interactions 57

4.1.2.3: Relationship between rectal temperature and respiration rate 59

4.1.2.4: Relationship between rectal temperature and food intake 62

4.1.2.5: Relationship between respiration rate and food intake 62

4.1.2.6: Relationship between rectal temperature and liveweight gain 66

4.1.2.7: Relationship between respiration rate and liveweight gain 66

4.1.2.8: Hair coat cover 66

4.1.2.9: 24-hour measurements 67

4.1.3: Trial I-b: Effect of clipping on respiration rate and rectal temperature changes 67

Page

4.2: Radiation Trial 70

4.2.1: Environmental conditions 70

4.2.2: Incident radiant heat load 70

4.2.3: Net radiant heat load 70

4.2.4: Effect of radiant heat load on rectal temperature and respiration rate 71

4.2.5: Sweating rates of calves under radiant heat load 73

CHAPTER FIVE - DISCUSSION

5.1: Trial I-a 74

5.1.1: Main effects 74

5.1.1.1: Effect of ambient temperature on rectal temperature and respiration rate 74

5.1.1.2: Breed effects 76

5.1.1.3: Diet effects 76

5.1.2: Interactions 76

5.1.2.1: Breed x temperature interactions 76

5.1.2.2: Temperature x diet interactions 77

5.1.2.3: Breed x diet interactions 79

5.1.3: Effect of prolonged heat exposure 79

5.1.4: Measurements of heat stress 80

5.1.5: The effect of air temperature, breed and hair coat weight 81

5.1.5.1: Main effects 81

5.1.5.1.1: Effect of ambient temperature on coat weight 81

5.1.5.1.2: Breed effects on coat cover 82

5.1.5.1.3: Effect of diet on coat weight 82

5.1.5.2: Interactions 82

5.1.5.2.1: Breed x temperature interactions 82

5.1.5.2.2: Breed x diet effects 83

5.1.5.2.3: Temperature x diet effects 83

5.2: Clipping trial 84

5.2.1: Effect of clipping on rectal temperature and respiration rate 84

5.2.2: Breed x clipping interaction effects 85

Page

5.3: Trial II: Effect of artificial radiation on sweating rate, rectal temperature and respiration rate 86

5.3.1: Effect of radiant heat load on sweating rate 86

5.3.2: Effect of radiation on rectal temperature and respiration rate 88

5.3.3: Effect of radiation on the different genotypes 89

CHAPTER SIX - CONCLUSIONS 92

REFERENCES 94

APPENDICES

LIST OF TABLES

		Page
I-a	Characteristics of cattle favouring heat tolerance	33
I-b	Relation between coat score and susceptibility of heat stress	38
II-a	Nominal composition of the two diets	50
II-b	Treatment groups for trial I-a	51
III	Treatment groupings in clipping trial	51
IV	Radiation experimental design	52
V	Analysis of variance model for trial I-a	54
VI	Analysis of variance for randomized blocks	55
VII	Room environment	56
VIII	Average positional ambient temperatures in hot room	57
IX	Individual mean rectal temperature values and treatment effects	58
X	Individual mean respiration rate values and treatment effects	58
XI	Changes in rectal temperature and the effects of treatments over the three periods during trial I-a	60
XII	Changes in respiratory frequency and the effects of treatments over the three periods during trial I-a	61
XIII	Correlation coefficients for the relationship between rectal temperature and respiration rate	62
XIV	Correlation coefficient values between rectal temperature and DMI (kg/100 kg Lw) and the regression coefficient values	63
XV	Correlation coefficient and regression coefficient values between respiration rate and DMI (kg/100 kg Lw)	64
XVI-a	Correlation coefficient and regression coefficient values between rectal temperature and liveweight gain	65
XVI-b	Correlation coefficient and regression coefficient values between respiration rate and liveweight gain	65
XVII	Individual hair coat weight (g/m^2) at the end of trial I-a	67
XVIII-a	Individual rectal temperature and room environment values during the clipping trial	68
XVIII-b	Individual breathing frequency during the clipping trial	68
XIX-a	Rectal temperature differences between periods A and B, ^{o}C	69
XIX-b	Respiration rate differences between periods A and B, count per minute	69

LIST OF TABLES
(continued)

		Page
XX	Mean ambient temperature, mean globe temperature and mean relative humidity values for the radiation trial	70
XXI	Incident radiant fluxes in radiation pens, kcal/m^2 hr	70
XXII	Average net radiant exchange at calves' coat, kcal/m^2 hr	71
XXIII-a	Mean values for rectal temperature ^oC for the radiation trial	72
XXIII-b	Mean values for respiration rate for the radiation trial (counts per minute)	72
XXIII-c	Breed influence on radiant heat load	73
XXIV	Individual mean sweat rate values (g/m^2 hr) measured simultaneously for each pair, values for rectal temperature in brackets	73
XXV	Effect of diet and ambient temperature on heat increment coefficients (ΔT_R); T_R ^oC per kg DMI	78

LIST OF FIGURES

Figure		F Page
2.14	A diagramatic relationship between heat production and heat loss at different environmental temperatures	13
2.2.2.1	Zone of vasomotor control	18
2.2.2.2	Influence of body temperature and skin temperature on the thermoregulatory responses	20
2.2.3	Relationship between level of feeding and critical temperature	25
4.1.1	The relationship between heat load and metabolism of *B. indicus* and *B. taurus*	34
4.2.7.1	Age changes in the population density of sweat glands in Beef Shorthorn cows up to 6 years old	41
3.2.1	Determination of treatment groups	50
3.12	Locations of thermometers in the twelve-hourly ambient temperature measurements	48
3.13	Calcium chloride capsule	48
3.14	Site for net radiant transfer measurements	49
3.22	Calf positions in trial I	51
3.23	Radiation room layout	52
4.1	Three-day mean ambient temperature and rectal temperature showing breed and diet effects - hot treatment only	56
4.2a	Mean values for rectal temperature for trial I-a showing significant effects	57
4.2b	Mean values for respiration rate for trial I-a showing significant effects	58
4.3a	Mean values for rectal temperature during the three periods in trial I-a	60
4.3b	Mean values for respiration rate during the three periods in trial I-a	61
4.3c	Relationship between rectal temperature and respiration rate; trial I-a	59
4.4	Relationship between DMI and rectal temperature trial I-a	62
4.5	Relationship between DMI and respiration rate trial I-a	64
4.6	Hair coat cover (g/m) showing significant effects	66
4.7	24 hr ambient temperature and rectal temperature	67
4.8	The relationship between the average of rectal temperatures measured at 8 am and 2 pm and that measured at 2 hour intervals for a 24 hour period	68

LIST OF FIGURES
(continued)

Figure		Page
4.9	Effect of radiation during the day on:	
	A. Rectal temperature °C at 4 pm	71
	B. Respiration rate at 4 pm	71
5.0	Mean daily rectal temperatures showing the effect of prolonged heat exposure trial I-a	80

LIST OF PLATES

PLATE NO.		Page
I	Area clipped for the estimation of hair coat cover	F. 48
II	A clipped calf used in the clipping trial	F. 51