INFLUENCE OF VARIOUS CLIMATIC FACTORS ON MILK PRODUCTION AND RELATED TRAITS IN MPWAPWA CATTLE AND THEIR CROSSES

BY

JAMES KUNDAELI KILEGHUA MSECHU

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY OF
SOKOINE UNIVERSITY OF AGRICULTURE

1994

ABSTRACT

A study was carried out to examine the influence of various climatic factors on milk production in Mpwapwa breed cattle and their crosses in Livestock Production Research Institute in Mpwapwa, Central Tanzania. It was based on daily milk yields and weather information recorded from 1964 to 1989. Milk yields of individual cows were accumulated for periods of 28 days and related to average weather records for the same periods and or the preceding period. A short term supplementary study was used to investigate reaction of different genetic groups of the cattle, in terms of daily milk yield, milk components, and rectal temperature, to weather conditions.

Over the study period, daily maximum and minimum temperatures averaged 26.2^{o}C, and 14.5^{o}C, while average daily temperature-humidity index was 68.5 and 74.1 (morning and afternoon), and annual rainfall averaged 785 mm. Least squares means for 28-day milk yield (kg) were 123.8, 179.1, 175.5, 213.3, 131.1, respectively for Mpwapwa, and Jersey, Ayrshire, and Friesian crosses, and Backcross. All were significantly different ($P<0.05$), except between Jersey and Ayrshire crosses.

The studies revealed that several of the weather variables had a significant influence on milk yield during the same or the subsequent period. However, the magnitude and sign of the partial regression coefficients were inconsistent and erratic. In most analyses, concurrent rainfall showed a positive relationship with milk as might be expected from the effect of rain on pasture growth. But, surprisingly, some of the temperature variables were also positively related to milk yield. Separate analyses of the data of each of the five genetic groups failed to demonstrate distinct differences between groups in reaction to the climatic factors studied.

In the supplementary study daily milk yield and yield of various milk components did not appear to be influenced by concomitant weather variables. Rectal temperature was, however, significantly influenced by weather variables recorded at the same time. The genetic groups did not differ significantly in rectal temperature.

The lack of conclusive results might have partly been caused by the close association between some of the weather variables. Inclusion of previous milk in most of the analyses, in an effort to increase precision, may have complicated the interpretation of the results also. Further investigation on the nature of the =relationships suggested by trends revealed by the study was recommended. Changes were recommended in the breeding programme to exploit the more productive F_1.

DECLARATION

I, James Kundaeli Kileghua Msechu, do hereby declare to the Senate of the Sokoine University of Agriculture that this thesis has not been submitted for a higher degree award in any other university.

Signature:------------------------------------

Date:---3 November 1994---------------------

COPYRIGHT

ACKNOWLEDGEMENT

The accomplishment of this study received support from several individual persons and institutions to whom the author owes a word of thanks. Professor Muze Mgheni provided supervision through the study period and offered advice all along. The author wishes to thank him for his support. The co-supervisor was Professor Ola Syrstad of the Agricultural University of Norway (AUN). He offered much needed guidance, particularly in the initial phase of developing the research proposal and during data processing and writing up. His advice, constructive criticism and interest in the work made the author more prepared to handle the work.

Financial support for the study programme was received principally from the Norwegian Agency for International Development (NORAD) through a project at Sokoine University of Agriculture (SUA), Animal Science Department. The author wishes to thank them for the support. Thanks are also due to Head, Animal Science Department, SUA, who accepted the author into the project. Supplementary financial support was obtained from the author's employers, Ministry of Agriculture (Tanzania). The author wishes to thank the Ministry of Agriculture for this and for allowing him study leave.

The Departments of Animal Science at AUN and at SUA provided a conducive working environment for data processing and writing up. The author wishes to thank Professor Nils Standal and all staff of the Department of Animal Science at AUN for the support provided, specially during data management and processing. Professor Muze Mgheni and staff of his department at SUA gave invaluable administrative and technical support, especially during the final stages of writing up. Secretarial services at the department are worth special mention. Thanks are due to Ms Evarista Mkulasyai and Ms Beatrice Msengi in this respect and for typing part of the manuscript. Messrs K.O. Ali and S.J. Nyakalo provided technical support during the last stage of the work and the author wishes to thank them for that.

The Director and staff of Livestock Production Research Institute, Mpwapwa, assisted the author tremendously during data collection. The author wishes to record his thanks for the support. Messrs J.O. Sagatwa and S. Sindamakoko, Field Officers at the time of data collection, were very helpful and deserve special thanks. The then Laboratory Technician, the late Mr. R.I. Mwassa deserves special mention for his invaluable technical assistance in the determination of milk composition.

Finally, the author wishes to thank all members of his family for their perseverance when his attention was diverted from them as he concentrated on this work. Encouragement received from them kept the author hoping for the best out of the effort. Their moral support was unequalled and I owe them all immensely.

Notwithstanding the foregoing, this work will probably still have some inadequacies and undetected errors, for which the author alone assumes full responsibility.

DEDICATION

To my wife Elfride, who exhibited unequalled forbearence at the temporary loss of my company several times while I pursued academic achievements culminating in the writing of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

Table: Page:

Table: Page:

Table: Page:

Table: Page:

LIST OF FIGURES

Figure: Page:

LIST OF APPENDICES

Appendix: Page:

LIST OF ABBREVIATIONS

am	"ante-meridian", used to describe records taken at 0900 h (9 o'clock in the morning)
ASCII	American standard code for information interchang
Avge	Average
BASIC	Beginners All-purpose Symbolic Instruction Code, a programming language.
BF	Butter fat(milk fat, expressed in % by weight)
BGHI	Black-globe-humidity index
degCels	degrees Celsius, measure of temperature
degFahr	degrees Fahrenheit, measure of temperature
DBtemp	Dry-bulb temperature reading (degrees Celsius)
ET	Effective temperature (in degrees Celsius)
F1,F2,F3	First, second, and third filial generatiom
FORTRAN	Formula Translation (computer programming language)
GxE	Genotype-by-environment interaction
GLM	General Linear Models, referring a procedure in the SAS programme.
LPRI	Livestock Production Research Institute(location where study was carried out).

max	maximum
min	minmum
mm	millimetre(s)
NORAD	Norwegian Agency for International Development
pm	"post-meridian", used to describe records taken at 1500 h (3 o'clock in the afternoon)
RH	Relative humidity (expressed in %)
SAS	"Statistical Analysis Systems" (computer software with various applications)
SUA	Sokoine University of Agriculture
temp	temperature(in degrees Celsius, unless stated otherwise)
THI	Temperature-humidity index
THIam	Temperature-humidity index at 0900 h
THIpm	Temperature-humidity index at 1500 h
THIday	Average daily THI from averaging THIam and THIpm
THSI	Temperature-humidity-sunshine index
TNZ	Thermal neutral zone
TSZ	Tanzania Shorthorn Zebu
var	variable
WBtemp	Wet-bulb temperature reading (degrees Celsius).

CHAPTER 1

INTRODUCTION

Climate is one of the most important factors that influence livestock distribution and productivity in the world. Tropical regions are characterized by high ambient temperatures, often high humidity, and much sunshine. These factors, together with air movement, are the principal components of climate which determine the level of heat stress on livestock. Inadequate cattle nutrition in the tropics is essentially an indirect result of climatic effects on pastures. The prevailing humid conditions in many tropical regions are favourable for many cattle disease pathogens and vectors.

The direct effect of heat stress on cattle in a tropical environment is manifested as changes in their feed and water intake and other physiological and behavioural adjustments which are detrimental to productivity. Under these conditions indigenous cattle with limited production potential and high level of tolerance to the prevailing conditions, desirable for survival and fitness have evolved.

With the foregoing background in mind, cattle breeders envisaged several methods of improving milk production in the tropics. Selection within indigenous populations was considered the simplest solution. However, this was too slow in bringing the required change in level of productivity. The adoption of imported breeds of high milk production potential was another attractive option. These were used in crossing and as purebreds. Conditions were too harsh for realization of the same high production of such animals as would be the case if they were bred in the cooler climates where they evolved. There was therefore limited success in crossbreeding, upgrading and breed development ventures based on introduced breeds. Two main factors may be associated with this: the direct and indirect influence of the hot environment, and the lack of management skills for managing the improved animals under the prevailing harsh conditions.

Cattle breeding in Tanzania followed a general trend similar to that in most other parts of the tropics, with all the foregoing approaches being tried. The Tanganyika shorthorn zebu (TSZ), which form the majority of cattle in Tanzania, are used as multiple-purpose animals, but mainly for milk and meat production. However, they are poor milk producers, producing barely enough for their calves, with little left for human consumption. Attempts to improve milk production in Tanzania have included importation of breeding animals, crossbreeding, and breed development.

Crossbreeding and upgrading of indigenous cattle at Mpwapwa, dating back to the 1920s encouraged use of *Bos taurus* dairy cattle until the poor performance of grade cattle due the climatic and husbandry conditions was evident. Two *Bos indicus* dairy breeds from Asia, Red Sindhi and Sahiwal, were then introduced to "dilute" the European "blood" in the stock at Mpwapwa in an attempt to improve their fitness. In 1958 a plan was put together to work on the resultant cattle towards developing a new breed. From then on the mixed-ancestry type of cattle with inheritance from African zebu, Indian zebu, and some European breeds was named the "Mpwapwa breed" after the place of its founding.

Since 1967 some Mpwapwa cows were bred to Ayrshire, Friesian and Jersey bulls. The resulting crossbred cows were bred back to Mpwapwa bulls to produce 3/4-Mpwapwa backcrosses. This programme therefore produced three crosslines (Ayrshire x Mpwapwa, Friesian x Mpwapwa, and Jersey x Mpwapwa) each with about 55% *Bos taurus* inheritance, and Backcrosses with about 32.5% *Bos taurus* inheritance. Preliminary indications of their performance suggest that they differ appreciably. But it is not known to what extent climatic factors may be involved in explaining variation in the productivity of these cattle.

It is generally assumed that climate is a serious constraint to livestock production in the tropics, but more detailed information is lacking. The specific objective of this study was to find out how various climatic factors influence milk production in Mpwapwa cattle and their crosses. The reaction of various genetic groups to changes in climatic factors was of particular interest.

In a supplementary study objective, the change in rectal temperature caused by heat stress in the field was examined. Rectal temperature was chosen as the response variable because it is reckoned to be the most reliable indicator of heat stress. The supplementary study also aimed at determining the effects of climatic factors on milk composition in the cattle studied.

Finally, the study aimed at drawing inferences, from the foregoing broad objectives, on the genetic group differences in adaptation, and suggesting strategic future use of the existing genetic groups of Mpwapwa cattle.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

The theory of heat tolerance or adaptation to hot climatic conditions is rather intricate because it embraces two complex systems, one of which is physical (climate) and the other physiological (animal). Lee (1965) recognised three sets of variables involved as the environmental conditions, individual animal characteristics, and criteria of measurement of the effect on the animal. Understanding of the mechanisms involved therefore calls for consideration of several aspects.

First, it is necessary to identify the major climatic variables involved in order to appreciate their contribution to the energy balance between the animal and the environment. The exchange of energy (mostly thermal energy) between the animal and the environment (climate and physical surroundings) is of primary concern. Then, the physiological responses of the animal to thermal stress and the mechanisms by which the animal maintains constant body temperature over a wide range of climatic conditions (thermoregulation) need to be comprehended before it becomes possible to appreciate acclimatisation and adaptation of animals to climatic stress.

2.2 The principal climatic factors

The influence of climate on livestock performance may be explained by direct or indirect effects of various aspects of climate. The major climatic factors are ambient temperature, atmospheric humidity, solar radiation, wind velocity (air movement) and precipitation (Lee 1965). Their direct effects are expressed through their influence on the animal's physiological processes responsible for performance (Johnson 1985). Indirect influences are manifested through the influence of the climatic factors on other factors on performance, such as feed availability, disease incidence, and management aspects.

Ambient temperature is recognised as the most important single climatic factor used in describing the thermal environment (Yousef 1985). The rest of the factors listed either worsen or lessen the adverse effects of ambient temperature. It is well known that the effect of high ambient temperature is moderated by that of wind (air movement) via forced convection and evaporative cooling. High humidity, on the other hand, impedes evaporative heat transfer from the animal to the environment and therefore enhances the adverse effect of high ambient temperature (Bianca 1961).

Outdoor radiation is a form of energy from the sun, which emits radiation that supports life on earth, and from the surroundings, ground, trees, clouds, and sky (Gates 1968). Its influence on the thermal environment is affected by many physical factors, such as nature of the surroundings, clarity of the sky, dust, clouds, atmospheric vapour, and the reflectivity or emissivity characteristics of the animal's coat (Ingram and Mount 1975; Yousef 1985). It is considered to be an important component of the total thermal environment (Yousef 1985). Precipitation, notably rainfall in the case of a hot climate, influences the thermal environment through its effect on air humidity and on evaporative heat transfer. It also influences livestock through its effect on soil characteristics and plant growth, hence indirectly on livestock feed availability (pasture production).

2.3. Principles of heat exchange

Heat is a form of energy that may be generated by transforming other forms of energy, such as chemical, mechanical, or light energy. The principles of energy transfer between objects apply to heat transfer. Heat transfer processes are therefore governed by the principles of thermodynamics (Monteith and Unsworth 1990).

Homeothermic animals are capable of maintaining a fairly constant deep body temperature over a range of environmental temperatures through various mechanisms of exchange of heat between their bodies and the surrounding environment. This is a subject that brings the principles of physics and physiology into interplay. The animal body obeys the physical laws of thermodynamics. This is made possible by the physiological functions of the animal body and physical laws of energy exchange.

2.3.1 Energy exchange between animals and the environment

The transfer of energy between the animal and the surroundings is such that the input energy plus energy generated by body functions is in a state of equilibrium with the amount of energy that the animal dissipates to the environment and that which the animal retained in its body tissues. Holmes (1979) described the relevant forms of energy that contribute to the mechanisms involved in the exchange of energy between the animal system and the environment as chemical energy (food, excrescency, body tissues), thermal energy (heat), mechanical energy (work), and light energy. The most important forms of energy in this respect are chemical and thermal energy, and a simplified approximation of the energy balance equation would include input energy in the form of food material (chemical) and thermal energy (heat) gained from the atmosphere on one side of the equation. The other side would include animal products, excreta and body tissue (chemical energy), heat dissipated to atmosphere and heat used in the body to maintain homeostasis.

2.3.2 Evaporative and nonevaporative heat transfer

The main avenues of heat loss from the animal were summarised by Yousef (1985a) as nonevaporative and evaporative. The former are governed by the physical laws of heat transfer and include conduction, convection and radiation. Evaporative heat transfer may be subdivided into sweating and panting as described by Robertshaw (1985). Sweating is the major avenue of heat loss from cattle, while panting plays a subsidiary role. When the rate of panting increases, a point is reached where the process becomes heat generating rather than simply heat dissipating.

Monteith and Unsworth (1990) described the components of the steady state heat balance of animals as metabolism, net radiation, latent heat loss, convection, and conduction. The metabolism of an animal is a heat producing process which regulates the heat budget of a homeothermic animal. It is a function of body mass and is influenced by quantity and type of food eaten, the animal's physical activity, and physiological status (that is, whether pregnant, lactating, growing or mature). Another major source of heat in the interrelation of the animal and its environment is radiation. But, radiation involves a two-way flow process of heat energy, and it is the net gain from radiation which should be accorded importance.

The remaining components are concerned with heat loss from the animal to the environment. Latent heat loss is principally by way of sweating and panting. An additional small amount of latent heat loss from an animal is through respiration, by which means relatively dry air picks up moisture from the inner lining of the respiratory tract (notably, in the alveoli of the lungs), and by diffusion of water vapour through the skin, sometimes referred to as "insensible perspiration".

Heat loss by convection depends on the area of body surface in relation to body mass, and the convection current. Convection is the process by which heat is transferred by movement of a fluid (gas or liquid) by molecular diffusion. Convection takes place in the boundary layer of air in contact with the animal and is regulated by several factors. First, there must be a temperature gradient for convection to take place. Secondly, the influence of air movement must be recognised, and distinction be made between free convection, when influence of air movement is not involved, and forced convection when it is.

Small animals might be expected to be at an advantage compared to large ones in dissipating heat to the atmosphere by convection because of their comparatively larger surface areas per unit body weight. However, metabolic heat production is not proportional to body weight. Surface area and metabolic heat production are related to body weight in the same way. Metabolic body weight is usually estimated as actual body weight raised to the power of 0.75, while surface area is proportional to body weight to the power of 0.67.

Furthermore, the major form of convection involved is forced convection, which is determined by air movement. Air movement increases with distance from ground level, and therefore a small animal would be at a disadvantage because it is close to the ground, except in special situations like those of flying or tree climbing animals (Monteith and Unsworth 1990).

Conduction is a process of heat transfer through contact, and is governed by the temperature gradient between the animal and the substrate in contact, and the conductivity of the substrate. The significance of conduction therefore depends on the flooring and bedding in the case of indoor animals, and on amount of time spent lying down and properties of the ground, for an outdoor situation.

2.4 Physiological responses to thermal stress

High ambient temperature affects body functions by direct and indirect ways. Among the more important manifestations of the effect are changes in rectal temperature, sweating rate, and respiratory rate. These are processes that are controlled by metabolic processes and that involve the digestive system, the endocrine system, the circulatory system and the respiratory system, as has been reviewed by various authors (Yousef 1985).

2.4.1 Hormonal responses

Yousef and Johnson (1985) reviewed literature on the effect of thermal environment on the endocrine system and concluded that high ambient temperatures seem to have direct effect of decreasing thyroid activity, and that this was probably initiated through effect on hypothalamus. Thyroxine is known to be involved in various metabolic processes. Feed restriction, which may be induced by exposure to high ambient temperature, is also reported to decrease thyroid secretions in cattle and in other mammals (Yousef and Johnson 1968). The adrenal gland is another gland whose hormones control various physiological processes involved with homeostasis. Yousef and Johnson (1985) reviewed literature which suggested that there is reduced adrenal activity with increased ambient temperature. However, results of various studies were inconsistent. Influence of thermal stress on the adrenal glands affects secrètion of glucocorticoids, mineralocorticoids, and catecholamines.

Pituitary and reproductive hormone secretions are also affected by thermal stress. Most notable among the hormones whose secretion is impeded by high temperatures are growth hormone from the pituitary gland and prolactin from the gonads (Yousef and Johnson 1985). Although some of the influences of thermal stress act directly on reproductive processes of the gonads, it is known that most environmental factors act through the hypothalamo-pituitary-gonad axis (Haynes and Howles 1981). The secretion of gonadotrophins from the anterior pituitary is impeded by the effect of high temperature. Therefore, the release of hormones from the gonads which depends on the level of the gonadotrophins is impaired. It is necessary to be cautious in interpreting the influence of climatic factors in this respect as the influence of photoperiod and nutrition may easily be mistaken for that of thermal stress in some instances.

2.4.2 Sweat secretion

Sweat secretion is one of the major avenues of heat transfer from cattle to the environment. Therefore, as ambient temperature rises and the physical means of heat transfer from the animal to the environment fail to cope, sweating is enhanced. Several factors influence sweat secretion on the animal's surface and there is variation between animals (McDowell 1972). It has been reported that sweating rate in cattle is higher in the neck and mid-rib areas compared to other parts of the body. Breeds of cattle have different sweating rates and it is known that zebu type of cattle have more sweat glands per unit area and that their sweat glands have higher capacity for sweat production than *B. taurus* cattle (McDowell 1972).

2.4.3 Respiratory rate

When an animal is under thermal stress its respiratory rate is enhanced. This is one of the mechanisms by which the animal dissipates heat to the atmosphere by evaporative cooling. The rate of respiration varies with breed of animal, time of day, level of ambient temperature, and exercise. Panting, which is a form of enhanced respiratory rate, is of limited value as a heat transfer process since it becomes a heat generating process as it increases (Robertshaw 1985). Pulse rate also increases with rising ambient temperature, but its effect on reducing heat load is rather irregular.

2.4.4 Rectal temperature

When an animal is under heat stress and the mechanism for maintaining body temperature fails, then it allows a limited amount of body temperature rise (Brody 1948). In a study on sweating rate in relation to rectal temperature, Finch *et al* (1981) reported that there were breed differences in rectal temperature. Such differences may be related to the relative levels of adaptability to heat stress of the breeds involved. The same authors reported a highly significant regression coefficient of sweating rate on rectal temperature.

Rectal temperature has been the most widely studied animal response variable in relation to the influence of climatic factors on animal performance. Most authors conclude that it is the most reliable index of thermal stress (Yousef 1985a; Johnson 1987a).

2.5 Thermoregulation, acclimatisation and adaptation

In homeothermic animals, such as cattle, maintenance of body temperature is brought about by a dynamic balance between heat gain and heat loss. In mammals, metabolic heat production is, by definition, proportional to metabolic body weight (Kleiber 1961; Blaxter 1967; Bartholomew 1982). Besides the heat gain from metabolism, the animal body gains heat by absorption of radiation and by conduction from the surroundings if the temperature gradient favours heat transfer towards the animal. Heat loss from the animal is mainly by nonevaporative or "sensible" transfer up to a certain level of ambient temperature. Beyond that, heat transfer is mainly by evaporative transfer (Ingram and Mount 1975). The latter mode of heat transfer is the most important in temperature regulation in cattle.

The effect of feed intake on the heat balance of a homeothermic animal includes the heat of warming which has a temporary negative effect on heat load. The mere activity of feeding involves generation of heat and thus also influences the animal's heat load. The action of mastication and movement in search of food are energy generating activities. In a heat stressed animal, such activities are avoided by the animal as a way of reducing heat load.

The balance between gain and loss of heat from the animal results in body temperature regulation. An animal has a certain range of ambient temperatures within which this balance can be maintained. Beyond that, maintenance of homeothermy is difficult. A point is reached where metabolic rate is reduced to maintain body temperature, and further stress leads to temporary stagnation of metabolism. Then it rises again as the heat load becomes excessive. The animal is hyperthermic and body temperature rises. With continued exposure to the stress of high ambient temperature, the animal's physiological processes may adjust to counter the strain. Depending on duration and sustainability of the adjustment, this may be termed acclimatisation or adaptation.

2.5.1 Thermoregulation

Changes in the physiology of the animal in the course of temperature regulation include changes in vascular blood flow, initiation of sweating, enhanced respiration rate (increases heat loss by evaporative means), changes in hormonal secretions, and a resultant change in water and body hydration state (McDowell 1972). These changes are a result of the involvement of the central nervous system (hypothalamus centres) and the endocrine system (Bianca 1968; McDowell 1972; Ingram and Mount 1975).

In addition to the foregoing physiological means of thermoregulation, cattle exhibit some specific behavioural reactions to counter the effect of heat stress (McDowell 1972; Ingram and Mount 1975). These include searching for shade, restlessness, postural changes, and drinking more water. In extreme hyperthermia when all physiological and behavioural means of thermoregulation fail, body temperature continues to rise until the animal dies of hyperthermia. In cattle it was established that the lethal body temperature is about 4.4°C above normal body temperature (Brody 1948).

The change in heat production in a homeothermic animal with ambient temperature to maintain body temperature has been a subject of many studies. Much terminology has been developed. Yousef (1985) described the relationships of ambient temperature and thermoregulation. At low temperatures metabolic heat production increases with lowering of ambient temperature to a point of "summit heat production" beyond which the animal begins to face danger of dying from hypothermia. On the other hand, a point is reached on increasing ambient temperature, where metabolic heat production in a resting animal is minimal and the only temperature regulation necessary is by nonevaporative means. This falls within a range of ambient temperatures conveniently termed the thermoneutral zone (TNZ).

The lower limit of the TNZ is named the lower critical temperature (LCT), and the upper limit the upper critical temperature (UCT). When the ambient temperature reaches the UCT the animal is heat stressed and metabolic heat production decreases. The animal progressively resorts to evaporative heat dissipation to the point where the regulatory mechanism fails and the animal faces the danger of death from hyperthermia.

The TNZ varies with animal species, breed, age, nutrition, previous acclimatisation, level of production, insulation and behaviour. The LCT and the UCT may therefore shift up or down, depending on prevailing conditions. For the average cow, the expected TNZ has been given as 0°C to 16°C, and the predicted UCT for a low-producing milk cow (up to 10kg milk per day) is 27°C, and that of a high-producing cow is 23°C (Yousef 1985). The suggested acceptable range of temperature for lactating dairy cows is 4°C to 24°C (Hahn 1976).

2.5.2 Acclimatisation

Physiological changes resulting from exposure of an animal to a stressful environment have been accorded different terms, depending on the source of stress and the duration of exposure. In the terminology reviewed by Yousef (1985), there are two terms used in relation to changes occurring in the animal's lifetime. One is acclimatisation and the other is acclimation. The former refers to a physiological change occurring within the life of an animal, which reduces the strain caused by the natural climate (seasonal or geographical). The latter refers to similar changes, but which are induced by experimentally imposed stress. Both are phenotypic short-term changes.

2.5.3 Adaptation

Long-term physiological changes that animals undergo due to exposure to stressful conditions have been defined as adaptation. Yousef (1985) gave the definition of adaptation that distinguishes phenotypic from genetic adaptation. The term adaptation is defined as "a change which reduces the physiological strain produced by a component of the total environment..." which "...may occur within the lifetime of an organism (phenotypic) or be the result of selection in a species or subspecies ... or its evolution (genetic adaptation), which favours survival in a particular total environment". The distinction between phenotypic and genetic adaptation is not only convenient but essential for livestock breeders. One definition refers to the animal's survival over a lifetime only, while the other crosses the generation barrier and is inherited. Breeders can therefore tap on the latter for sustaining better adapted animals through artificial selection.

2.6 Influence of hot climate on cattle productivity

The most important aspect of the effect of climatic factors on cattle is their influence on production performance (McDowell 1972), otherwise it would be of mere academic interest. The study of adaptation of cattle must therefore address itself to productivity in the relevant environment. Various authors have reported the association of some economic traits with climatic factors. Most studies on aspects of the influence of high temperature on cattle productivity have been carried out in simulated hot climate conditions, in climate chambers (Ragsdale *et al* 1948, 1950, 1951, 1953; Richardson 1961; Cargill *et al* 1962; Johnson *et al* 1963; Bayer *et al* 1980). A number of studies have also been carried out under field conditions (Macfarlane and Stevens 1972; Dragovich 1978,1979,1981; Thomas and Acharya 1981; Ansell 1981; Sharma *et al* 1983). Results of the two types of study conditions have been similar in many respects and may therefore be considered to be complementary. Among the economic traits of cattle that attention has been focussed on in this respect are growth, reproduction and milk yield.

2.6.1 Growth and development

In a study based on pairs of Jersey identical twins separated and reared in New Zealand and Fiji, Hancock and Payne (1957) reported differences in growth between heifers raised in New Zealand and those raised in Fiji. They attributed the reduction in growth rates of the Fiji group to environmental differences, notably high temperature in Fiji. There were also differences in linear body measurements (development). The Fijian group had consistently smaller skeletal dimensions except with respect to their larger heart girth, explained as an acclimatization aspect to higher water intake and probably heavier breathing.

The influence of climatic effects on feed intake, digestibility and water intake may be cited as causes of the reduced performance of cattle under high temperature conditions that has been reported in many studies in the literature (Frisch and Vercoe 1972; McDowell 1972; Vercoe and Frisch 1987). However, it must be recognised that some indirect effects may influence growth too. These are such factors as those on feed availability and quality, diseases and parasites.

2.6.2 Reproductive performance

Seasonal differences in cattle fertility are observed as a common phenomenon, with hot summer conditions being associated with low fertility. Male reproductive performance is known to be influenced by temperature conditions. Reduced fertility has been reported in bulls due to hot conditions which have been the cause of impaired spermatogenesis, reduced semen volume and quality. Meyerhoeffer *et al* (1985) studied the effects of elevated ambient temperature on semen characteristics. They reported, among other effects, reduction in semen volume and percentage of motile sperm.

In his review of cattle reproduction in the tropics, Roman-Ponce (1987) stated that there was a consistent gross observation that the length of oestrous period was reduced during thermal stress. This in itself would mean that the level of fertility would be lower during periods of thermal stress.

Results of studies relating cattle reproduction with climatic factors suggest that low fertility is explained by the stress of temperature and humidity at the time of insemination (Gwazdauskas *et al* 1973, 1975; Ingram 1974). Johnson (1965) reported in his review that results of studies on influence of temperature have revealed that maximum temperature on the day after oestrus significantly affected conception rate.

In an Australian study on the relationships between rectal temperature and fertility in cattle, Turner (1982) concluded that differences in thermoregulatory efficiency accounted for differences in fertility. There was curvilinear relationship between rectal temperature and fertility. Since temperature has long been established as a reasonable indicator of heat stress, then this finding serves as an example of the influence of heat stress on fertility in cattle.

2.6.3 Milk production and composition

Literature on the influence of climatic factors on cattle productivity invariably show that milk yield is depressed by high ambient temperature and humidity (Johnson 1965, 1987b; Morrison 1983; Yousef 1985). In his earlier review, Johnson (1965) contended that ambient temperature was the most important climatic factor and that it had the main direct effect on the ability of terrestrial mammals to secrete milk. He also recognised the fact that indirect effects of temperature under field conditions will also alter lactation characteristics.

Climate chamber studies have consistently demonstrated that thermal stress reduces milk yield and milk components in cattle (Ragsdale *et al* 1948, 1950, 1951, 1953; Richardson 1961; Cargill *et al* 1962; Johnson *et al* 1963; Bayer *et al* 1980). The studies also demonstrated the influence of temperature and humidity on water intake, feed intake, and body weight, which are all depressed by high temperature and humidity effects.

Reports of studies carried out under practical management or field conditions have largely confirmed the climate chamber observations (Macfarlane and Stevens 1972; Dragovich 1978, 1979, 1981; Ansell 1976, 1981; Thomas and Acharya 1981; Sharma *et al* 1983).

2.7 Climatic factors on Mpwapwa cattle productivity

There is a general paucity of published information on the Mpwapwa breed and its crosses in respect to the influence of climatic factors on productivity.

Nevertheless, several studies have been reported which revealed some influences of various environmental factors on production and reproductive performance of the Mpwapwa breed and crosses thereof (Macha and Msuya 1977; LPRI 1981; Msechu and Mkonyi 1984; Getz *et al* 1986; Msechu *et al* 1987; Kasonta 1988; Mchau 1988; Das *et al* 1990; Mpiri 1990; Mchau and Syrstad 1991).

Differences reported in the milk production level of the various genetic groups of Mpwapwa cattle cannot be easily associated with climatic variables directly. Some of the differences may be associated with interaction between genotype and some aspects of the environment like climatic variables. However, in his review, Mpiri (1990) contended that, since the management of animals was similar for all genotypes, then any differences must have been genetic. Differences in adaptability to climatic stress between genotypes would account for at least part of the observed variation in production traits.

Year and season of calving effects that have been reported to have been significant sources of variation in lactation length and yield in some of the reports on Mpwapwa cattle (Msechu and Mkonyi 1984; Mchau 1988; Mchau and Syrstad 1991), may be associated, *albeit* only partly, with climatic factors such as ambient temperature, humidity, and precipitation. It is imperative that such climatic factors would most likely influence soil and plant growth characteristics, and thence affect cattle feed availability and quality. This is particularly true in a grazing situation, such as that in Mpwapwa. Through such an effect there would be an indirect influence of these climatic variables on milk production and other traits of Mpwapwa cattle and their crosses.

CHAPTER 3

MATERIALS AND METHODS

3.1 Source of data

Data were collected at Livestock Production Research Institute, Mpwapwa. The institute is located in the Mpwapwa District of Dodoma Region in Central Tanzania. The location lies on latitude 6^{o} 20' South and longitude 36^{o} 30' East and falls in the semi-arid zone (Pratt and Gwynne 1977). Hills and vegetation surrounding the greater part of the farm area make the microclimate slightly cooler than neighbouring areas. The main farm is at an average altitude of 1100 metres above sea level, while two allied farmlets are at 1750 metres and 900 metres, respectively. The lower altitude farmlet is in a typical semi-arid location, while the other one has a cool sub-tropical climate. Soils are sandy loams on the slopes of hills and clay loams at valley bottoms. They are low in Nitrogen and Phosphorus content. Natural vegetation is dominated by trees of the genera *Acacia, Cassia, Commiphora* and *Lannea*. The predominant natural pasture grasses are *Cenchrus* and *Cynodon* species.

The long term average daily minimum temperature is 15.5^{o} C, while the long term daily average maximum temperature is 26.5^{o} C. November has the highest value for average daily maximum temperature of 27.9^{o} C, while July has the lowest of 24.5^{o}C. Rainfall averages 660mm per year and is unreliable. It falls between November and May, often punctuated by a dry spell of up to two weeks in January. The rest of the year is dry, with poor quality standing hay being the only roughage at the peak of the dry season. The bulk of the data analysed for purposes of this study were obtained from the record books of the institute and included calving and milk production records for cows that calved between 1965 and 1988 and meteorological records kept between 1964 and 1989. Additional data were collected in November 1989.

3.2 Herd management and feeding

The management of cattle at the research institute was based on daytime herding and night paddocking. Animals were released from the night paddocks at 0700 hours and taken to pasture within the institute by a herdsman. They were put into a paddock at 1800 hours for overnight grazing. Exceptions to this general management procedure were in cases like those relating to animals being handled at the work crush for some time, sick animals, heavily pregnant animals, and lactating cows. The first two categories were handled in *ad hoc* procedures determined as the situation arose.

Pregnant animals expected to calve within a week were removed from the regular herd and placed in a calving paddock close to the dairy barn. Lactating cows had two sessions of grazing/herding separated by an afternoon milking. They were removed from the night paddock at about 0500 hours for milking. After going for grazing at 0700 hours they were brought back for afternoon milking scheduled to start at 1400 hours. After milking they were taken back to grazing up to 1800 hours and then taken to a night paddock.

Little supplementary feeding was practised in the management of the herd. Only specific classes were given supplementary feed, while the rest of the herd received only mineral licks as a general practice. At milking lactating cows were given concentrate feed, based on maize bran or wheat bran, mixed at the institute. The amount given varied slightly by animal, but has been estimated at 1.5kg per cow at each milking, on average. When such feed was unavailable the cows were given chopped green fodder sprinkled with molasses or brine, just to calm them down during milking. Milking was by machine in two dairy units. When machine milking was, for some reason, not feasible, then hand milking was adopted.

Other classes that received some supplementary feeding were calves up to weaning, weaner heifer calves to yearling, and stud bulls. Calves were removed from their dams at least 12 hours after birth, and in any case not later than 24 hours after birth. At that time they were identified with metal ear tags and their birth weight was recorded along with dam calving weight. The calves were then trained to suck milk from an artificial teat attached to a small bucket. Rearing was in individual calf pens, where the calves were reared on whole milk to weaning at 75 days. They were each given four litres of milk per day until weaning. Roughages were introduced in the first week, along with concentrate feed, mixed locally at the institute. After weaning the calves were separated by sex.

Heifer weaners continued to receive supplementary feed in the dry season to alleviate post-weaning weight loss in an effort to bring them to breeding size early. The supplementary feed was given at 1 kg per weaner per day for the major part of the dry season, until they were about one year old. Often feed ran out before the dry season was over and they went without supplement for the remaining part. At the age of one year they were placed in a heifer group in which they received no further concentrate feed until they were heavily pregnant and had to go into a period of training and steaming up in the milking parlour.

Stud bulls were separated from the main herd and received supplementary concentrate feed in the dry season to ensure that they went into the mating season in good condition. Natural mating was allowed to run for 70 days in each of two seasons commencing at the beginning of March and at the beginning of September every year. Subsequent calvings from these matings were during December-February and June-August, respectively, for wet and dry season.

Routine animal health measures included dipping with acaricides once a week to contain tick challenge and strategic drenching against common gastrointestinal parasites. Other routine animal health matters were vaccinations against brucellosis, foot and mouth disease, blackquarter and anthrax, lumpy skin disease, and haemorrhagic septicaemia. There was routine annual testing for tuberculosis and brucellosis, followed by slaughter of reactors. Other animal health activities were treatment of sick animals as and when the situation called for it.

The foregoing routine management procedures were not inflexible. They were interfered with to allow for data collection during the second stage of data collection, but such interference was kept to a minimum. Most data collection was superimposed on an ongoing routine activity, notably the afternoon milking. Major departures from the routine were avoided for fear of possible influence on the animals' physiology and thus on the reliability of data. For instance, if a cow appeared too nervous at the first attempt to record her rectal temperature, the process was stopped for a while and then tried again. If she failed to calm down, her record was left out and presumed missing for purposes of the study.

3.3 Data management and statistical analyses

The raw data were obtained in different formats depending on the original format of the source and on the initial imagination of the anticipated processing to follow. For the first stage data, milk and calving data were in one file, and long-term meteorological data were in another. Two more data sets were generated from the second stage of data collection: one contained cow identification information, their afternoon milk records, rectal temperature, and dry- and wet-bulb temperatures. The other one carried cow identification information, morning and afternoon milk yields, and milk composition records along with weather information recorded on the sampling day.

3.3.1 Long term milk production records

Milk yield for individual cows was recorded at each milking through the lactation. A recorder sitting at an elevated platform where he could see all cows during milking, kept a hard bound note book with a list of cows that were in milk. The book acted as a guide on calving dates, date lactation commenced and anticipated drying dates, after 305 days of lactation. The cows in milk for any particular day were also entered into a card named the "weekly byre sheet" which had blank columns for recording dates and milk yields for the morning and afternoon milking as well as totals.

As soon as the milking was over for one cow a milker brought the milk to a clock-face milk weighing scale close to the recorder. The recorder read off the milk weight and entered it against the cow's ear tag number in the relevant column of the weekly byre sheet. At the end of the day the recorder carried out arithmetic to generate an entry for total yield for the day for each cow. An exception to this was in the case of cows still in the "colostrum period", in which case the milk was not recorded, but bulked for feeding to calves. The colostrum period included the first five days after calving. At the end of the week the filled out byre sheet was replaced and filed for future reference. The weekly totals of milk yield were generated for transfer into a final summary card named the "lactation summary card". Each cow had one such card for each lactation.

The lactation summary card had blank spaces for entering the cow's pedigree information, date of birth, date of calving, calf sex and identification, date the lactation commenced, date the lactation ended, lactation length, lactation yield, average yield per day of lactation, and recorder's notes. In addition, the record card had columns for recording weekly totals as they came in from the weekly byre sheets, four-week totals, and running totals in any week. For any completed lactation, if the recording procedure was followed strictly, the lactation summary card contained a fairly complete summary on the cow in relation to the particular lactation. From such summaries, the initial set of cow records for the present study were extracted.

Data were coded as they were extracted from the lactation summary card and entered into double-foolscap ruled sheets of paper in preparation for entering into a computer. Information extracted comprised of cow identification number, cow genetic group, date born, date lactation commenced, lactation number(parity), date dried, lactation length, lactation yield, and four-week milk yield totals over the entire lactation. A possible total of 11 four-week totals (hereafter referred to as part yields) were recorded for each lactation because length was limited to 305 days as a matter of routine at the institute. Each entry of the coded data therefore represented one lactation and was composed of up to 19 columns of varying widths. Cows that milked for shorter than 84 days were culled from the herd, and were excluded from the data set, leaving only lactations with at least three part yields.

From the nature of the routine recording procedures it was imperative that there would be recording errors of varying magnitude. Chances of making errors were in such processes as calculating total yields and lactation lengths by hand calculator, transferring information from the weekly byre sheets to lactation summary cards, and extraction thence onto coded data sheets. On entering the data into computer a further source of errors was that of mis-punching. A checking procedure was therefore adopted to rectify as much of this as possible. Data were initially checked by visual evaluation.

Several procedures were adopted to identify errors in the data after entering into computer. In one, a programme in BASIC language was made to check on two aspects of the data and give error messages which indicated where correction was required. It directed the computer to add up the part yields over the lactation and compare the total to the lactation yield. If the two differed it gave the cow identification number and indicated what the two figures were. Then, it directed the computer to calculate the interval between date lactation commenced and date it ended and then compared that with computed lactation length. If there was a difference it indicated what the figures were in the same manner as was the case for milk yield above. In so doing it was possible to bring to light many errors that would have otherwise gone unnoticed.

Another way of checking was by using a word-processing package with a searching facility to pick punching errors. In this case the search revealed such instances as where a period was missing, and where zero was punched as capital "O", or comma in the place of a period in indicating the decimal point. Data were sorted by cow identification number and lactation number to reveal repetitions for deletion. Finally, in the initial data processing the minimum and maximum values for each of the columns in the data file were generated using the "MEANS" procedure of the Statistical Analysis Systems (SAS) package. This revealed figures which were too large or too small to be acceptable values from the knowledge of the data.

3.3.2 Meteorological records

Standard routine procedures were used in recording meteorological data used in this study. For each day there was an entry for the date, dry- and wet-bulb thermometer readings at 0900 hours and at 1500 hours, maximum and minimum temperature readings recorded at 0900 hours, rainfall recorded at 0900 hours, and in some years, wind vane readings at 0900 hours and at 1500 hours. These were recorded in a hard bound note book from which information used in the present study were extracted.

Data were extracted into similar type of paper as was used for coding the milk data. Necessary checks were made using similar procedures as were used for the milk data file, with necessary adjustments to suit the weather data file. A total of 8826 records were obtained. This number represented the number of days included, which was from 1 November 1964 to 31 December 1988. Each record entered covered one specific date in the record book.

3.3.3 Merging milk and weather data files

The major statistical analyses required that variables in the milk data file and those in the meteorological data file be brought together into the same file. This called for merging the two edited data files described in the preceding section. The aim was to have the part yields contained in the milk file acting as the response variables, while the variables in the meteorological data file acted as independent variables in the analyses. Two programming languages were used to make *ad hoc* programmes to effect the merging. One was the SAS language, which was used to make data step applications; the other was the FORTRAN programming language. The programmes were used to generate data to be used in the merging exercise, which was itself in several stages, using SAS.

The intention of merging was to generate totals and averages of data contained in the weather file and to put them into the same records as part yields recorded during the same period as that of weather recording. These would then be analysed as concomitant variables. It was further viewed that the average weather conditions in the period preceding the period when milk was recorded might have had some influence on the level of production. Therefore, average figures of weather data from the preceding period had to be generated also and serve as independent variables in the investigation.

First, the two data files which were in machine independent (ASCII) characters were used to create SAS data files. The two files had one factor in common which facilitated merging; that was date, recording date in the weather file, and calving date in the milk file. Using a SAS data step statement, a dummy variable, N, was initiated in the weather file to serve as an index which would facilitate reference to any point in the file as the starting date at the stage of calculating totals and averages. The dummy variable, which had values running from 1 to 8826 (the number of records in the weather file), was retained pegged to the dates in the weather file as an intermediate stage of the merging exercise.

Then, for each entry in the milk file, a date which was 28 days previous to the date of commencing of lactation was generated using a SAS statement. This was to serve as an equivalent of the starting date for calculations to be carried out on the data in the weather file. The SAS data set containing cow number, calving date, and the date generated (conveniently named "date" to conform with "date" in the weather file), was then sorted by cow number and date using a SAS statement.

The part of the weather file containing the date and the dummy variable N and the part of the milk file containing cow number, calving date, and date were merged using the common criterion of date. In the course of merging there were points where either of the files did not have data because of overlap. For example, if a cow calved in early November 1964, then there would be an entry for date in the part that originated from the milk file but there would be no value for the dummy variable because weather data only went as far back as 1 November 1964. And, where a cow calved later than December 1988, there might not be weather records since the weather data in the file were recorded up to 31 December 1988 only. The programme for this merging exercise was tailored so that when the machine encountered a missing value for cow number or N, the record was deleted. This generated an intermediate file containing cow number, calving date, date, and dummy variable N. This file, named dummy sample, was stored for use in subsequent stages.

A programme was made in FORTRAN language to calculate the totals and means of the weather variables and to put those together with information from the dummy sample file into a file to be merged with part yield data from the milk file. The programme made the computer read the weather variables into vectors initiated for holding the data to be used in the calculations. Then it caused the computer to read data from the dummy sample file and instructed it to use the dummy variable as a subscript for each of the variables from the weather file. The use of the dummy variable N from the dummy sample file ensured that while working on the weather data there was still association with cow number as a reference identifier for purposes of linking to the part yields contained in the milk file.

The programme instructed the computer to calculate the total and average of 28 consecutive entries of each weather variable starting with the Nth record, where N was the value from the dummy sample file. This was repeated 11 times (using subsequent 28 entries each time) or until the end of the weather file. The 12 totals and averages had to be generated because there were 11 part yields in the milk file, each of which needed a concomitant average weather record, and an extra record was required for the period previous to the first part yield. Hence, for any calving date there would be obtained by this process a total and an average value of the weather data that were recorded during any 28-day period, starting from 28 days prior to beginning of lactation.

While calculating the total and average weather data values, a count was kept of missing values encountered. At the end, the programme caused to be created a file containing the dummy sample entries with appended average temperature and total rainfall figures computed from the weather file. Where one or more missing rainfall values or more than three missing temperature values were encountered in the calculation, a missing value symbol was substituted for the total or average. The resulting file, named "averages sample", was stored for later use.

Using a SAS data step programme, each lactation was broken into several records so that each part yield and the previous part yield formed the milk yield variables. At the same time a new factor was initialised to stand for stage of lactation. This was such that for the part of the lactation where part yields 1 and 2 were in the record the lactation stage was coded 1, where part yields were 2 and 3 stage was coded 2, and so on until stage 10 where the last two part yields in a full 305-day lactation were in the record. The resulting file for each stage of lactation was sorted by cow number and named stage sample, with a suffix on stage to indicate the stage of lactation.

All the descriptive columns in the original milk file were retained in this file for use as variables in the statistical analyses that followed.

Another *ad hoc* SAS application was employed to merge each of the stage files with files created from judicious extraction of information from the averages sample file, containing the total rainfall and average temperature values for the relevant 28-day periods. In this case the merging was effected by the sort criterion of cow number which was common to both the averages sample and stage sample files. By joining the merged files end to end using a SAS programme a big data set resulted which contained milk and weather information in a format that could be processed using routine SAS procedures as intended.

The final format of the data for statistical analyses therefore contained the information from the milk raw data file and the weather data derived from the original weather file. Each record was composed of the columns coded to represent cow number, cow genetic group, calving date, age at calving, parity, stage of lactation, lactation length, lactation yield, previous part yield, current part yield, and average temperature and total rainfall values recorded in the period previous and concurrent to each of the two part yields.

3.3.4 Derived variables

The temperatures recorded in the study were used to derive other required variables. The formula adopted by Kibler(1964) for deriving temperature-humidity index(THI) for cattle was employed to obtain THI as an index for use in investigating the combined influence of temperature and humidity. This formula, written in its original form, is shown in Equation (1):

$$THI = 0.4(DBtemp + WBtemp) + 15 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

DBtemp = dry-bulb temperature (degFahr)

WBtemp = wet bulb temperature (degFahr)

For each set of dry- and wet-bulb thermometer readings, one value of THI was derived. An average value for each day was calculated as the mean of the morning value and the afternoon value.

Effective temperature(Tef), originally defined as "the temperature at which motionless, saturated air would impart the same sensation of comfort as that induced by the actual conditions of temperature, humidity and air movement" (Huschke 1959, cited by Rosenberg *et al* 1983), was adopted as an alternative index. The principle of this index gave rise to formulae, initially developed for human subjects and later adapted for livestock. For cattle this is given in Equation (2), adopted from Ingram (1974).

$$Tef = (0.35 \times DBtemp) + (0.65 \times WBtemp) \quad \ldots\ldots\ldots(2),$$

where:

DBtemp and WBtemp are the dry- and wet-bulb temperatures (expressed in degrees Celsius).

The use of the formula for effective temperature for cattle made it possible to derive this as an additional study variable. In a similar manner adopted for the other variables, a value was calculated from the temperatures recorded in the morning and in the afternoon, and a mean value was calculated for the day.

3.3.5 Supplementary animal and weather data

Additional data were collected in November 1989 to augment the routine data obtained from record books and from the institute weather station. Recording procedure was adopted so that it involved little change in the normal routine of activities of the animals. Afternoon milk yield was recorded by the regular recorder. It was extracted by the author at the end of milking on the same day and entered into the coded data sheet for use in the study. At the same afternoon milking the rectal temperature of each cow was taken using a digital thermometer fitted with a general purpose probe. At the same time dry- and wet-bulb temperatures were recorded using a whirling psychrometer.

The cows were allowed to come into the dairy barn as was usual practice, with about half an hour of rest outside the milking parlour prior to milking. During the resting time they were allowed access to drinking water. Relative humidity, effective temperature and temperature-humidity index, not recorded directly in this part of the study, were derived as explained earlier (Section 3.3.4), prior to statistical analyses.

The data file from the records collected this way comprised of columns for cow number, genetic group, cow coat colour code (dark or light), pregnancy status (indicating whether cow was pregnant or empty and stage of pregnancy), date born, date of observation, rectal temperature, milk yield, time of recording, and weather variables recorded on the same day as the cow variables.

Further supplementary records specifically intended for investigations on variation in milk fat, ash (gross mineral content) and total solids were taken. This was done by sampling the evening milk for laboratory analyses and recording weather conditions on the sampling day. The milk samples were refrigerated overnight before analyses were carried out to determine their fat and ash content as estimates of milk fat and mineral contents, respectively. Sub-samples were dried at constant temperature (105^{o}C) to obtain the total solids component of the milk.

Each record in the new supplementary set of data had a column for cow number, genetic group, pregnancy status date born, date calved, date sampled, morning milk yield, afternoon milk yield, fat per cent, total solids per cent, ash per cent, and weather variables recorded on the day of sampling. Temperature-humidity index, not recorded directly, but viewed as useful for this part of the investigation was derived from dry- and wet-bulb temperatures as explained in Section 3.3.4.

3.3.6 Statistical analyses

Statistical analyses of the data were effected using routine procedures of the SAS package. First, the MEANS procedure was used to obtain the simple statistics of all variables included in the study. Then, the rest of the analyses which form the backbone of the study results were effected with the adoption of two regression procedures of the SAS package (SAS Institute Inc. 1990). The first runs investigated the relative importance of different covariates in explaining variation in the response variables. These used the backward elimination option of model selection in the stepwise regression procedure of SAS. Then, the generalised linear models (GLM) procedure was adopted for the analyses of covariance with suitable options to control output.

Due to the nature of the records, different models were adopted for data from the two stages of data collection. The maximal model adopted for analyses of stage one data contained part yield as the response variable, and previous part yield, lactation length, age of cow at calving, and the weather variables as covariates. It included, as class variables (factors) in the model, cow genetic group, parity, stage of lactation, and year of calving. Algebraic representation of this is shown in the relevant equation in the detailed model descriptions given in Appendix 8.

The maximal model for the analyses of data on daily milk yield contained milk yield as the response variable, while age of cow, rectal temperature, and weather variables acted as covariates. For class variables in these analyses the maximal model adopted cow genetic group, pregnancy status, and coat colour. The last two factors were found to be of unimportant from the preliminary analyses and were left out of the study. Most animals were empty and light coloured, making it unnecessary to make comparisons based on the two factors.

Separate analyses used rectal temperature as the response variable to see how it may have been influenced by weather variables. For purposes of the investigation relating to possible differences in genetic groups, a reduced model was adopted for separate analyses for each genetic group, where deemed necessary, after the preliminary analyses.

For the analyses of the milk composition data, similar models were adapted with modification. The maximal model in this case contained fat or total solids or ash component as response variables. Age of cow, milk yield, and weather variables acted as independent variables together with the two class variables, cow genetic group and pregnancy status. A reduced model was adopted for analyses of data from each genetic group separately after preliminary analyses.

Detailed description of the various models and sub-models adopted for the most relevant intermediate and final analyses of the data is given in Appendix 8.

CHAPTER 4

RESULTS

4.1 Weather variables

Weather variables included in the study, rainfall and temperatures, varied by season as would be considered normal. The variation would be expected to influence milk yield and other cattle characteristics. The following sections show the variations experienced over the period covered by the present study.

4.1.1 Rainfall

Rainfall was variable but showed an almost definite yearly pattern. There was a long dry period from June to September (inclusive) each year. In some years this dry period extended from May to November.

The average daily rainfall records over the study period revealed a seasonal variation, which is shown in Figure 1. The rainfall pattern is unimodal, with a peak somewhere between December and March and a depression to near zero values in August.

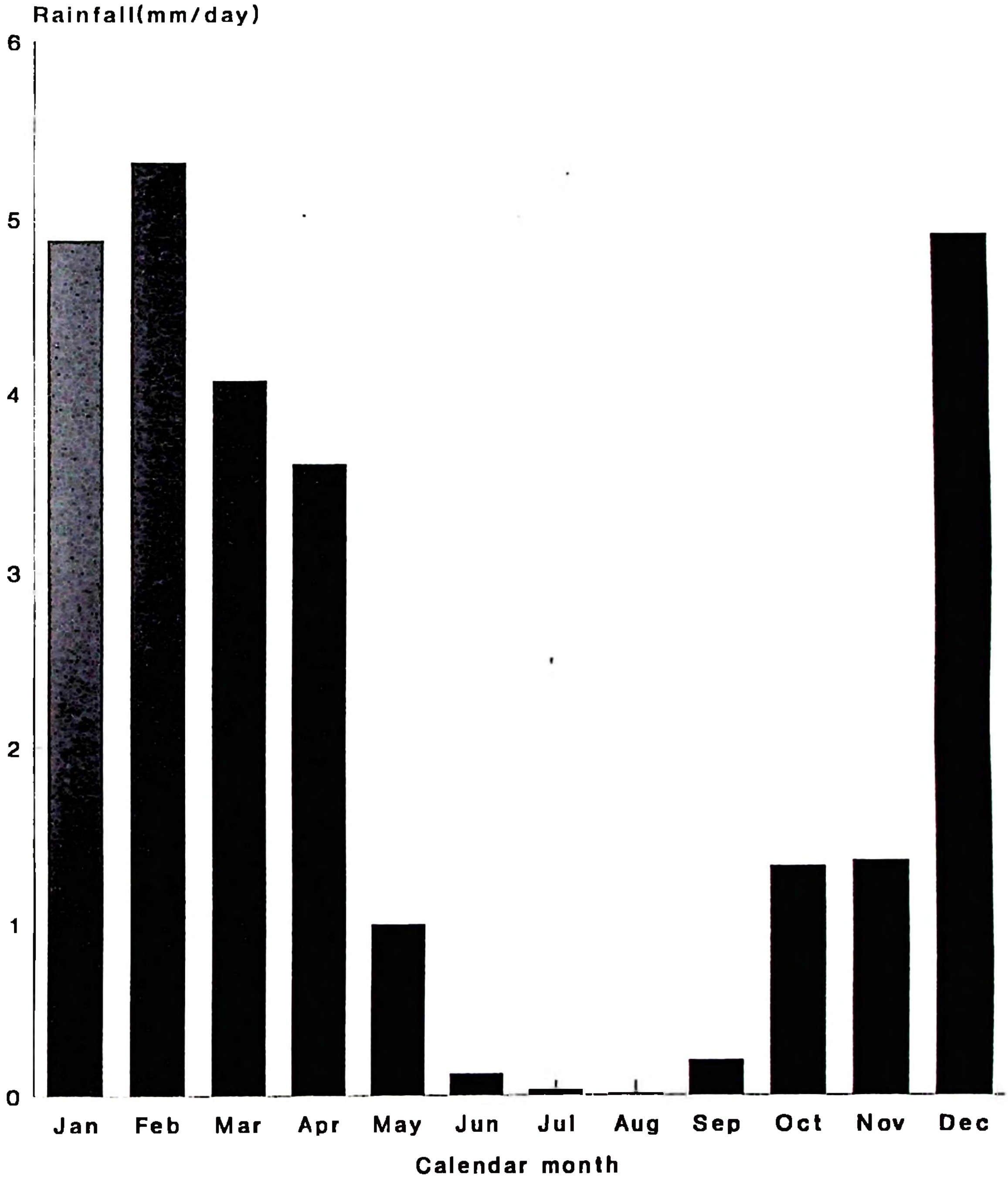


Figure 1: Average daily rainfall(mm) by calendar month for the period Nov 1964 - Dec 1988

4.1.2 Average daily temperatures

Overall mean daily temperatures are given in Table 1. Variations from month to month are depicted by Figure 2, which shows unadjusted daily means of the various temperatures in different months, based on data used in the study.

The overall daily mean dry-bulb temperature recorded in the morning(0900 h) ranged from 18.36^{o}C to 23.13^{o}C, while the range of wet-bulb temperatures recorded in the same period was 15.30^{o}C to 19.41^{o}C.

Mean dry-bulb temperature recorded in the afternoon (1500 h) was in the range of 23.71^{o}C to 29.50^{o}C. Wet-bulb temperatures during the same period ranged from 17.62^{o}C to 23.71^{o}C.

Table 1: Summary of weather variables, showing unadjusted means[1] and standard errors for the period November 1964 to December 1988

Weather variable	n	Mean ± S E
DB temperature at 0900 h, °C	8535	20.85 ± 0.02
WB temperature at 0900 h, °C	8537	17.91 ± 0.02
Maximum temperature, °C	8540	26.19 ± 0.03
Minimum temperature, °C	8228	14.51 ± 0.04
DB temperature at 1500 h, °C	8403	26.45 ± 0.03
WB temperature at 1500 h, °C	8403	20.08 ± 0.03
Rainfall, mm	8657	2.15 ± 0.08

[1]Generated from the means procedure of SAS programme;

n is number of observations

DB = Dry-bulb, WB = Wet-bulb

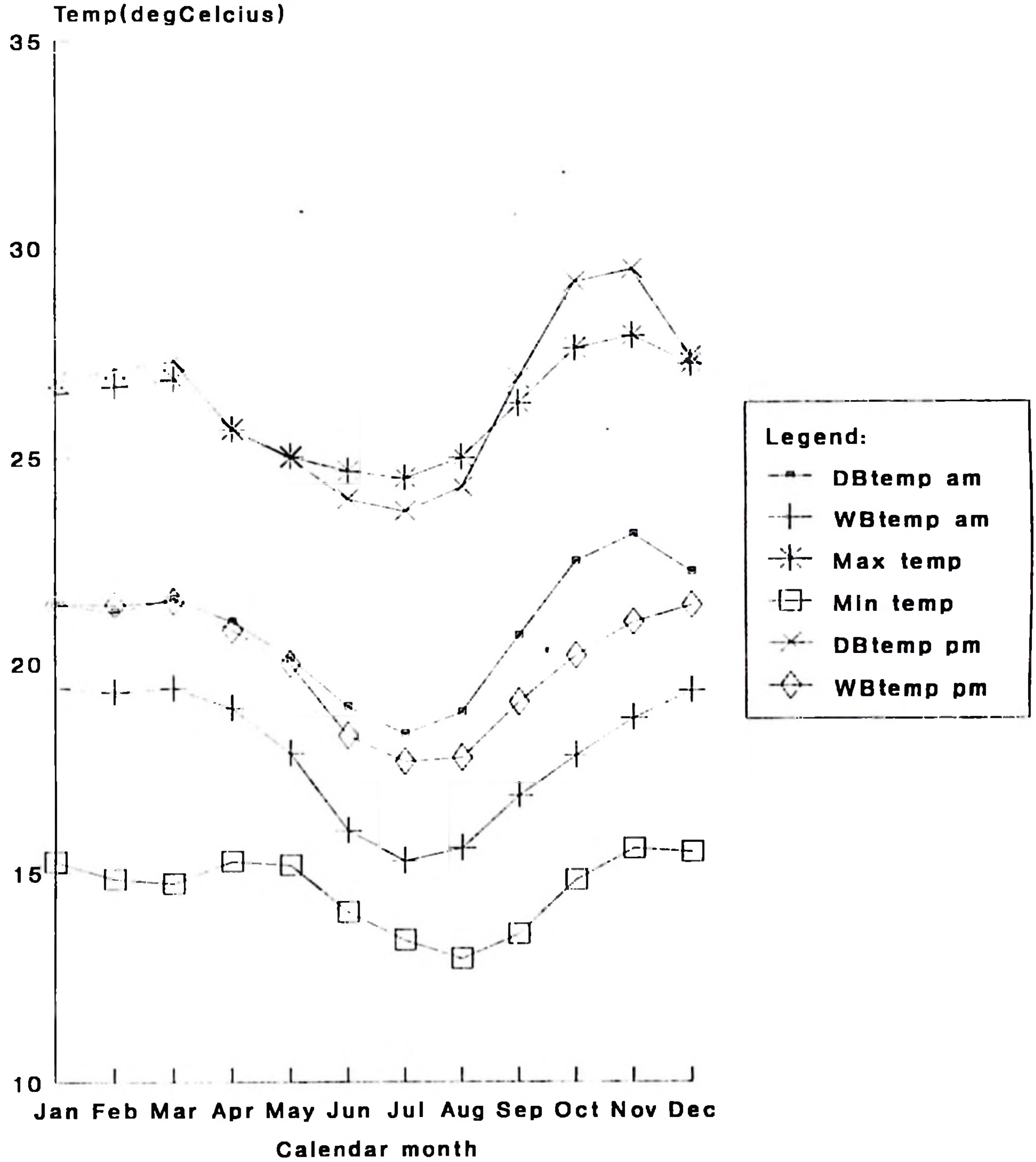


Figure 2: Mean daily temperatures by calendar month for Nov 1964 to Dec 1988

The highest monthly average daily maximum temperature was in the month of November at 26.72^{o}C, over the period covered by the study, and the lowest monthly average daily minimum temperature was in July at 12.96^{o}C. The full range of month to month variations of daily average maximum and minimum temperatures is shown in Figure 2 along with other temperatures.

4.1.3. Association between weather variables under study

The weather variables in the study were positively correlated ($P<0.05$). Simple correlation coefficients between the weather variables were as shown in Table 2. The coefficients were computed using mean values of 28 consecutive days, for temperature, and total values for the same 28-day periods for rainfall, over the study period.

The only variable with low coefficient of correlation with all the others was minimum temperature. Rainfall had low correlation with most other weather variables also. It was only closely related to wet-bulb temperatures. The coefficients of correlation were nevertheless significant in all cases.

Table 2: Simple correlation coefficients between the weather variables used in the study[1]

Correlated weather variables	1	2	3	4	5	6	7
1 DBtemp at 0900 h:	-	0.79	0.73	0.23	0.86	0.75	0.30
2 WBtemp at 0900 h:		-	0.53	0.26	0.56	0.87	0.64
3 Maximum temp.,			-	0.13	0.74	0.48	0.19
4 Minimum temp.,				-	0.15	0.23	0.24
5 DBtemp at 1500 h:					-	0.65	0.10
6 WBtemp at 1500 h:						-	0.51
7 Concurrent rain							-

[1]All correlation coefficients were positive and significant (all at $P<0.001$). Number of paired observations used in calculating the correlation coefficients varied from 19812 to 21152 due to missing values in the data set for some variables.

4.2 Relative importance of weather variables to 28-day milk yield

Initial data processing considering the relative importance of various sources of variation in the cow variables highlighted on the relative importance of the various weather variables, prior to their being used as independent variables in covariance analyses. The results from these preliminary runs are presented in the subsections that follow.

4.2.1 Stepwise regression procedures

Preliminary model selection analyses using the backward elimination option of the stepwise regression procedure of SAS showed that most of the weather variables under study were important sources of variation ($P<0.10$). Results of the analyses are presented in Table 3, showing sums of squares contributed by various concurrent weather variables towards variation in 28-day milk yield.

The most important weather variable revealed by these exploratory analyses was minimum temperature followed by wet-bulb temperature recorded at 1500 h. These temperatures were retained in the model and had a significant relationship with milk yield ($P<0.05$) at all stages of lactation. Partial regression coefficients from the analyses are presented in Table 4.

The regression coefficients of 28-day milk yield on morning dry- and wet-bulb temperatures were negative in all lactation stages, while those on maximum, minimum, and afternoon wet-bulb temperatures were positive at all stages. Partial regression on concurrent rain was also positive.

Table 3: Summary of results of stepwise regression of 28-day milk yield on concurrent weather variable, showing sums of squares attributed to independent variables retained in the model[1] in the backward selection procedure in each of 10 stages of lactation.

Independent variable[3]	Stage of lactation (28-day period from the beginning of lactation)[2]									
	1	2	3	4	5	6	7	8	9	10
DBtemp, a.m.	-	23565	27088*	123833*	47631*	140836*	-	94640*	133021*	131925*
WBtemp, a.m.	70702*	119225*	182888*	54835*	59318*	-	17383*	-	-	-
Max temp	-	46807*	88754*	50412*	31533*	20293*	31525*	-	-	-
Min temp	362163*	249396*	270998*	389689*	295866*	356641*	373471*	170079*	133970*	118915*
DBtemp, p.m.	208453*	50705*	18490*	-	-	-	233154*	-	23893*	23715*
WBtemp, p.m.	255469*	413647*	360015*	235983*	252879*	301202*	242931*	157093*	54834*	46963*
Rain	-	48512*	129414*	-	33702*	-	-	21922*	65640*	29899*
R-square (%)	4.6	6.8	7.0	5.0	5.5	7.0	9.8	8.6	10.8	8.8

*$P<0.05$, else $^{+}0.05<P<0.10$

[1]Retention was set at the $P<0.10$ level of probability

[2]Weather variables not retained are indicated with a dash (-)

[3]DBtemp, WBtemp = dry-bulb and wet-bulb temperature, respectively.

Table 4: Summary of results of stepwise regression of 28-day milk yield on concurrent weather variables showing regression coefficients on independent variables retained in the model[1] in the backward elimination option of the procedure in each of 10 stages of lactation.

Independent variable[3]		Stage of lactation (28-day period from beginning of lactation)[2]									
		1	2	3	4	5	6	7	8	9	10
DBtemp, a.m.	b	-	-7.30	-7.40	-9.60	-6.75	11.94	-	-8.96	-15.07	-14.80
	±SE	-	3.94	3.53	2.07	2.16	2.11	-	1.83	2.28	2.15
WBtemp, a.m.	b	-6.92	-17.49	-18.25	-6.49	-8.48	-	-3.88	-	-	-
	±SE	2.22	4.19	3.34	2.11	2.43	-	1.93	-	-	-
Max temp	b	-	4.50	5.63	3.78	3.32	3.01	3.18	-	-	-
	±SE	-	1.72	1.48	1.28	1.30	1.40	1.41	-	-	-
Min temp	b	4.34	3.52	3.32	4.01	3.60	4.00	4.43	3.17	2.94	2.75
	±SE	0.61	0.58	0.50	0.49	0.46	0.45	0.48	0.48	0.44	0.42
DBtemp, p.m.	b	-7.68	-8.35	-3.54	-	-	-	-9.20	-	3.71	3.55
	±SE	1.44	1.97	2.04	-	-	-	1.25	-	1.32	1.21
WBtemp, p.m.	b	13.14	22.36	18.96	11.24	10.24	10.81	13.74	9.64	6.39	5.64
	±SE	2.22	2.88	2.48	1.73	1.42	1.31	1.83	1.52	1.51	1.37
Rain	b	-	0.10	0.16	-	0.09	-	-	0.06	0.13	0.09
	±SE	-	0.04	0.03	-	0.04	-	-	0.02	0.03	0.03

[1] Retention was set at $P<0.10$ level of probability

[2] Weather variables not retained are indicated with dash ("-")

[3] DBtemp, WBtemp = dry-bulb and wet-bulb temperature, respectively.

In general the same weather variables appeared to be important to variation in 28-day milk yield, whether the weather variables were recorded in the same period as milk yield or in the preceding period. Tables in Appendices 1 and 2 show the results of the same analyses as those whose results are presented in Tables 4 and 5, but adopting previous weather variables.

Another investigation using stepwise regression procedures showed that effective temperature (ET) was not effective in explaining variation in milk yield. When ET was used to replace dry- and wet-bulb temperatures in the analyses, R-square was reduced from 6.2% to 4.8%. In contrast, temperature-humidity index (THI) was more useful in explaining variation in 28-day milk yield than ET.

Since the two indexes were alternatives picked from the literature for possible adoption in the place of dry- and wet-bulb temperatures, THI was chosen for later analyses. The ET as an alternative index was disregarded from this point.

4.2.2. Fitting various models to 28-day milk yield data

Adopting models described in detail in Appendix 8, allowed for choice of factors and independent variables for use in investigating the influence of the weather variables on milk yield. Results from fitting various models and sub-models thereof were many, but only the most important ones relevant to the investigation are summarised herein.

Table 5 summarises the results of covariance analysis of 28-day milk yield pooled across all genetic groups and all stages of lactation, adopting Model 1. With the exception of parity and age of cow, all cow variables included in the model were significant sources of variation in milk yield. Among the weather variables, only wet-bulb temperature at 1500 h was not an important source of variation ($P>0.10$).

It was found out that Model 1, whose analysis results were presented in Table 5, accounted for 87.18% of total variation in milk yield as depicted by the R^2 value. The major proportion of sums of squares was contributed by the three independent variables previous milk, lactation stage, and lactation length.

Table 5: Results of covariance analysis[1,2] of 28-day milk yield, showing sums of squares(S S) attributed to various factors and independent variables and regression coefficients(b) on invoking Model 1

Term in model[3]	S S	b ± S.E.
Genetic group(5)	185970***	na[4]
Year of calving(24)	288358***	na
Lactation stage(10)	2510235***	na
Parity(9)	6764ns	na
Age of cow	<1ns	0.00 ± 0.01
Lactation length	1464876***	0.22 ± 0.01
Previous milk	32462680***	0.79 ± 0.00
DB temp at 0900 h	3042*	0.94 ± 0.48
WB temp at 0900 h	5415**	1.22 ± 0.46
Maximum temperature	5951**	0.72 ± 0.26
Minimum temperature	42414***	0.84 ± 0.11
DB temp at 1500 h	6860**	-0.74 ± 0.25
WB temp at 1500 h	1012ns	0.36 ± 0.31
Previous rain	23908***	-0.02 ± 0.00
Concurrent rain	19544***	0.02 ± 0.00
Full model(df=55)	SS=99257608	R^2 = 87.19%
Residual(df=18740)	SS=14587488	-

***$P<0.001$ **$0.001<P<0.01$ *$0.01<P<0.05$ ns$P\geq0.10$

[1]Type III sums of squares(SAS Institute Inc. 1990).

[2]See model description in Appendix 8.

[3]Number in parentheses shows number of categories.

[4]In this and subsequent tables milk is expressed in kg, rainfall in mm and temperatures in °Centigrade and 'na' stands for 'not applicable'.

It was noteworthy from the results summarised in Table 5, that only two of the independent variables, dry-bulb temperature at 1500 h and previous rainfall, had an inverse relationship with the response variable.

When THI values from morning and afternoon recording were used in the place of dry- and wet-bulb temperatures, the results were similar to the preceding results. The effects of age of cow and parity were the only cow variables that were not significant. The weather variables were all significant with the exception that the influence of maximum temperature was marginal($P<0.10$). The relationship of THI with milk yield was positive in the morning but negative in the afternoon. The most important variables in contributing to variation in milk yield were the same as in the previous case. The results are as summarised in Table 5.

When Model 3 was invoked so that average daily THI value was used to replace the two values of THI used in the preceding situation, the results were very similar. These are presented in Table 8.

Table 6: Results of covariance analysis[1,2] of 28-day milk yield, showing sums of squares(S S) attributed to various factors and independent variables and regression coefficients(b) on invoking Model 2.

Term in model[3]	S S	b ± S.E.
Genetic group(5)	185278***	na
Year of calving(24)	289746***	na
Lactation stage(10)	2505983***	na
Parity(9)	6886^{ns}	na
Age of cow	<1^{ns}	0.00 ± 0.01
Lactation length	1460057***	0.22 ± 0.01
Previous milk	32615971***	0.79 ± 0.00
THI at 0900 h	33166***	1.77 ± 0.27
THI at 1500 h	5201**	-0.50 ± 0.19
Max temp	2180^{+}	0.40 ± 0.24
Min temp	41366***	0.82 ± 0.11
Previous rain	21480***	-0.02 ± 0.00
Concurrent rain	33644***	0.03 ± 0.00
Full model(df=53)	SS=99250335	R^2 = 87.18%
Residual(df=18742)	SS=14594760	-

***$P<0.001$ **$0.001<P<0.01$ $^{+}0.05<P<0.10$ $^{ns}P\geq0.10$

[1]Type III sums of squares (SAS Institute Inc 1990).

[2]Detailed model description is given in Appendix 8.

[3]Number in parentheses shows number of categories.

Table 7: Results of covariance analysis of 28-day milk yield showing sums of squares(S S)[1] attributed to various factors and independent variables[2] and regression coefficients(b) on invoking Model 3.

Term in model[3]	S S	b ± S.E.
Genetic group(5)	186928***	na
Year of calving(24)	268373***	na
Lactation stage(10)	2489237***	na
Parity(9)	6775ns	na
Age of cow	<1ns	0.00 ± 0.01
Lactation length	1459361***	0.22 ± 0.00
Previous milk	32594827***	0.79 ± 0.00
Average daily THI	17107***	0.82 ± 0.17
Max temp	2048ns	0.39 ± 0.24
Min temp	45461***	0.86 ± 0.11
Previous rain	15894***	-0.02 ± 0.00
Concurrent rain	67006***	0.03 ± 0.00
Full model(df=52)	SS = 99228469	R^2 = 87.16%
Residual(df=18743)	SS = 14616627	-

***$P<0.001$ ns$P\geq0.10$

[1]Type III sums of squares(SAS Institute Inc. 1990).

[2]See model description in Appendix 8.

[3]Number in parentheses shows number of categories.

The same cow variables that were significant in the situation where Model 2 was used for the analyses were significant when daily average THI was used in the place of THI values for morning and afternoon conditions. Previous rain and age of cow were the only continuous variables negatively related to milk yield on employing Model 3. In the latter case the model accounted for 87.16% of the variation in milk yield, as indicated by the marginal reduction in the value of R^2.

When previous rain was dropped from the model the change in R^2 value was small. Notable changes were that all the continuous variables were positively related to milk yield, and that all weather variables were significant sources of variation. The results from these analyses are presented in Table 8.

Table 8: Results of covariance analysis of 28-day milk yield showing sums of squares(S S)[1] attributed to various factors and independent variables[2] and regression coefficients(b) on invoking Model 4.

Term in model[3]	S S	b ± S.E.
Genetic group(5)	192731***	na
Year of calving(24)	288473***	na
Lactation stage(10)	2492865***	na
Parity(9)	6548ns	na
Age of cow	<1ns	0.00 ± 0.01
Lactation length	1474181***	0.22 ± 0.01
Previous milk	32945939***	0.79 ± 0.01
Average daily THI	10242***	0.61 ± 0.17
Max temp	6223**	0.66 ± 0.23
Min temp	42500***	0.83 ± 0.11
Concurrent rain	49529***	0.03 ± 0.00
Full model(df=51)	SS = 99310920	R^2 = 87.12%
Residual(df=18744)	SS = 14681326	-

***$P<0.001$ **$0.001<P<0.01$ ns$P\geq0.10$

[1]Type III sums of squares (SAS Institute Inc. 1990).

[2]See model description in Appendix 8.

[3]Number in parentheses shows number of categories.

When an additional cow variable, parity, was dropped from the model the results were as presented in Table 9. These were results of analyses using Model 5, in which period of calving was used in the place of year of calving with a reduced number of categories. Age of cow was then significantly related to milk yield, with a negative regression coefficient. All other continuous variables had a positive relationship with milk yield.

The regression coefficients of milk yield on all the cow independent variables included in Model 5 were significant. Coefficients on weather variables were also mostly significant, except those on maximum temperature and afternoon THI. The R^2 value associated with the variables included in Model 5 was 87.07%, which was close to that in the previous situation with Model 4. The results of analyses carried out using Model 5 are presented in Table 9.

Table 9: Results of covariance analysis of 28-day milk yield showing sums of squares(S S)[1] attributed to various factors and independent variables[2] and regression coefficients(b) on invoking Model 5.

Term in model[3]	S S	b ± S.E.
Genetic group(5)	180413***	na
Period of calving(5)	152926***	na
Lactation stage(10)	2518911***	na
Age of cow	3239*	-0.01 ± 0.01
Lactation length	1462422***	0.21 ± 0.00
Previous milk	37719673***	0.80 ± 0.00
THI at 0900 h	11302***	0.91 ± 0.24
THI at 1500 h	29.5ns	0.11 ± 0.17
Max temp	2018ns	0.32 ± 0.20
Min temp	60896***	0.61 ± 0.07
Concurrent rain	24737***	0.03 ± 0.00
Full model(df=25)	SS = 99011867	R^2 = 87.01%
Residual(df=18745)	SS =14780805	-

***P<0.001 *0.01<P<0.05 nsP≥0.10

[1]Type III sums of squares (SAS Institute Inc. 1990).

[2]See model description in Appendix 8.

[3]Number in parentheses shows number of categories.

The effect of adopting previous rain to replace previous milk as independent variable was investigated in an alternative run using all the other independent variables included in Model 5. The results were as presented in Table 10. The R^2 value was drastically reduced (from 87% to 54%) and residual sums of squares increased by a factor of 3.5. This demonstrates that inclusion of 'previous milk' as a covariate was indeed efficient in reducing the error variation. However, the sums of squares ascribed to independent variables increased much more than the residual sums of squares, mostly more than tenfold.

The results were different from those in which previous milk was adopted as a covariate. In the latter case the importance of the independent variables was more pronounced, with the exception of that of maximum temperature which was unimportant($P>0.05$), judged from the results. The other independent variables were highly significant ($P<0.001$). Except for THI in the morning and maximum temperature, the relationship of the independent variables with milk yield was positive.

Table 10: Results of covariance analysis[1] of 28-day milk yield showing sums of squares(SS) and regression coefficient estimates(b)[2] for various independent variables adopted in Model 5 on replacing previous milk with previous rain

Independent variable	S S	b ± S.E.
Genetic group(5)	11834094***	na
Calving period(5)	2179183***	na
Lactation stage(10)	30174515***	na
Age of cow	1941027***	0.35 ± 0.01
Lactation length	12034631***	0.58 ± 0.01
Previous rain	350578***	0.07 ± 0.01
Concurrent rain	656266***	0.11 ± 0.01
THI at 0900 h	294096***	-4.72 ± 0.46
THI at 1500 h	128600***	2.21 ± 0.32
Maximum temp	2107^{ns}	-0.33 ± 0.38
Minimum temp	779207***	2.16 ± 0.13
Full model(df=25)	SS=61630573	R^2 = 54.2%
Residual(df=18712)	SS=52014920	-

***$P<0.001$ $^{ns}P\geq0.10$

[1]Analysis pooled across genetic group

4.2.3 Sources of variation in 28-day milk yield for different genetic groups.

Sums of squares from analyses using Model 6 are presented in Table 11, along with the levels of significance for each term in the model. Three non-weather variables, previous milk yield, lactation stage and lactation length, contributed appreciably to 28-day milk yield ($P<0.05$) in all genetic groups, but age of cow assumed no importance ($P>0.10$).

Among the weather variables only THI recorded at 0900 h had influence in all the genetic groups. Year of calving was an important factor on milk yield in Mpwapwa, Friesian x Mpwapwa and Backcross cows ($P<0.01$), but not in Jersey or Ayrshire cross cows($P>0.10$). Total rainfall during the same period as that of recording the cumulative 28-day milk yield had significant influence on the milk yield in Mpwapwa ($P<0.001$), Friesian cross ($P<0.05$) and Backcross ($P<0.01$) cows. Maximum temperature influenced milk yield in Jersey cross ($P<0.05$), Ayrshire cross ($P<0.01$) and Friesian cross ($P<0.10$) cows only. Minimum temperature had least influence on the basis of these analyses as it affected milk yield in Backcross cows only($P<0.05$).

Table 11: Results of separate covariance analyses of 28-day milk yield for each genetic group, showing sums of squares(SS)[1] associated with each term in Model 6.

	Genetic group[3]				
Term in model[2]	Mpwapwa	J x M	A x M	F x M	Backcross
Calving year(12)	84405^{*}	6601^{ns}	13512^{ns}	64603^{*}	52736^{*}
Lactation stage(10)	96331^{*}	136295^{*}	175806^{*}	248949^{*}	407582^{*}
Age of cow	$<1^{ns}$	36^{ns}	2772^{ns}	882^{ns}	267^{ns}
Lactation length	528716^{*}	25765^{*}	14277^{*}	9381^{*}	236090^{*}
Previous milk	9815148^{*}	1865738^{*}	961087^{*}	2158033^{*}	4856911^{*}
THI at 0900 h	17893^{*}	3771^{+}	11429^{*}	19842^{*}	8713^{*}
THI at 1500 h	957^{ns}	1648^{ns}	166^{ns}	3117^{ns}	338^{ns}
Max temp	455^{ns}	4894^{*}	12651^{*}	4872^{+}	1193^{ns}
Min temp	378^{ns}	182^{ns}	1151^{ns}	165^{ns}	3812^{*}
Rain	8755^{*}	814^{ns}	8^{ns}	8056^{*}	7985^{*}
Model(df=28) SS	24178992	4961986	3454174	9020622	11854330
Residual SS	4525272	690711	648142	1232837	2831265
Residual df	6032	611	526	871	3416

$^{*}P<0.05$ $^{+}0.05<P<0.10$ $^{ns}P\geq 0.10$

[1]Type III sums of squares(SAS Institute Inc. 1990, p.936); Model 6 as described in Appendix 8.

[2]Number in parentheses indicates number of categories.

[3]Genetic groups as explained in the text(see Chapter 3).

Regression coefficients from the analyses adopting Model 6 are summarised in Table 12, along with the R-square values indicating the percentage contribution of the model towards the variation in 28-day milk yield.

The values presented in Table 12 varied little by genetic group. Of the non-weather variables, only age of cow gave erratic results with regard to sign of the regression coefficient, but the regression on age was nonsignificant, making apparent trends unimportant. The regression on lactation length and previous milk yield were both consistently positive for all genetic groups. Each had similar values in magnitude for all genetic groups.

The regression coefficient on the apparently most important weather variable, THI at 0900 h, was consistently positive and did not vary significantly between genetic groups. The regression 28-day milk yield on THI at 1500 h was inconsistent in sign between the genetic groups, but it was nonsignificant in all the genetic groups.

Table 12: Regression coefficients of 28-day milk yield on various independent variables included in covatiance analyses[1] for each genetic group, involving model 6.

	Regression coefficients (b±SE) for various genetic groups				
Term in model	Mpwapwa	J x M	A x M	F x M	Backcross
Age of cow	0.00 ± 0.01	0.01 ± 0.05	-0.11 ± 0.07	0.03 ± 0.04	0.01 ± 0.02
Lactation length	0.024 ± 0.01	0.23 ± 0.05	0.23 ± 0.07	0.36 ± 0.14	0.22 ± 0.01
Previous milk	0.78 ± 0.1	0.84 ± 0.02	0.75 ± 0.03	0.77 ± 0.02	0.76 ± 0.1
THI at 0900 h	2.44 ± 0.50	3.50 ± 1.92	6.88 ± 2.26	6.52 ± 1.74	2.28 ± 0.07
THI at 1500 h	-0.37 ± 0.33	1.57 ± 1.30	0.57 ± 1.55	-1.71 ± 1.15	0.30 ± 0.47
Max temp	-0.32 ± 0.41	-3.25 ± 1.56	-5.86 ± 1.83	-2.59 ± 1.42	-0.72 ± 0.60
Min temp	0.20 ± 0.27	0.58 ± 1.44	-1.70 ± 1.76	0.41 ± 1.19	0.91 ± 0.42
Rain	0.02 ± 0.01	-0.02 ± 0.03	0.00 ± 0.03	0.05 ± 0.02	0.03 ± 0.01
Model R^2	84.23	87.78	84.20	87.98	80.72

[1]Model 6 described in Appendix 8; genetic groups as explained in Chapter 3.

Regression coefficients on average daily maximum temperature were consistently negative, but varied in magnitude by genetic group. The coefficients from F_1 cross (JxM, AxM and FxM) records were significant, and had a notably higher numerical value than those from Mpwapwa and Backcrosses, which were in addition nonsignificant. It is also notable that the regression coefficients were all negative. Regression on minimum temperature was positive in all but one genetic group, Ayrshire x Mpwapwa. But it was also nonsignificant in all but one genetic group, the Backcross.

The coefficients of regression on total rainfall were positive, except for that from Jersey cross cow records. However, the differences were small, except in the case of Ayrshire crosses, which showed a substantially lower coefficient; and the coefficient was nonsignificant in the Jersey and Ayrshire crosses.

The R-square values showed that the model adopted in this case was more precise in describing variation in 28-day milk yield in Friesian cross and Jersey cross cows than in the other groups. The model accounted for between 80% and 88% of total variation in 28-day milk yield, as shown by the R^2-values.

4.2.4 Differences in 28-day milk yield among genetic groups

Least squares means from the covariance analyses carried out using as independent variables genetic group, period, lactation stage, age of cow, lactation length, previous rainfall, concurrent rainfall, and concurrent THI at 0900 h, THI at 1500 h, maximum temperature, and minimum temperature are listed in Table 13. The least squares means are indicated with results of mean separation carried out by genetic group. Except for the means for JxM and AxM which were similar, all means were different from each other (P<0.05).

Table 13: Least squares means of 28-day milk yield for different genetic groups across lactation stages adjusted for current weather variables and previous rain[1]

Genetic group	Mean 28-day milk yield(kg±S.E.)[2]
Purebred Mpwapwa	123.8[d] ± 0.5
Jersey x Mpwapwa	179.1[b] ± 1.7
Ayrshire x Mpwapwa	175.5[b] ± 1.9
Friesian x Mpwapwa	213.3[a] ± 1.5
Backcross(3/4Mpwapwa)	131.1[c] ± 1.0

[1]Least squares means generated from covariance analyses of 28-day milk yield with genetic group, period of calving, and stage of lactation (class variables) and cow age, lactation length, previous rainfall and concurrent THI(a.m. and p.m.) maximum and minimum temperatures and rainfall (covariates) as independent variables.

[2]Means bearing different superscripts are significantly different from each other ($P<0.05$).

Figures 3 through 6 show the differences between genetic groups in cumulative 28-day total milk yield in each stage of lactation, for the first four lactations from all five genetic groups under study. The data used in making the charts were unadjusted means as recorded in the study.

In Figure 3 all genetic groups displayed lactation curves with similar trends. There was an upward trend in the seventh lactation period in the Ayrshire cross average yield. A reduced slope in the graph from Backcross and Jersey cross records at about the same stage was also notable. The Friesian cross records showed similar first lactation curves with a characteristic rise in production from the first to the second stage of lactation.

The second, third and fourth lactation record averages are summarised in the line charts in Figures 4 through 6. The second and subsequent lactations did not have the characteristic initial rise in milk yield in the second 28-day period, except for that of the Jersey cross cows in the third and fourth lactations(Figures 5 and 6, respectively).

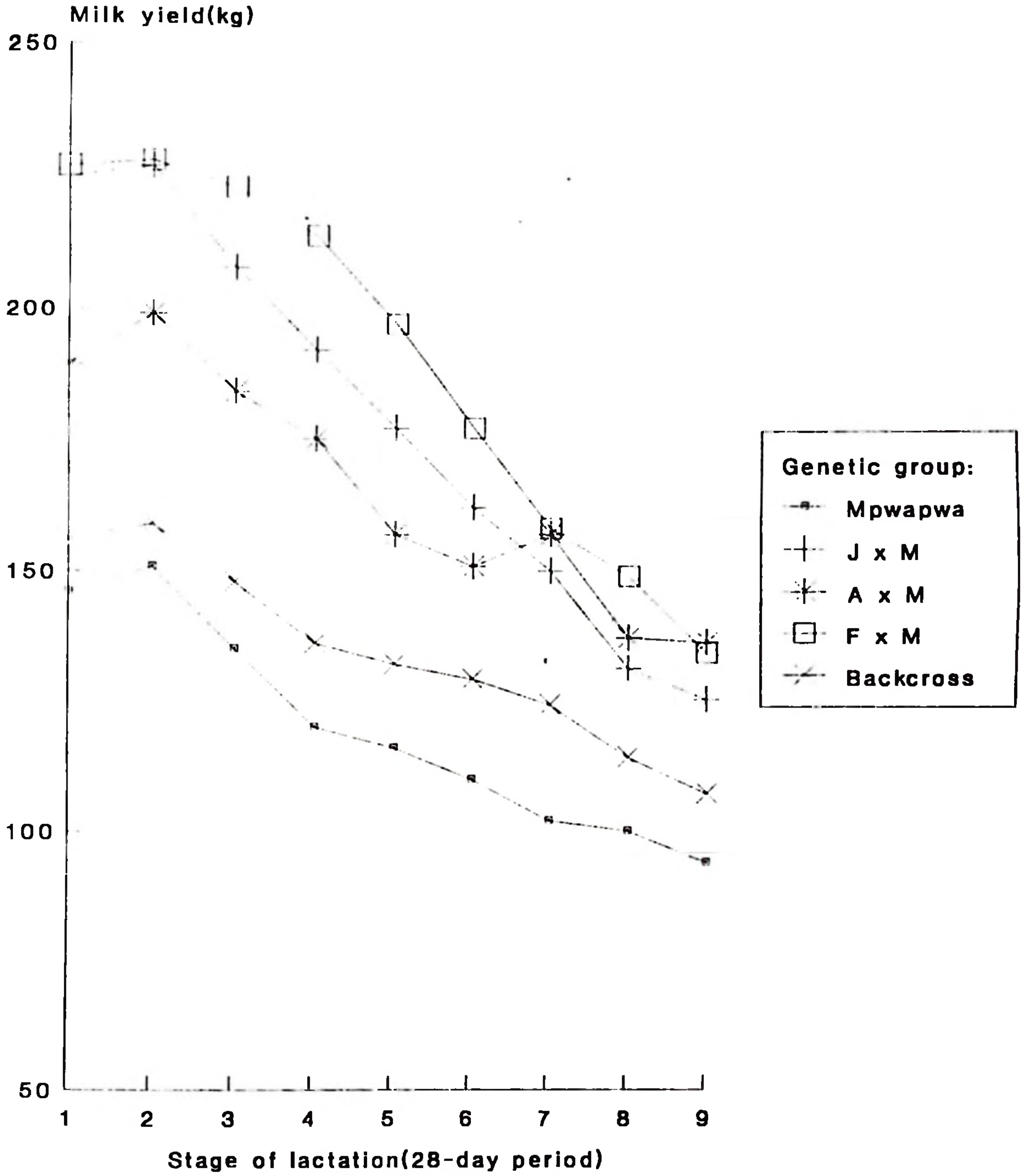


Figure 3: Mean 28-d milk yield at each stage of first lactation for various genetic groups

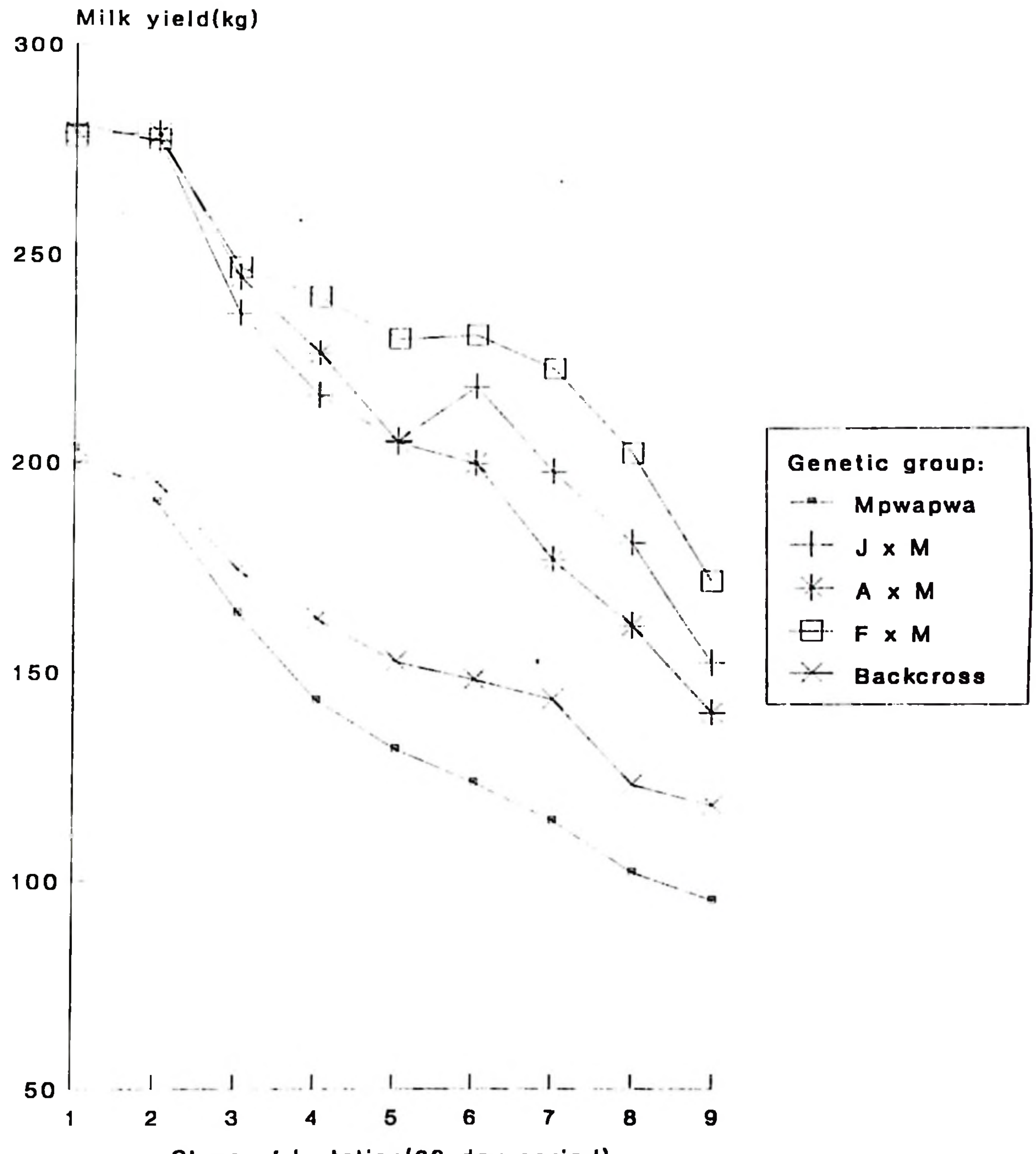


Figure 4: Mean 28-d milk yield at each stage of second lactation for various genetic groups

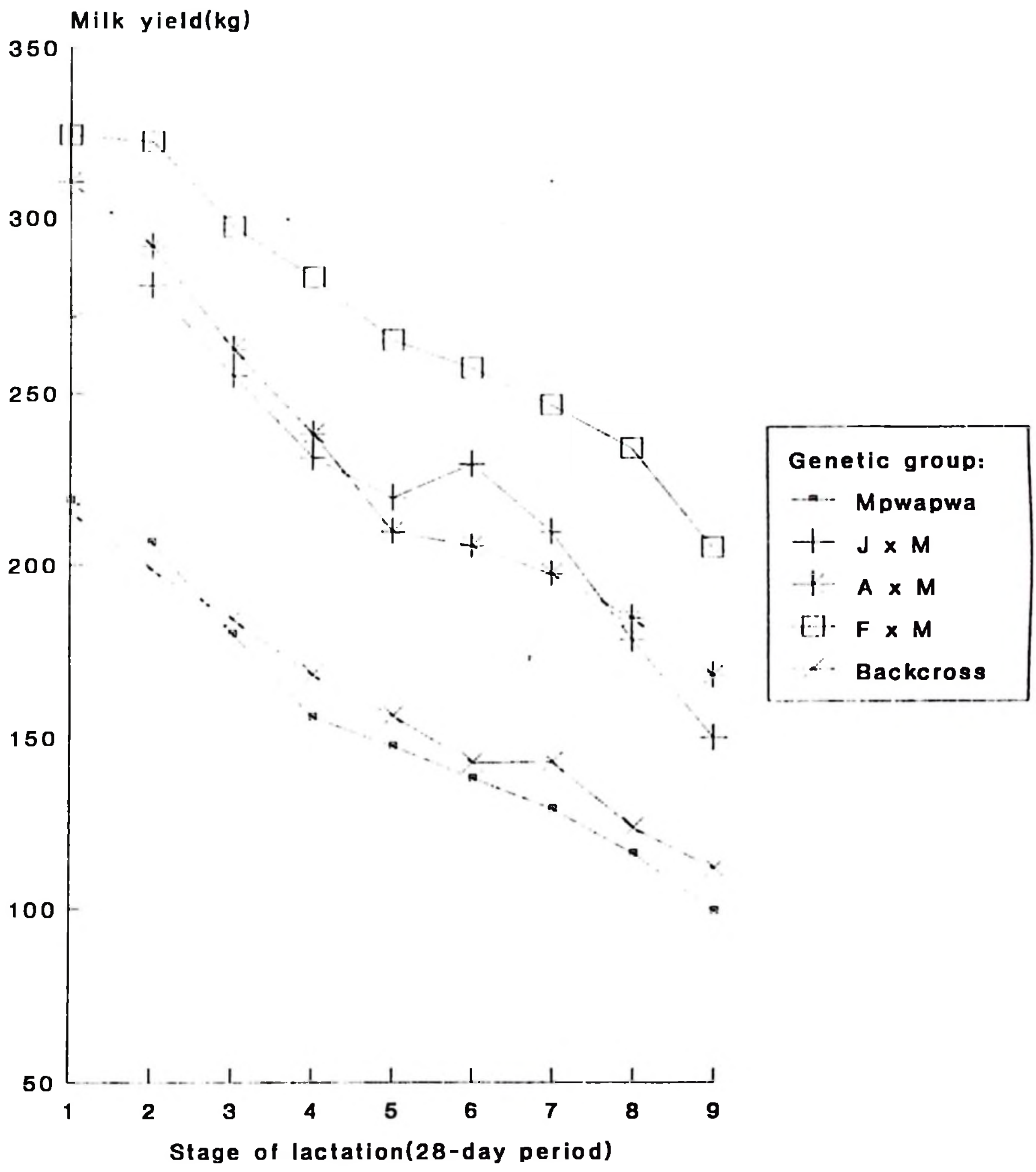


Figure 5: Mean 28-d milk yield at each stage of third lactation for various genetic groups

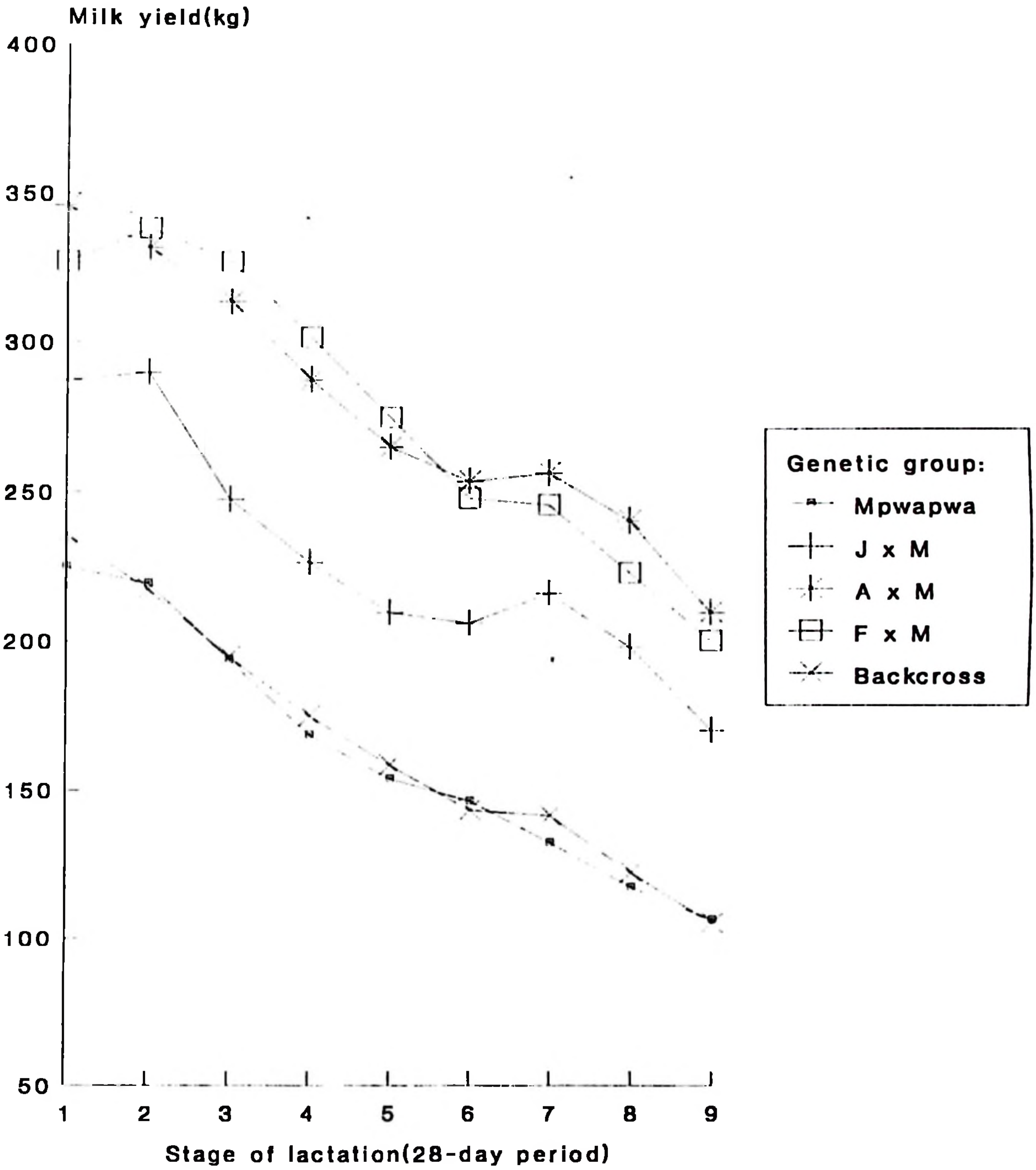


Figure 6: Mean 28-d milk yield at each stage of fourth lactation for various genetic groups

4.3 Supplementary study on milk yield, milk components, and rectal temperature

4.3.1 Daily milk yield

Records of milk from the supplementary study gave indication of level of production of the current herd at the study location. The sections that follow show the average levels of production and the factors that influenced milk yield based on records collected in the study.

4.3.1.1 Sources of variation in afternoon milk yield

Analysis of covariance for data pooled across genetic groups gave the results shown in Table 14. Genetic group and age of cow were significantly related to afternoon milk, but THI was not.

When analyses were carried out for each genetic group separately, age of cow was found to be a source of variation ($P<0.10$) to afternoon milk yield in four out of the five genetic groups. The exception in this respect was the Friesian x Mpwapwa group of cows. Sums of squares and levels of significance from results of the analyses are given in Table 15.

Table 14: Results of covariance analysis of afternoon milk yield showing sums of squares (SS)[1,2] attributed to genetic group, age of cow, and afternoon THI, along with regression coefficients (b).

Term in model[3]	SS	b ± SE
Genetic group(5)	13.36*	na[4]
Age of cow[5]	8.06*	0.00 ± 0.00
THI at recording	0.21^{ns}	-0.02 ± 0.04
Model(df=6)	SS = 22.28	R^2 = 6.68%
Residual(df=250)	SS =310.97	-

*0.01<P<0.05 $\quad$ $^{ns}P \geq 0.10$

[1,2]Type III sums of squares (SAS Institute Inc 1990); detailed model description in Appendix 8.

[3]Number in parentheses shows number of categories.

[4]na = not applicable.

[5]Regression coefficient of afternoon milk yield on age of cow was 0.00015791 ± 0.00006203 before rounding to 2 decimal places.

Table 15: Results of covariance analysis of afternoon milk, showing sums of squares attributed to age of cow and temperature-humidity index for each genetic group[1]

Independent variable	Genetic group				
	Mpwapwa	J x M	A x M	F x M	BCR
Age of cow	3.46^{+}	3.20^{+}	12.20^{***}	0.49^{ns}	8.92^{**}
THIpm	0.63^{ns}	0.26^{ns}	0.96^{ns}	0.98^{ns}	0.29^{ns}
Model(df=2)	3.79	3.78	12.74	2.17	9.43
Residual SS	112.72	42.43	7.50	52.94	71.55
Total SS	116.51	46.21	20.24	55.11	80.98
Residual df	99	40	15	20	68
Model R-square	3.26	8.18	62.94	3.94	11.65

$^{***}P<0.001$ $^{**}0.001<P<0.01$ $^{*}0.01<P<0.05$

$^{+}0.05<P<0.10$ $^{ns}P\geq0.10$

[1]Genetic groups as defined in Chapter 3, except for BCR which stands for Backcross.

Regression coefficients from the regression of afternoon milk yield on age of cow and THI recorded at afternoon milking time are shown in the table in Appendix 3 for the five genetic groups. The regression coefficient on THI at milking was negative in three out of the five cow genetic groups, namely, Mpwapwa, Jersey x Mpwapwa, and Ayrshire x Mpwapwa.

4.3.1.2 Differences in daily milk yield between genetic groups

Milk yield differences between genetic groups revealed by the data collected in the supplementary study showed similar trends as those in the long term data. Mean separation in analysis of covariance of afternoon milk showed that the Friesian cross produced more milk than the other genetic groups except the Ayrshire cross. However, the latter was not significantly different from the other genetic groups.

Figure 7 shows the levels of the unadjusted means of recorded milk yields in the morning, afternoon and total for the day, as obtained from records collected during the supplementary study.

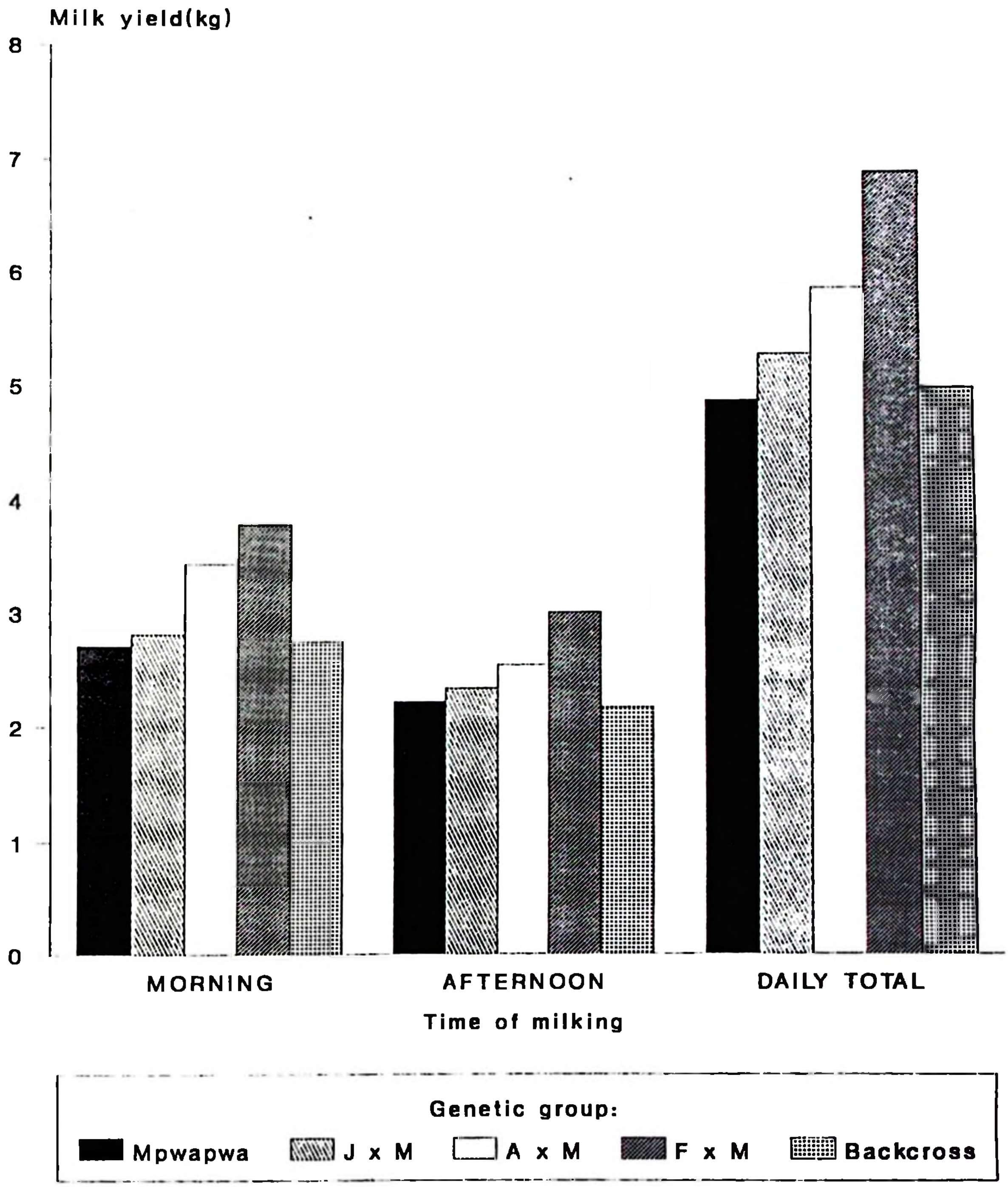


Figure 7: Average daily milk yield by milking time for various genetic groups

The trends shown in Figure 7 placed the Friesian cross cows as the highest producers, followed by the Ayrshire and Jersey cross cows which were not very different from each other. The Mpwapwa and Backcross cows recorded the lowest yields and were close to each other in level of production in this respect.

4.3.2 Milk components yield

The yield of milk components studied differed little between genetic groups. The differences in the milk fat yield, total milk solids and ash yield are presented in another sub-section. In the next section are presented results of analyses carried out on milk composition data, showing the sources of variation.

4.3.2.1 Sources of variation in milk components

Results of regression analyses of yield of milk components using Model 12, are presented in Tables 16, 17, and 18, for fat, ash and total milk solids, respectively. Regression coefficients of the milk components on age of cow and THI recorded in the morning and afternoon of the same day that milk fat was recorded are tabulated as Appendices 4, 5, and 6.

Table 16: Results of regression[1] analysis of the milk fat component, showing sums of squares (SS) attributed to age of cow, and temperature-humidity index for various genetic groups.

Independent variable	Genetic group			
	Mpwapwa	J x M	F x M	Backcross
Age of cow	11009^{ns}	13067*	14718*	414^{ns}
THI at 0900 h	2542^{ns}	9958^{+}	8509^{ns}	760^{ns}
THI at 1500 h	9444^{ns}	18432*	24278*	4063^{ns}
Model SS	22002	31524	40598	5889
Residual SS	130773	1340	25289	71472

$^{*}0.01<p<0.05$ $^{+}0.05<P<0.1$ $^{ns}P\leq0.10$

[1]Based on Model 12 described in detail in Appendix 8; THI = Temperature-humidity index (explained in text); genetic groups described in Chapter 3.

[2]Type III sums of squares (SAS Institute Inc 1990).

Table 17: Results of regression[1] analysis of the milk ash component, showing sums of squares (SS) attributed to age of cow, and temperature-humidity index for various genetic groups

Independent variable	Genetic group			
	Mpwapwa	J x M	F x M	Backcross
Age of cow	250^{ns}	280^{+}	9^{ns}	28^{ns}
THI at 0900 h	82^{ns}	58^{ns}	162^{ns}	3^{ns}
THI at 1500 h	231^{ns}	270^{+}	351^{+}	13^{ns}
Model SS	502	606	365	100
Residual SS	3311	46	790	1150

$^{+}0.05<P<0.1$ $^{ns}P\geq 0.10$

[1]Based on Model 12, as defined in Appendix 8; THI = Temperature-humidity index (explained in text); genetic groups described in Chapter 3.

[2]Type III sums of squares (SAS Institute Inc 1990, p.936).

Table 18: Results of regression[1] analysis of the milk total solids component, showing sums of squares attributed to age of cow, and temperature-humidity index for various genetic groups

Independent variable	Genetic group			
	Mpwapwa	J x M	F x M	Backcross
Age of cow	41068^{ns}	71928*	17244^{ns}	8654^{ns}
THI at 0900 h	57527^{ns}	29025^{+}	18997^{ns}	89^{ns}
THI at 1500 h	103668^{ns}	108017*	116547^{+}	6665^{ns}
Model	146590	197736	168557	31149
Residual	1735251	3761	186153	678576

$^{*}0.01<p<0.05$ $^{+}0.05<P<0.1$ $^{ns}P\geq 0.10$

[1]Based on Model 12, which is described in Appendix 8; THI = Temperature-humidity index (explained in text); genetic groups described in Chapter 3.

[2]Type III sums of squares (SAS Institute Inc 1990, p.936).

4.3.2.2 Differences between genetic groups in milk components

The levels of milk components for each genetic group are presented graphically in Figure 8, based on the unadjusted means obtained from preliminary analyses of the data obtained from the short term study.

The milk components closely followed the same trend as the milk yield variables. The average proportions (%) of milk ash, milk fat and total milk solids components are presented graphically in Appendix 7.

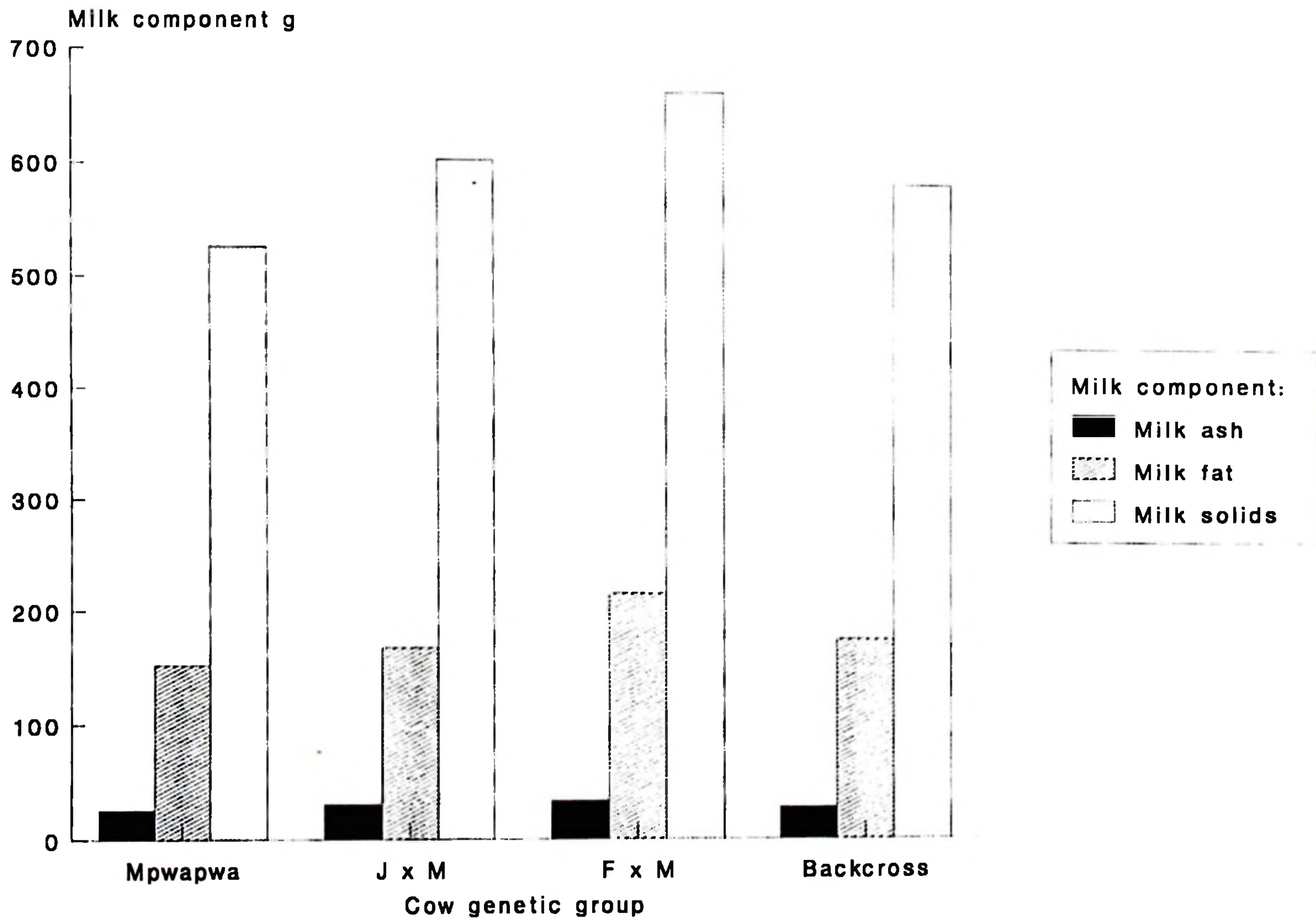


Figure 8: Mean milk ash, fat, and total solids (grammes) by genetic group

4.3.3 Cow rectal temperature

There was little difference in rectal temperature from animal to animal in the data collected during afternoon milking. Variation from one genetic group to another was also little. The levels of rectal temperature by genetic group and contribution of various sources of variation towards the observed variation are shown in the results presented in the subsection that follows.

4.3.3.1 Sources of variation in rectal temperature

Results of covariance analysis of rectal temperature showed that genetic group differences were unimportant to rectal temperature variation. Temperature-humidity index at afternoon milking was an important factor to rectal temperature recorded at that time ($b=0.07\pm0.01$, $P<0.001$). The model adopted for these analyses (Model 9) accounted for 8.59% of total variation in rectal temperature.

Unadjusted mean rectal temperatures are presented in Table 19 for the genetic groups under study. The mean rectal temperatures were similar for all genetic groups.

Table 19: Unadjusted means of cow rectal temperature by genetic group (^{o}C)

Genetic group	n	Rectal temperature (Mean ± SE)
Purebred Mpwapwa	138	38.99 ± 0.04
Jersey x Mpwapwa	55	38.94 ± 0.06
Ayrshire x Mpwapwa	21	38.75 ± 0.10
Friesian x Mpwapwa	30	39.03 ± 0.04
Backcross	95	38.99 ± 0.05

n = group sample size

4.3.4 Association between rectal temperature and milk yield

The results of analyses of covariance carried out on afternoon milk pooled across genetic group and utilising information on cow age and rectal temperature and the dry- and wet-bulb temperatures as terms in the model were as summarised in Table 20. They show the relationship of rectal temperature with milk yield recorded at the same time. The factors of importance to the milk yield were genetic group ($P<0.05$), age of cow ($P<0.01$) and rectal temperature ($P<0.10$). The model accounted for 8.11% of variation in milk yield as indicated by the R-square value.

Table 20: Results of covariance analysis of afternoon milk yield, showing sums of squares (SS)[1,2] attributed to genetic group, age of cow, rectal temperature and afternoon dry- and wet-bulb temperatures, along with respective regression coefficients[3] (b).

Term in model[4]	S S	b ± SE
Genetic group(5)	13.69*	na[5]
Age of cow	9.55**	0.00 ± 0.00
Rectal temperature	3.82+	0.25 ± 0.14
DB temp at recording	0.89ns	-0.04 ± 0.05
WB temp at recording	0.06ns	-0.01 ± 0.05
Model(df=8)	SS = 27.02	R^2 = 8.11%
Residual(df=247)	SS =306.13	-

**0.01<P<0.05 *0.01<P<0.05 +0.05<P<0.10 nsP≥0.10

[1,2]Type III sums of squares (SAS Institute Inc 1990), generated from model described in Appendix 8.

[3]Very small coefficient for age of cow recorded as 0.00 due to rounding for consistency.

[4]Number in parentheses show number of categories.

[5]na = not applicable.

CHAPTER 5

DISCUSSION

5.1 Effect of weather variables

The weather variables whose averages were presented in Chapter 4 clearly showed that the animals had to go through several months of hardship in the year, especially in relation to feed availability and quality due to drought. An added stress from weather variables may have been in the form of temperature and humidity effects or heat stress. The levels of rainfall and temperature realised during the period covered by the study are discussed in the sections that follow.

5.2 Regression of 28-day milk yield on weather variables

From the stepwise regression of 28-day milk yield on weather variables, the single most important weather variable was concurrent wet-bulb temperature recorded in the afternoon. This was followed in importance by minimum temperature. The same was the case on adopting previous weather variables, suggesting that afternoon wet-bulb temperature was the most important single variable overall, in both periods.

Wet-bulb temperature in the afternoon was judged the most important source of variation in cumulative 28-day milk yield on the basis of the number of times it was significantly related to milk yield, considering all stages of lactation. However, the sign of the partial regression coefficient was positive. One would logically expect the relationship of wet-bulb temperature with milk yield to be negative, because it is a function of ambient temperature and relative humidity. The effect of humidity plays a major role in affecting productivity of the animal (Ansell 1976, 1981; Yousef 1985; Berbigier 1991). It is the levels of temperature and humidity together that really count, hence the importance of wet-bulb temperature. The positive regression, however, leaves doubt as to the nature of relationship involved.

Several aspects of the results of the regression analyses raise questions. The regression coefficients, in particular, are startling in some cases. The sign of the partial regression of cumulative 28-day milk yield on wet-bulb temperature in the morning was negative for most stages of lactation, while that in the afternoon was positive. This was true for previous and current weather variables, suggesting that this was a trend, and not a mere chance occurrence. The rest of the coefficients were not as noticeable as this, and showed no trends.

Reasons that may be advanced for the negative relationship of 28-day milk with morning wet-bulb temperature and positive with the same variable in the afternoon would be largely speculative. It would be logical to imagine that if the morning wet-bulb temperature was high, this would be indicative of a high ambient temperature and or high ambient humidity. These would be conditions that would affect the day's milk yield negatively. No definite reason could be advanced to explain why the average afternoon wet-bulb temperature was positively related to milk yield.

Some aspects of the environment which were not addressed in the present study could possibly explain the apparent discrepancy. Such factors as disease and disease causing agents could fluctuate with weather and hence cause a distortion of the picture expected in the effect of weather variables on milk yield. In addition, changes in the population of biting insects and ticks with changing climatic conditions could also get into the picture and distort the expected direct effect of weather variables on milk yield. Since such aspects were not part of the study, one cannot be sure if indeed they were involved.

From the understanding of the diurnal changes in temperature, hot humid conditions in the afternoon would be followed by comparatively cool nights. This would partly reduce the negative influence of heat stress on milk yield, likely to be caused by high afternoon wet-bulb temperature. If any influence of this cooling was to affect milk yield, it would be expected to show its influence in the next day's milking. The cooling and a resultant additional night time grazing would reduce the bad effect of a previous stressful afternoon. But it is likely that this would cancel out only part of the bad effect of the afternoon stress. It is hard to speculate on the effect being strong enough to reverse the sign of the regression, to lead to a positive relationship as was found in the current study.

5.2.1 Rainfall

The rainfall pattern reported over the study period (Figure 1) left no doubt that there was a dry season between June and September of most years. Rain often stops around mid-May or soon thereafter, and the period from then to early November is completely dry (LPRI 1984). In some years there are only showers in December and January. Rain of any noticeable impact is not received until late February in such years, and cattle live on standing hay and cattle live on standing hay whose quality and quantity deteriorate fast with advance of the dry season.

Humidity in the dry months of the year may be low, hence ameliorating the effect of heat stress on animal productivity. However, the effect of weather conditions on feed availability in these dry months may be very serious. The necessity of supplementary feeding is imminent in these periods. The implication of this in the light of livestock farming and the economic base of the livestock keepers in the semi-arid zone of Central Tanzania need not be overemphasised. In the dry months, even organised livestock keepers like the institute where the present study was carried out, find it difficult to satisfy the requirements of their animals. Weight losses are always experienced.

5.2.2 Temperatures

The mean temperature conditions presented in Chapter 4 (Table 1), left an impression that there were times when heat stress was an issue to be considered seriously. The average monthly temperatures reported suggest that THI values were often above the critical levels for optimal dairy cattle performance (McDowell 1972; Hahn 1976; Yousef 1985a). On invoking the formula used by Kibler(1964), figures in Table 1 showed that the average daily THI at 0900 h was 68.5, while afternoon THI, at 1500 h, worked out to be 74.1.

Findings reported in the literature show that if THI fell below 70, then it would have no serious effect on milk yield (McDowell 1972). The level of THI represented by the mean daily values of dry- and wet-bulb temperatures in the afternoon in the present study was therefore in the range known to cause lowered voluntary feed intake and reduced milk yield (McDowell 1972; Yousef 1985). By the same argument conditions in the morning would have been expected not to pose serious bad effect on milk yield. This strengthens the suggestion that a different factor not pursued by the present study may have been involved.

The average dry-bulb temperature in the afternoon was found to be 26.5^{o}C, which is itself outside the thermoneutral zone for dairy cows suggested by Yousef(1985b) to be 0^{o}C to 16^{o}C. It is slightly beyond the acceptable range of 4^{o}C to 24^{o}C, for optimum temperature recommended for dairy cows (Hahn 1976; Yousef 1985a). It was however, just below the upper critical temperature for those cows with potential for producing up to 10 kg per day, which has been estimated at about 27^{o}C (Yousef 1985). This was the level of most cows in the herd under study.

Serious effects of these temperature conditions would therefore not be expected except for some of the cows. The average cow would however be expected not to be seriously affected.

The foregoing applies to the average year in the analyses. It must be recalled that actual temperatures would have at times been much higher and therefore much more stressful to the cows. At other times it must have been cooler and therefore had the opposite effect. It is the difference from these two extremes which would determine the level of stress of the environment. The actual situation cannot be known for sure from information obtained in the analyses of the present study.

5.3 Non-weather variables

Some non-climate variables were included in the covariance analyses to increase precision. Their influence on the response variables is discussed in the following subsections on the basis of results of covariance analyses carried out adopting the various models described in Chapter 3.

Results from GLM covariance analyses across genetic groups that were summarised in Chapter 4, suggested that, among the non-climate factors, previous milk yield, lactation stage, lactation length, genetic group, and year of calving were significant sources of variation and, for precision, need to be considered in the evaluation of factors on 28-day milk yield. These results further showed that, although it may be expected that milk yield varies with lactation number, this need not be adjusted for after correcting for age of cow.

5.3.1 Year or period of calving

The effect of year of calving was found to be significant in all the analyses of covariance in which it was considered, showing that it was necessary to adjust for year effects in assessing the influence of other factors. Year of calving effects may be explained by management related factors as well as climatic effects.

The effect of year was also reported by other authors working with similar type of animals in Tanzania. Msechu and Mkonyi (1984) reported similar significant year effects in a study on sources of variation in the performance of dairy cattle in two research herds. Mchau (1988) reported highly significant year effects on milk production in Mpwapwa cows. The present results were also in agreement with those of Mchau and Syrstad (1991), again with Mpwapwa cows. Kiwuwa (1974) also reported year effects on the milk yield of Friesian and Jersey cows in privately owned herds in Kenya.

Udo (1992), working on records from crossbred cows in the Mpwapwa herd also reported significant year of calving effects on milk yield. He attributed the year of calving effect to inconsistent management practices and fluctuation in rainfall pattern. The same may be speculated as causes of the influence of year in the present study, but not without reservation.

In the present study, since the effect of year of calving was significant over and above the effects of climatic variables, the major aspect not accounted for would be management, including financial constraints and consequent reduced feed supply. Supply of feed or factors related to nutrition may have a direct effect on milk yield. For example, when there was shortage of funds, the feeding of the cows may have suffered and, in turn, affected the level of milk yield. Such factors would invariably affect the cumulative 28-day milk yield at any stage.

The significant effect of period in the analyses in which period was adopted instead of year of calving would largely be explained by the same arguments as those advanced in the foregoing. The only difference in this case would be the fact that period would tend to be less variable as it covers several years, in this case five years. It would not matter whether year or period were the criterion used in the case of the present study as the results were the same. Only if ease of computation is required would there be an advantage of adopting period in this case, because it had fewer categories.

5.3.2 Genetic group

The effect of genetic group was significant in all analyses carried out, implying that there were important differences between the genetic groups under study. Differences due to genetic group are undoubtedly due to the inherent animal differences by genetic group. These suggest that the different genetic groups in the herd should be considered samples from different populations in this respect.

The findings support those reported by Msechu and Mkonyi (1984) on similar crossbred cattle in two research herds in Tanzania. In the present study, mean separation in all analyses showed that Jersey and Ayrshire crosses used in the study did not differ significantly, while the rest of the differences between genetic groups were significant.

5.3.3 Age of cow

The effect of age of cow and that of parity or lactation number cannot be separated because of their nature. It was no surprise therefore when both were nonsignificant when included together in the covariance analysis model. When either was excluded the other assumed more importance, but age had more influence and was retained in all analyses. As a cow gets older, from first lactation on, it is known that her milk yield increases (Schmidt and van Vleck 1974). In the present study age was significant in two of the analyses in which it was included without including parity with which it bore relationship.

The influence of age may have different facets. First the young animal has to partition her feed into growth requirements and lactation requirements. This would place her at a disadvantage in terms of milk yield. Therefore, as the requirements for growth become less, more of the feed goes to support milk production. This would mean that, until maturity, the trend would be for milk yield to increase with age. Also, with increase in age the function of the udder to produce milk is enhanced due to development which is, between specific limits, a function of age.

5.3.4 Stage of lactation

The stage of lactation effect was significant in all analyses and contributed a high proportion of the sums of squares in the analyses, leaving an impression that it was a vital consideration.

Stage of lactation would be expected to be associated with level of the milk yield because of the nature of lactation curve and factors influencing it (Wood 1969; Mchau 1991). It was therefore not unexpected, that the effect of stage of lactation was significant in all genetic groups. These results confirmed the presumption that in the study of cumulative 28-day milk yield, stage at which milk was collected must be considered. Level of milk yield is closely related to stage of lactation and stage yield is, in turn, known to be related to total lactation yield(Miller *et al.* 1972).

5.3.5 Lactation length

Lactation length was previously found to be associated with milk yield in Mpwapwa cattle and their crosses (unpublished results of analyses carried out by the author in 1985). The major cause of low yields was the premature drying-up of cows due to nutritional inadequacies and possibly due to failure of cows to let down milk because of inappropriate milking procedure. It is known that zebu cows also fail to let down milk without the presence of their calves (McDowell 1972). This may have played part in influencing the duration of lactation, although it has not been investigated with the Mpwapwa breed cows. The significant influence of lactation length may be explained by the same phenomena.

5.3.6 Previous milk yield

Level of milk previous to the 28-day milk yield analysed was significantly related to the subsequent milk yield used as the response variable. This significant relationship is explained by the fact that both were part of the same lactation and were therefore strongly related through their common relationship to lactation yield.

It would be expected that previous milk yield would also have some indirect relationship with some weather variables through the relationship with current milk yield, which is presumed to be related to the weather variables in question. This may be the reason why some relationships between some weather variables and concurrent milk yield changed in magnitude and sometimes also in sign when previous milk was excluded from the model (see Table 10). The weather variables in question were THI in the morning and afternoon, maximum temperature, and previous rainfall.

5.4 Reaction of various genetic groups to weather variables

The influence of genetic group on milk yield was evident from the analyses discussed in the previous section. A brief discussion on the results shows some of the differences among genetic groups on the basis of the covariance analyses of data pooled across genetic groups. Comments are also made on differences shown by the lactation curves from the data used in the study.

5.4.1 Variation in 28-day milk yield

The contribution of various climatic and non-climate factors to variation in milk yield characteristics of the various genetic groups under study summarised in Chapter 4 indicate that a major part of the variation was accounted for by those factors included in the models adopted for covariance analyses.

The changes in the level of milk yield in each of the stages of lactation depicted by Figure 3 gave the picture of a standard lactation (Wood 1969), except for a few notable differences. The lower producing genetic groups (purebred Mpwapwa and Backcross) displayed the characteristics expected of lactation curves. The other genetic groups had curves with notable departures from those normally expected. The sudden upward change at the seventh stage of lactation in the graph from Ayrshire cross records was unexplainable as there were no known factors in the biological situation to support it. Nor were there obvious technical reasons to explain it.

The differences between genetic groups in lactation curve for first lactation suggest that the Mpwapwa and Backcross genetic groups were not influenced by whatever factor influenced the other genetic groups to make their lactation curves atypical. It may be speculated that since their production level was much lower, then nutritional demands may have been either satisfied or nearly met by the feeding regime, which may have been inadequate for the other groups. Another reason that may explain part of the difference between the low producing groups and the higher producing ones is the fact that as soon as lactations ended the stage milk yield included zero values by default for the remaining part of the 28-

day period, but not for the whole lactation. More such short lactations will have been experienced by the lower producers because they dry up relatively earlier as reported by Mkonyi (1982).

Subsequent lactation curves depicted by Figures 4 - 6 did not follow the same trends as in the earlier lactations for any of the genetic groups. It may be speculated that, the increased milk yield for the Mpwapwa and Backcross groups may have meant that for them too the feeding regime was inadequate (cf first lactation). This would explain why all of the genetic groups depicted curves that differed widely from the normal curves of lactation as explained by Wood (1969). The flatter milk yield curves for the Mpwapwa and backcross may be because of their premature drying up and the exclusion of zero values as stated earlier.

In addition to the influence of THI that was found in stepwise regression analyses on weather variables, the regression coefficient of milk yield on THI was found to be significant in the case of analyses where adjustment was made for non-climate variables. However, it appeared from the results of the present study that THI recorded at 0900 h was a more important factor on 28-day milk yield than that recorded at 1500 h, if only level of significance is considered. There was no obvious explanation why THI in the morning was more prominent. The signs on regression coefficients on THI were erratic, but in many cases positive for THI records obtained in the afternoon and negative for those obtained in the morning. This was difficult to explain.

The fact that the effect of THI varied from one genetic group to another in magnitude and sign may suggest that there may have been differences between genetic groups in reacting to THI level. However, in some cases regression on wet-bulb temperature was different in sign from that on dry-bulb temperature in the regression results. For this reason it was difficult to justify the combining of the two weather variables in an additive index, such as THI. This may have been responsible for the inexplicable results.

It has been established through research work elsewhere that the milk yield of zebu cattle, presumed to be more adapted to hot conditions, is affected to a lesser extent by heat stress, while *Bos taurus* dairy cattle are more vulnerable(Berbigier 1991). The crosses between the two extremes would be expected to have intermediate characteristics in this respect. The results of the present study do indicate marginally more response of the less zebu genetic groups, but the sign on the regression coefficients were in many cases the opposite of what would have been expected. This confused the picture and obscured the real nature of relationship involved.

The differences between the genetic groups in regression of milk yield on THI were in most cases marginal (as depicted by Tables 12 and 13). This implies close similarity between the ~~the~~ genetic groups in this respect. And, due to the obscure nature of actual relationships involved, no conclusive inferences may be justifiable from the current results.

The regression of milk yield on maximum temperature was negative for all genetic groups(Table 12), suggesting consistency in the influence that would be expected with temperature after correcting for the other factors. However, the results from pooled data across genetic groups (Table 6), had given the impression that maximum temperature had a positive relationship with milk yield. This contradiction leaves scope for doubting, and raises questions that are not answerable within the current study. The F_1 crosses were more sensitive to maximum temperature than contemporary purebred and 3/4 Mpwapwa, judging from magnitude and significance of regression coefficients shown in Table 12.

Regression of milk yield on minimum temperature was significantly different from zero in the case of Backcross cows only (P<0.05). There was no evidence of noticeable differences between genetic groups in their reaction to minimum temperature.

Regression of milk yield on total rainfall suggested an increase in milk yield with increased rainfall in Mpwapwa, Friesian cross and Backcross cows, but not in the other two genetic groups. Rainfall has two possible influences in respect to heat stress and cattle productivity. First, there is the imperative immediate effect of cooling the animal on wetting its surface followed by evaporative heat transfer. Then, there is a long term effect through feed availability via effects on pasture growth. As to the differences between genetic groups, two aspects were noteworthy. First, the results would leave the impression that cows in different genetic groups reacted differently to the effect of rainfall. With the exception of the nonsignificant effect of rainfall in Jersey and Ayrshire crosses, the effect of rainfall on milk yield was significant.

The slightly lower R-square value obtained from all the analyses of records from Backcross cows compared to other groups suggested a possible trend, but the amount of variation acounted for by terms in the model did not differ much between genetic groups. The R^2-values varied from 80% to 88%, depending on genetic group.

5.4.2 Daily milk yield

Trends depicted by Figure 5 were similar to those discussed in the preceding section in many respects. However, factors envisaged to contribute to variation in daily milk records under study may be slightly different.

The influence of genetic group and age of cow reflected in the covariance analyses of afternoon milk (Table 14) may be explained as was the case for the cumulative 28-day milk yield in the previous section. It would appear that these confirm the idea that the genetic groups have inherent differences in milk production potential, with the exception that Jersey crosses and Ayrshire crosses were not significantly different.

When rectal temperature was included in the covariance analysis model, dry- and wet-bulb temperature influences were nonsignificant, suggesting that having adjusted for rectal temperature, the influence of the weather variables on daily milk yield was unimportant. This, by implication, supports the view that the two temperatures were factors determining the level of rectal temperature.

The regression coefficients of afternoon milk on age of cow and THI recorded at afternoon milking did not suggest any consistent trends. It would have been expected that a negative sign would be realised for all regression coefficients of milk yield on THI, but only in three out of the five genetic groups was this the case. No definite reason may be advanced for this, but since the regression was not significant in this case, then chance effects may be assumed.

5.4.3 Milk components

The variation of yields of milk components that was found to follow a similar trend to milk yield may be explained by the fact that the proportions of the milk components by weight did not differ substantially between genetic groups. The results were based on limited sample sizes due to non-availability of F_1 cows in lactation in the genetic groups in question at the time of data collection. The A x M group did not have any cows in milk when records were collected for this part of the study.

The limitation of sample size dictates that conclusions need to be drawn cautiously and that the results should logically be treated as tentative trends, except where strongly backed by information from other studies. Large R-squared values were realised largely because of small samples.

5.4.3.1 Sources of variation in milk fat

Regression of milk fat on age of cow and THI on sampling day, suggested that the two independent variables were important in the case of F_1 cows only. Due to the significant effect of THI at 1500 h on J x M and F x M and not Mpwapwa and Backcross, it would appear that the latter two reacted differently to THI, presumably due to their higher proportion of zebu blood.

The consistently negative regression coefficient of milk fat on THI at 1500 h in all genetic groups suggested that there may have been a definite trend for milk fat to decrease with increasing THI recorded at 1500 h. This appears to be in agreement with results reported in the literature, where it was shown that fat secretion decreased under heat stress (Gordon 1985). Reaction to THI at 0900 h was small and inconsistent, implying that it was not important as a factor on the afternoon milk fat yield.

The apparent influence of age of cow on milk fat in the two F_1 cow groups and not in the Mpwapwa or Backcross groups does not appear to have any explicit explanation as it was inconsistent in sign. It may be that, by chance the ages of the cows in the two groups were such that they appeared to have a significant effect. Nevertheless, the negative regression coefficient of milk fat on age of cow in the J x M cow group was in agreement with what has sometimes been reported, that there is a slight decrease in fat and non-fat solids with age (Schmidt and van Vleck 1974); but research reports on the subject have not been consistent. The results in the case of the F x M cow records gave the opposite impression and may be explained by chance effects.

5.4.3.2 Sources of variation in milk ash

Milk ash yield analyses showed less definite trends as the regression coefficients only approached significance on THI at 1500 h in J x M and F x M ($P<0.10$). Regression of ash on age of cow was generally unimportant, except in the case of J x M ($P<0.10$). The negative sign of regression of milk ash on THI at 1500 h in all genetic groups is suggestive of a trend of the ash to decrease with increasing afternoon THI. These results may be viewed as being similar to those that have been reported from studies on the influence of heat stress on milk minerals (Thompson 1985; Richardson 1961). Regression of milk ash yield on THI at 0900 h was nonsignificant for all genetic groups, implying that it was not an important source of variation in milk ash. This may be because the level of THI at that time of the day was not high enough to be of any consequence on the mineral content of milk.

5.4.3.3 Sources of variation in total milk solids

The regression coefficients of the yield of total milk solids on age of cow and THI showed similar trends as those obtained for milk fat, with only one exception. The exception was that results of analyses of milk fat suggested existence of a positive relationship with age of cow in the F x M cow group($P<0.05$), whereas this was not found to be the case for total milk solids. The similarities in the behaviours of milk fat and total solids components would be expected if fat was one of the major milk solids. The fact that fat and total solids are "part" and "whole", would mean that there may have existed a strong part-whole relationship (Wood 1970), hence similarity in the results.

The consistently negative sign in the regression of total milk solids on THI at 1500 h (see table in Appendix 6) would be largely explained by similar phenomena as suggested and discussed under milk fat. It is imperative that if the solids forming the major proportion of total milk components decrease under heat stress, then total solids would be expected to do likewise. In fact it has been reported in the literature that milk fat, protein, lactose, citric acid, calcium, and potassium tend to decrease during heat stress (Gordon 1985). These form the major part of milk solids; and this would explain the fact that total milk solids decreased with increasing THI, which is an index for heat stress.

5.4.4 Rectal temperature

Differences in rectal temperature were found to be small between genetic groups, suggesting that rectal temperature is a stable variable for cattle of varying genetic backgrounds. Regression of rectal temperature on cow age showed that there was a slight increase in rectal temperature with increasing age ($P<0.10$).

A positive relationship between rectal temperature and THI was revealed by the regression of the former on the latter ($P<0.001$). This was in agreement with a well established effect of heat stress on rectal temperature (Yousef 1985a; Johnson 1987). The temperature and relative humidity levels in the study site appear to have been severe enough at the time of afternoon milking to cause a rise in rectal temperature. This would, in turn, be suggestive of the possibility of existence of an effect on the milk yield recorded at the same time. This was, however, not the case.

The fact that afternoon milk recorded at same time as the rectal temperature was not influenced by THI recorded at that time reflects a view that the temperature and humidity conditions were harsh enough to influence rectal temperature but not milk yield. This is in close agreement with the well established fact that rectal temperature is the most sensitive measurable response variable under heat stress in cattle (Bianca 1962; Yousef 1985a; Johnson 1987a). It supports the views expressed by Berbigier (1991), that for evaluating the influence of temperature and humidity on milk yield and or feed intake it would be appropriate to use daily average THI values as the indicator of stress, while in the case where the response variable is a physiological variable (such as rectal temperature) hourly average THI values would be recommended.

The amount of variation in rectal temperature accounted for by age of cow and THI was barely 8.11% of total variation. This implies that only a small proportion of the total variation in rectal temperature was covered by the sources of variation used in building up the model adopted for the analyses. Therefore, much of the variation must have been from unknown factors. It was hard to speculate on other sources of variation in the biological situation. Errors in taking the measurements may partly account for the unknown sources, because the instrument used lacked precision.

5.5 Genetic group differences and relative merit

The variation of cumulative 28-day milk yield by genetic group was found to suggest that the F x M cows produced higher yields than any other group. This would mean that in respect to milk production this would be the genetic group of choice. The relative position of the genetic group is the same as that reported by Udo(1992) in a comparative study of lactation yields of similar animals from the Mpwapwa herd.

The J x M and A x M cows were next in ranking on the level of cumulative 28-day milk yield. They were not appreciably different between themselves in this respect ($P>0.10$). The possible reasoning that the A x M cow group would be expected to produce more milk due to the usually relative superior parental sire breed in milk production is not supported by the results of the present study. The results of the current study would suggest that the J x M genetic group may be placed next to the F x M genetic group in merit in terms of cumulative 28-day milk yield.

The superiority of the Jersey crosses was inferred principally due to their not differing appreciably from Ayrshire crosses in milk yield after adjusting for various environmental factors, despite their smaller size. Their smaller size implies that they would need less feed for the same level of production as the A x M, and hence be preferred. In addition, the latter appeared to be more vulnerable to heat stress. Previous studies have shown that tendency has been for the Jersey or Jersey cross to compete and at times outyield the Ayrshire or Ayrshire cross in many cases where the two have been assessed under similar conditions in Tanzania (Bruhn and Mgheni 1977; Shekimweri 1982; Kifaro 1984).

The Mpwapwa and Backcross groups were lowest in the ranking list in respect to the cumulative 28-day milk yield. The differences between the two with regard to this criterion were marginal, but important($P<0.05$). The Backcross has previously been reported to be slightly superior to the Mpwapwa in size(Msanga 1984) and milk yield (Mkonyi 1982; Udo 1992).

With regard to daily milk yields on the basis of the results of the short term study of afternoon milk, the impression is the same as that given under the discussion of the results from analyses of cumulative 28-day milk yield. The same ranking order was found to exist.

In terms of milk composition there was more influence of weather variables on the yield of milk components from the F_1 crosses than the higher zebu-component genetic groups, placing the latter in better ranking if decision were to be based on that. However, for as long as milk quality is not the basis for pricing or for any other economic reason, this influence would have little bearing on determining the relative merits of the genetic groups.

The results of the analyses of rectal temperature did not suggest any superiority differences to be of consequence in comparing the genetic groups. Differences in rectal temperature *per se* could not in any case have been enough ground for preferential consideration of superiority of genetic groups. The critical evaluation should therefore be based on the level of production, as recommended McDowell (1972), and not on the physiological responses only.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1. Influence of weather variables on cow variables

Results in the current study have indicated that prevailing average temperatures were high enough to be expected to affect milk yield in dairy cows. The influence of temperatures or temperature-humidity index did not show a distinct trend to allow for any definite conclusions. It depended largely on whether adjustment was made for non-climate factors, such as previous level of milk yield, stage of lactation and age of cow. The influence was, in addition erratic, in that the relationship with milk yield was at times positive where it would have been theoretically expected to be negative.

For data unadjusted for non-climate variables milk yield was influenced by average daily wet-bulb temperature at 1500 h and minimum temperature in most stages of lactation. But for data adjusted for year of calving, age of cow, lactation stage, lactation length and level of previous yield, the major effects were those of the non-climate independent variables. Although in a few cases weather variables approached significance the amount of variation accounted for by individual weather variables were negligible.

The inclusion of previous milk as a covariate (without including previous weather variables) might have confused the interpretation of the results. It is therefore suggested that conclusions be based mainly on the analyses where previous milk was not considered, i.e. Table 3, Table 4 and Table 10 in Chapter 4. These results are consistent in indicating that milk yield is negatively influenced by high morning temperatures (dry- and wet-bulb), but positively influenced by high minimum temperatures, and high afternoon wet-bulb temperatures. Yield is also positively influenced by high rainfall, both concurrent and previous.

The effect of THI on daily milk yield was negligible but followed similar trend to that on cumulative 28-day total yield. Influence of weather variables on milk composition was significant with the F_1 cow records, but the results were considered inconclusive because of inconsistent trends which were attributed to effects of chance due to small sample sizes. The tentative conclusion drawn was that there was a decrease in the yield of milk fat and total solids with increasing THI, and a less definite similar trend in the case of milk ash.

Cow rectal temperature recorded at afternoon milking increased with increasing THI recorded at the same time. It was concluded that the weather conditions represented by the THI at afternoon milking (ca. 1500 h) were harsh enough to reflect in a rise in rectal temperature, but not in changes in milk yield recorded at the same time.

6.1.2. Relative merit of cow genetic groups

From the discussion in Chapter 5 the Friesian cross genetic group may be judged to be the best in milk production after adjusting records for the various climatic and other environmental factors. This is followed by the Jersey cross, the Ayrshire cross, the Backcross and the purebred Mpwapwa, in that ranking order. This conclusion, based on the results of the current study, would need validation through studies on the nature of the relationship of milk yield and weather variables which was obscure in the current results. Further validation is also required through study of survival and reproductive performance of the genetic groups, and the economics of production.

6.2 Recommendations

6.2.1 Proposed strategy for future breeding work

The current breeding strategy in the Mpwapwa breed development programme was put together a few years ago on the basis of the then available breeding material, knowledge of performance of the genetic groups, and presumed relative adaptation of the genetic groups to the semi-arid environment for which the Mpwapwa was intended. Some of the assumptions made then no longer need to be made as some knowledge has emerged from the results of recent studies and from the current study. It appears to be unjustifiable that the Backcross was chosen as the basis for future breed development work in view of the close similarity of that group to the purebred Mpwapwa.

The reaction of the F_1 crosses to environmental stress suggested by the current study did not place them in a comparatively worse position, in terms of milk yield, than the other genetic groups containing more zebu blood. Even after adjusting the production records for all known and presumed sources of a variation, the Friesian cross appeared to be by far the best of them all. Unless this genetic group is objectively proven to be worse for other reasons, it should be recommended as the crossbred type upon which future breeding work should be based.

The limitation of using the Friesian cross, apparently due to its presumed relative disadvantage in reacting to the stress of the environment was unjustifiable. All the genetic groups would be expected to express their potential in the intended environment if given a minimum of the extra care required for milking animals. Based on the information from the current study, it is recommended that a change be introduced in the programme to take advantage of the superior potential of the Friesian or Jersey cross in improving milk production in the intended dual-purpose animal for the semi-arid environment of Central Tanzania.

6.2.2 Proposed future research

There are several limitations in the adoption of some of the recommendations from the current study that require attention in future research efforts. First, it was difficult to draw definite inferences on the reactions of the F_1 cows in terms of the yields of milk components because of limited numbers of observations, and inability to include some milk solids in the study. Secondly, the nature of relationship between milk yield and weather variables was in some cases inconsistent with theory.

Future work is recommended in view of the limitations. Such work may be superimposed onto the ongoing research activities with little extra effort. Monthly recording of all possible milk components may be initiated for all lactating animals with a view to future evaluation of the various genetic groups in the herd on yield of milk solids. Secondly, in view of the superiority ranking suggested by the results of the current study being in conflict with the current breeding strategy, it is recommended that some research effort be directed towards evaluating the genetic groups on aspects not covered in the present study. Studies on viability and reproductive performance should be carried out. Other work should be done to answer questions relating specifically to the economics of production systems based on these types of animals under the socioeconomic circumstances of the target farming community.

REFERENCES

Ansell, R.H. 1976. Maintaining European dairy cattle in the Near East. *World Animal Review, 20*: 1-7.

Ansell, R.H. 1981. Extreme heat stress in dairy cattle and its alleviation: a case study. In: *Aspects of housing for animal production*, by Clark, J.A. (editor); Butterworths, London. pp.285-306.

Bartholomew, G.A. 1982. Body temperature and energy metabolism. In: *Animal physiology and adaptations, 4th Edition*, by Gordon, M.S; Bartholomew, G.A; Grinnel, A.D.; Jorgensen, C.B.; and White, F.N. (editors); Macmillan Publishing Company, New York, USA.

Bath, D.L.; Dickinson, F.N.; Tucker, H.A.; and Appleman, R.D. 1985. Factors affecting composition and yield of milk. In: *Dairy cattle: Principles, Practices, Problems, Profits, 3rd Edition*, Lea and Febiger, Philadelphia, USA; pp. 298-304.

Bayer, von W.; Hippen, H.; Steinhauf, D.; and Weniger, J.H. 1980. Some effects of high ambient temperature and different levels of relative humidity on thermoregulation and performance traits of lactating cows. *Zeitschr Tierzuchtung Zuchtungsbiol, 97*: 9-20.

Berbigier, P. 1988. Bioclimatologie des ruminants domestiques en zone tropicale. INRA Publication, Versailles. 237pp.

Berbigier, P. 1991. Productive responses of ruminants under high temperature conditions. *Proceedings of the International Symposium on Animal Husbandry in Warm Climates*; Veterbo, Italy, 25 - 27 October, 1990. EAAP Publication No. 55, Pudoc Publications, Wageningen, Netherlands.

Bianca, W. 1961. Heat tolerance - its concept , measurement, and dependence on modifying factors. *International Journal of Biometeorology, 5*: 5-30.

Bianca, W. 1962. Relative importance of dry- and wet-bulb temperatures in causing heat stress in cattle. *Nature, 195*: 251-252.

Bianca, W. 1968. Thermoregulation. In: *Adaptation of farm animals* by Hafez E.S.E., Ed; Lea and Febiger, USA.

Bianca, W. 1976. The significance of meteorology in Animal Production. *International Journal of Biometeorology, 20*:139-156

Blaxter, K.L. 1967. *The energy metabolism of ruminants.* Hutchison, London.

Brody, S. 1948. Environmental physiology and shelter engineering. Physiological backgrounds. *Missouri Agricultural Experiment Station, Bulletin No 423*. 53pp.

Bruhn K. and Mgheni M. 1977. Dairy production under Morogoro conditions. *Proceedings of Tanzania Society of Animal Production (TSAP), 4:* 242-258.

Cargil, B.F.; Stewart, R.E.; and Johnson, H.D. 1962. Environmental physiology and shelter engineering, with special reference to domestic animals. LXII Effect of humidity

Das, S.S.M. 1988. Reproductive efficiency and viability of calves of Mpwapwa cattle and their crosses. *M. Sc.(Agric.), Thesis*, Sokoine University of Agriculture, Morogoro Tanzania.

Das, S.M.; Msechu, J.K.K.; and Mkonyi, J.I. 1990. Culling patterns of improved zebu cattle and their crosses in the semi-arid zone of Tanzania. *Proceedings of 17th Scientific Conference of Tanzania Society of Animal Production, Volume 17, pp.128-137.*

Dragovich, D. 1978. Influence of high temperature on milk production of Friesian dairy cows grazed on farms in a pasture-based feed system. *International Journal of Biometeorology, 22*: 279-284.

Dragovich, D. 1979. Effect of high temperature-humidity conditions on milk production in dairy herds grazed on farms in a pasture-based feed system. *International Journal of Biometeorology, 23:* 15-20

Dragovich, D. 1981. Thermal comfort and lactation yields of dairy cows grazed on farms on a pasture-based feed system in East New South Wales, Australia. *International Jopurnal of Biometeorology, 25:* 167-174

Finch, V.A.; Bennett, I.L.; and Holmes, C.R. 1982. Sweating response in cattle and its relation to rectal temperature, tolerance of sun and metabolic rate. *Journal of Agricultural Science, Cambridge, 99*:479-487.

French, M.H. 1940. Cattle breeding in Tanganyika and developmental problems thereto. *Empire Journal of Experimental Agriculture, 8:* 11-22.

French, M.H. 1941. The failure of pure and high grade European cattle in hot climates. *East African Agricultural and Forestry Journal, 6*: 189-193.

Gates, D.M. 1968. Physical environment. In: *Adaptation in domestic animals (Edited by Hafez, E.S.E.)*;Chapter 4, pp. 43-60.

Getz, W.R. 1973. Lactation characteristics of Tanzania shorthorn zebu in Mpwapwa. *Mimeograph*; 23pp

Getz, W.R.; Hutchison, H.G.; Macha, A.M.; and Mpiri, D.B. 1986. Development of a dual-purpose cattle composite in the tropics. In: *Proceedings of the IVth International Congress on Genetics Applied to Livestock Improvement, Nebraska, USA*. pp 363-369.

Gordon, M.S. 1985. Body temperature and energy metabolism. In: *Animal function: Principles and adaptations*. Macmillan, London; Chapter 8, pp. 290-354.

Gwazdauskas, F.C.; Thatcher, W.W.; and Wilcox, C.J. 1975. Environmental and management factors affecting conception rate in a subtropical climate. *Journal of Dairy Science, 58*: 88-92.

Gwazdauskas, F.C.; Thatcher, W.W.; and Wilcox, C.J. 1973. Physiological, environmental and hormonal factors at insemination which may affect conception. *Journal of Dairy Science, 56*: 873.

Hafez, E. S. E. (editor) 1968. *Adaptation of domestic animals.* Lea and Febiger, Philadelphia, USA.

Hafez, E.S.E. and Bouissou, M.F. 1975. The behaviour of cattle. In: *Behaviour of domestic animals* by Hafez E. S. E. (editor), 3rd Edition; Bailliere Tindall, London. Chapter 10, pp.203-245.

Hahn, G.L. 1976. Shelter engineering for cattle and other domestic animals. In: *Progress in Biometeorology Volume 1 Part 1*, by H. D. Johnson (Editor); Swets and Zeitlinger BV, Amsterdam; Chapter 1, pp. 497-503.

Hancock, J. and Payne, W.J.A. 1957. The direct effect of tropical climate on performance of European type cattle. 1. Growth. *Empire Journal of Experimental Agriculture, 23*: 55-74.

Haynes, N.B. and Howles C.M. 1981. The environment and reproduction. In: *Environmental aspects of housing for animal production* by Clark J.A. (Editor); University of Nottingham School of Agriculture; pp. 63-84.

Holmes, C.W. 1979. *The effects of climatic factors on the productivity of farm animals.* Teaching Manual, Dairy Husbandry Department, Massey University, Palmerston North, New Zealand; 162pp.

Huschke, R.E. 1959. *Glossary of Meteorology*. American Meteorological Society, Boston, Massachussets, USA. 638pp.

Hutchison, H.G. 1958. Development of an Indo-African dual-purpose Zebu - the Mpwapwa breed; Project No. LB 3, Animal Breeding Department, Livestock Production Research Institute Mpwapwa, Tanzania; ***Mimeograph***; 15pp.

Ingram, D.L. 1974. Heat loss and control in pigs. In: *Heat loss from animals and man,* by Monteith, J.L. and Mount L.E.(editors), Butterworths, London, UK; pp. 233-254.

Ingram, D.L. and Mount, L. E. 1975. *Man and animals in hot environments.* Springer Verlag, Berlin, Germany.

Johnson, H.D. 1965. Environmental temperature and lactation (with special reference to cattle). *International Journal of Biometeorology,* 9: 103-116.

Johnson, H.D 1985. Physiological responses and productivity of cattle. In: *Yousef, M.K.(editor), Stress physiology in livestock, Volume 2: Ungulates*; CRC press, Boca-Raton, Florida, USA. pp. 3-23.

Johnson, H.D. 1987a. *Bioclimatology and the adaptation of livestock.* Elsevier Publishers, Amsterdam, Netherlands; 279pp.

Johnson, H.D. 1987b. Bioclimates and livestock. In: *Bioclimatology and the adaptation of livestock* by Johnson, H.D. 1987 (editor). Elsevier Publishers, Amsterdam, Netherlands; pp. 3-16.

Johnson, H.D.; Ragsdale, A.C.; Berry, I.L.; and Shanklin, D. 1963. Temperature-Humidity effects, including influence of acclimation in feed and water consumption of Holstein cattle. *Missouri Agricultural Experimental Station, Research Bulletin No. 846*, 43pp.

Kasonta, J.S. 1988. Population analysis and model calculations for a breeding scheme in the Mpwapwa cattle of Tanzania. *Dissertation, Dr. sc. agr.*, Hohenheim University, Germany.

Kibler, H. H. 1964. Thermal responses of various temperature-humidity combinations on Holstein cattle as measured by eight physiological responses. *Missouri Agricultural Experimental Station Research Bulletin*, No 862.

Kifaro, G.C. 1984. The prodution efficiency of *Bos taurus* dairy cattle in Mbeya Region. *M.Sc.(Agric.), Thesis*, SUA, Morogoro.

Kiwuwa, G.H. and Kyomo, M.L. 1971. Milk composition and yield characteristics of Mpwapwa cattle. *East African Agricultural and Forestry Journal*, 36: 290-295.

Kiwuwa, G.H. 1974. age, year and season effects on dairy performance of Friesian and Jersey cattle on privately owned farms in Kenya. *East African Agricultural and Forestry Journal, 39:* 298-306.

Kleiber, M. 1961. *The fire of life: an introduction to animal energetics.* Wiley and Sons, New York. 454pp.

Lee, D.H.K. 1965. Climatic stress indices for domestic animals. *International Journal of Biometeorology, 9*: 29-35.

LPRI, 1981. *Annual Report for 1980,* Livestock Production Research Institute (LPRI), Private Bag Mpwapwa, Tanzania.

LPRI, 1984. Livestock Production Research Institute (LPRI), Introductory Pamphlet, Published by LPRI, Private Bag Mpwapwa, Tanzania. *LPRI Bulletin No. 01-1983*

Macfarlane, J.S. and Stevens, B.A. 1972. The effect of natural shade and spraying with water on the productivity of dairy cows in the tropics. *Tropical Animal Health and Production, 4*: 249-253.

Macha, A.M. and Msuya, D.G. 1977. Performance of Mpwapwa cattle and crosses there of. *Proceedings of 4th Scientific Conference of Tanzania Society of Animal Production; Volume 4, pp. 72-99.*

McDowell, R.E. 1972. *Improvement of livestock production in warm climates*. W.H. Freeman & Co., San Francisco, USA; 711pp.

Mchau, K.W. 1988. Production characteristics of Mpwapwa cattle. 1. Lactation yield and length. *World Animal Review*, 65: 11-17.

Mchau, K.W. 1991. The impact of upgrading the Tanzania Shorthorn Zebu on smallholder dairy production in Mbeya Region. *Ph.D. Thesis*, SUA Morogoro.

Mchau, K.W. and Syrstad, O. 1991. Production characteristics of Mpwapwa cattle. 2. Shape of lactation curve. *World Animal Review, 66*: 48-54.

Meyerhoeffer, D.C.; Wetterman, R.P.; Coleman, S.W.; and Wells, M.E. (1985). Reproductive criteria of beef bulls during and after exposure to increased ambient temperature. *Journal of Animal Science, 60*: 352 - 357.

Miller, R.H.; Pearson, R.E.; Fohrman, M.H.; and Greegan, M.E. 1972. Methods of projecting complete lactation production from part-lactation yield. *Journal of Dairy Science, 55*: 1602-1606.

Mkonyi, J.I. 1982. A comparative study of the milk production of Mpwapwa cattle and their crosses. *M.Sc.(Agric), Thesis*, University of Dar es Salaam.

Monteith, J.L. and Unsworth, M.H. 1990. *Principles of Environmental Physics, 2nd Edition.* Edward Arnold, London, UK; Chapter 12, pp.199-217.

Morrison, S.R. 1983 Ruminant heat stress: effect on production and means of alleviation. *Journal of Animal Science*, 57: 1594-1600.

Mpiri, D.B. 1990. *Advances in cattle breeding in Tanzania.* Ministry of Agriculture and Livestock development, Tanzania; 74pp.

Msanga, Y.N. 1984. Study of growth of Mpwapwa cattle and their crosses from birth to 108 weeks. *M.Sc.(Agric), Thesis*, SUA Morogoro.

Msechu, J.K.K.; Das, S.M.; and Mpiri, D.B. 1987. Improvement of zebu cattle productivity through breeding. *Proceedings of 14th Scientific Conference of Tanzania Society of Animal Production; Volume 14, pp. 1-20.*

Msechu, J.K.K. and Mkonyi, J.I. 1984. Factors influencing dairy cattle performance, with special reference to two research herds in Tanzania. *Proceedings of 10th Scientific Conference of Tanzania Society of Animal Production; Volume 10, pp. 72-97.*

Pratt, D.J.; and Gwynne, M.D. (editors) 1977. *Rangeland management and ecology in East Africa.* Hodder and Stoughton, London, UK; 310pp.

Ragsadale, A.C.; Brody, S.; Thompson, H.J.; and Wostell, D.M. 1948. Influence of temperature 50°F to 105°F on milk production and feed consumption in dairy cattle. *Missouri Agricultural Experiment Station, Research Bulletin No. 425;* 27 pp.

Ragsdale, A.C.; Thompson, H.J.; Worstell, D.M.; and Brody, S. 1950. Milk production and feed and water consumption responses of Brahman, Jersey, and Holstein cows to changes in temperature 50° to 105°F and 50° to 8°F. *Missouri Agricultural Experiment Station, Research Bulletin No. 460;* 28 pp.

Ragsadale, A.C.; Thompson, H.J.; Worstell, D.M.; and Brody, S. 1951. Influence of increasing temperature, 40° to 105°F, on milk production in Brown Swiss and Brahman cows and heifers. *Missouri Agricultural Experiment Station, Research Bulletin No. 471;* 22 pp.

Ragsdale, A.C.; Thompson, H.J.; Worstell, D.M.; and Brody, S. 1953. The effect of humidity on milk production and composition, feed and water consumption and body weight in cattle. *Missouri Agricultural Experiment Station, Research Bulletin No. 521;* 23 pp.

Richardson, C.W. 1961. Effects of various combinations of environmental temperatures and humidity on the composition of milk and milk fat of the dairy cow. *Dissertation Abstracts, Series B, 21*: 2426.

Robertshaw, D. 1985. Heat loss of cattle. In: *Stress physiology in livestock, Volume I. Basic principles* by Yousef, M.K. (Editor); CRC Press Inc., Roca Baton, Florida, USA; Chapter 6, pp. 55-66.

Rodriguez, L.A.; Mekonnen, G.; Wilcox, C.J.; Martin, F.G.; and Krienke, W.A. 1985. Effect of relative humidity, maximum and minimum temperature, pregnancy, and stage of lactation on milk composition and yield. *Journal of Dairy Science, 68:* 973-978.

Roman-Ponce, H. 1987. Reproduction of dairy cattle in humid tropical environments. In: *Bioclimatology and the adaptation of livestock*, by Johnson, H.D. (editor), Elsevier, Amsterdam, Netherlands; pp. 69-80.

Rosenberg, N.J.; Blad, B.L.; and Verma, S.B. 1983. *Microclimate - the biological environment, 2nd Edition* John Wiley and Sons, New York, USA.

SAS Institute Inc. 1990. Statistical Analysis Systems(SAS), *SAS/STAT User's Guide, Release 6.04 Edition*, Cary, North Carolina, USA.

Schmidt, G.H. and van Vleck, L.D. 1974. *Principles of Dairy Science*. W.H. Freeman and Company, San Francisco, USA; Chapter 5: Factors affecting yield and composition of milk, pp. 84-98.

Sharma, A.K.; Rodriguez, L.A.; Mekonnen, G.; Wilcox, C.J.; Bachman, K.C.; and Collier, C.J. 1983. Climatological and genetic effects on milk composition and yield. *Journal of Dairy Science, 66*: 119-126.

Shekimweri, T.J.M. 1982. A comparative study of the performance of dairy cattle crosses in the humid coastal belt of Tanzania. *M.Sc.(Agric.) Thesis*, University of Dar es Salaam.

Thomas, C.K. and Acharya, R.M. 1981. Note on the effect of physical environment on milk production in *Bos indicus* x *Bos taurus* crosses. *Indian Journal of Animal Science, 51*: 351-356.

Thompson, G.E. 1985. Lactation and thermal environment. In: *Stress physiology in livestock, Volume 1: Basic Principles;* by Yousef, M.K.(editor); CRC Press Inc., Chapter 11, pp. 122-131.

Turner, H.G. 1982. Genetic variation of rectal temperature in cows and its relationship to fertility. *Animal Production, 35*: 401-412.

Udo, M.G. 1992. Comparative study on growth and lactation performance of different crosses in the Mpwapwa cattle herd. *M.Sc.(Agric.) Thesis*, Sokoine University of Agriculture, Morogoro, Tanzania.

Vercoe, J.E. and Frisch, J.E. 1987. Pre- and post-weaning growth of differrent breeds of beef cattle in the tropics. In: *Bioclimatology and adaptation of livestock* by Johnson, J.D. (editor); Elsevier Publishers, Amsterdam, Netherlands; pp.59-68.

Wood, P.D.P. 1969. Factors affecting the shape of the lactation curve in cattle. *Animal Production, 11*: 307-316.

Wood, P.D.P. 1970. The predictive value of partial sums. *The Statistician, 19*: 163-170.

Wood, P.D.P. 1972. A note on seasonal variation in milk production. *Animal Production, 15:* 89-92.

Yousef, M.K. 1985. *Stress physiology in livestock, Volume I: Basic principles.* CRC Press, Roca Baton, Florida USA; 217pp.

Yousef, M.K. 1985a. Measurement of heat production and heat loss. In: *Stress physiology in livestock, Volume I: Basic Principles* by M.K. Yousef,M.K. (editor) CRC Press, Roca Baton, Florida, USA; pp.35-46.

Yousef, M.K. (1987). Principles of bioclimatology and adaptation. In: *Bioclimatology and the adaptation of livestock* by Johnson, H.D.(editor), Elsevier, Amsterdam, Netherlands; pp.17-31.

Yousef, M.K. and Johnson, H.D. 1968. *Adaptation of cattle* In: *Adaptation of domestic animals.* by Hafez, E.S.E (editor). Lea and Febiger, Philadelphia, USA; pp. 233-245.

Yousef, M.K. and Johnson, H.D. 1985. Endocrine system and thermal environment. In: *Stress physiology in livestock Volume 1, Basic principles,* by Yousef, M.K. (editor) CRC Press Inc., Roca Baton, Florida, USA; pp. 133-141.

Appendix 1: Summary of results of stepwise regression of 28-day milk yield on previous weather variables, showing sums of squares attributed to each independet variable retained in the model[1] in the backward selection procedure in each of 10 stages of lactation.

Independent variable[3]	Stage of lactation (28-day selection from the beginning of lactation)[2]									
	1	2	3	4	5	6	7	8	9	10
DBtemp, a.m.	-	-	64091*	-	-	-	-	-	56405*	71998*
WBtemp, a.m.	69290*	28055*	86961*	356528*	103232*	33460*	-	-	-	-
Max temp	-	-	116785*	98192*	-	-	-	-	-	-
Min temp.	525987*	414200*	330169*	386475*	291906*	233671*	335512*	231086*	193836*	68584*
DBtemp, p.m.	41547*	246574*	20349*	127266*	-	-	-	91556*	-	30940*
WBtemp, p.m.	136736*	219416*	323328*	326294*	171914*	180410*	407009*	309562*	151637*	8134
Rain	-	-	27385*	92165*	36259*	33200*	-	-	-	107800*
Model R-square	4.2	5.5	7.6	6.7	4.8	5.6	9.5	9.3	8.9	9.6

*P<0.05, else 0.05<P<0.10

[1]Retention was set at the P<0.10 level of probability

[2]Weather variables not retained are indicated with a dash (-)

[3]DBtemp, WBtemp = dry-bulb and wet-bulb temperature, respectively.

Appendix 2: Summary of results of stapwise regression of 28-day milk yield on previous weather variables showing partial regression coefficients on the independent variables retained in the model[1] in the backward elimination option of the procedure in each of 10 stages of lactation.

Independent variable[3]		Stage of lactation (28-day period from the beginning of lactation)[2]									
		1	2	3	4	5	6	7	8	9	10
DBtemp, a.m.	b	-	-	-12.0458	-	-	-	-	-	-7.2065	-11.6515
	±SE	-	-	3.7267	-	-	-	-	-	1.6765	2.2824
WBtemp, a.m.	b	-6.1854	-4.3471	-14.9340	-20.0351	-9.8426	-5.4202	-	-	-	-
	±SE	2.0000	2.1594	3.9664	2.5312	2.1457	1.9819	-	-	-	-
Max temp	b	-	-	-7.1138	5.9176	-	-	-	-	-	-
	±SE	-	-	1.6304	1.4246	-	-	-	-	-	-
Min temp	b	5.2031	4.6381	4.0476	3.9797	3.5213	3.2259	3.8992	3.5311	3.4284	2.2145
	±SE	0.6109	0.5956	0.5517	0.4829	0.4565	0.4464	0.4396	0.4558	0.4303	0.4445
DBtemp, p.m.	b	-31232	-8.3919	-3.3919	-6.8546	-	-	-	-5.2567	-	4.4017
	±SE	1.3048	1.3094	1.8624	1.4495	-	-	-	1.0781	-	1.3153
WBtemp, p.m.	b	8.8409	12.1512	19.7657	17.3978	9.2472	8.3182	7.4154	10.4460	9.0355	2.5812
	±SE	2.0359	2.1586	2.7226	2.2976	1.5621	1.3099	0.7590	1.1651	1.2829	1.5043
Rain	b	-	-	0.0734	0.1320	0.0754	0.0862	-	-	-	0.1674
	±SE	-	-	0.0347	0.0328	0.0277	0.0316	-	-	-	0.0268

[1]Retention was set at the P<0.10 level of probability.

[2]Weather variables not retained are indicatedd with a dash (-).

[3]DBtemp, WBtemp = dry-bulb and wet-bulb temperature, respectively

APPENDIX 3: Regression coefficients of afternoon milk yield on age of cow and THI at the time of recording rectal temperature in various genetic groups[1].

Independent variable		Genetic group				
		Mpwapwa	J x M	A x M	F x M	Backcross
Age of cow(d)	b	0.0002^{+}	-0.0002^{+}	0.0010^{***}	0.0001^{ns}	0.0003^{**}
	SE	±0.0001	±0.0001	±0.0002	±0.0003	±0.0001
THIpm	b	-0.0416^{ns}	-0.0408^{ns}	-0.1233^{ns}	0.1185^{ns}	0.0339^{ns}
	SE	±0.0561	±0.0829	±0.0889	±0.1944	±0.0645
R-square		2.08	7.64	33.21	13.38	16.91

$^{***}P<0.001$ $^{**}0.001<P<0.01$ $^{*}0.01<P<0.05$
$^{+}0.05<P<0.10$ $^{ns}P\geq0.10$

[1]Notes:

Generated from analyses using Model 10 mentioned in Chapter 3, and described in detail in Appendix 8;

Genetic groups as defined in Chapter 3;

Sums of squares from the same analyses appear in Chapter 4 as Table 15.

APPENDIX 4: Regression coefficients of milk fat component on age of cow, and temperature-humidity index and regression R-square values for various genetic groups[1]

Independent variable	Genetic group			
	Mpwapwa	J x M	F x M	Backcross
Age of cow	0.02 ± 0.01	-0.34* ± 0.08	0.03* ± 0.02	-0.01 ± 0.02
THI at 0900 h	5.84 ± 8.22	25.57+ ± 6.63	16.72 ± 10.19	3.85 ± 8.79
THI at 1500 h	-9.17 ± 6.69	-27.75* ± 5.29	-22.52* ± 8.13	-7.16 ± 7.08
Regression R^2(%)	14.40	95.92	61.62	7.61

*P<0.05 +0.05<p<0.10

[1]Genetic groups as defined in Chapter 3, except that there were no Ayrshire x Mpwapwa cows in milk during the supplementary study.

THI = Temperature-humidity index (explained in text).

APPENDIX 5: Regression coefficients of milk ash component on age of cow, and temperature-humidity index and regression R-square values for various genetic groups[a]

Independent variable	Genetic group			
	Mpwapwa	J x M	F x M	Backcross
Age of cow	0.00 ± 0.00	-0.05⁺ ±0.01	0.00 ± 0.00	0.00 ± 0.00
THI at 0900 h	1.05 ± 1.31	1.95 ± 1.23	2.30 ± 1.80	-0.24 ± 1.12
THI at 1500 h	-1.43 ± 1.06	-3.36⁺ ±0.98	-2.71⁺ ±1.44	-0.40 ± 0.90
Regression R^2(%)	13.16	92.94	31.58	7.99

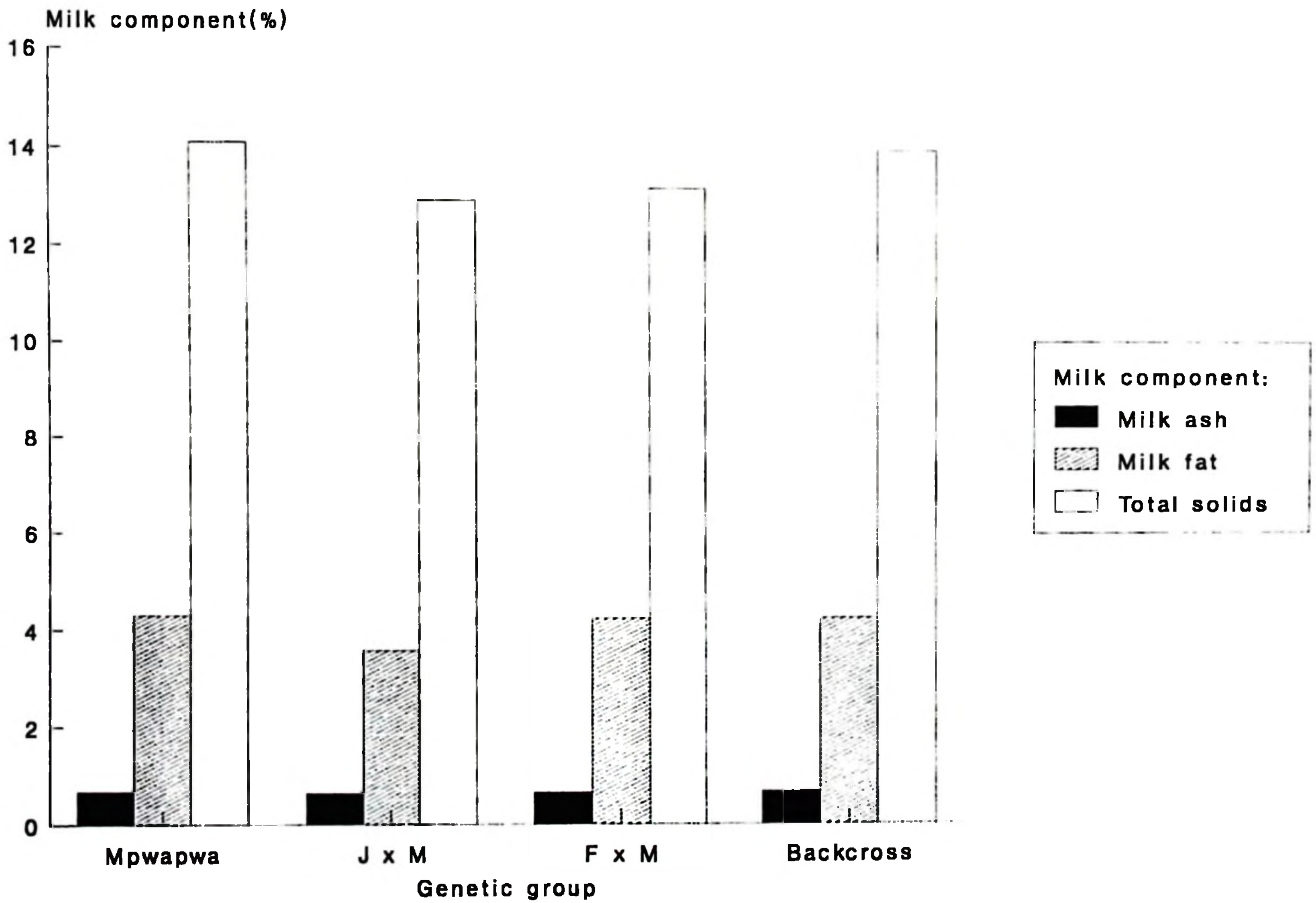
⁺$0.05<P<0.10$

[a]Genetic groups as defined in Chapter 3, but there were no Ayrshire x Mpwapwa cows in milk during the supplementary study; THI = Temperature-humidity index (explained in text); Coefficients for Mpwapwa, Friesian cross, and Backcross cows recorded as zero were 0.00293862, 0.0008457, and 0.00206761, respectively before rounding.

APPENDIX 6: Regression coefficients of the total milk solids component on age of cow, and temperature-humidity index along with regression R-square values for different genetic groups[1]

Independent variable	Genetic group			
	Mpwapwa	J x M	F x M	Backcross
Age of cow	0.04 ± 0.05	-0.81* ± 0.13	0.04 ± 0.04	0.04 ± 0.08
THI at 0900 h	27.80 ±29.94	43.66+ ±11.11	24.98 ±27.64	-1.32 ±27.10
THI at 1500 h	-30.37 ±24.37	-6.75* ± 8.86	-49.34+ ±22.05	-9.17 ±21.81
Regression R^2(%)	7.79	98.13	47.52	4.39

[1]Genetic groups as defined in Chapter 3, but there were no Ayrshire x Mpwapwa cows in milk durng the supplementary study; THI = Temperature-humidity index (explained in text).



Appendix 7: Average milk ash, fat, and total solids components(%) by genetic group

Appendix 8: Detailed description of models used in statistical analyses

Models invoked for the analyses of 28-day milk yield data across genetic group included some non-climatic factors and various weather and some cow variables as covariates. The factors and variables were as described in Chapter 3.

Three cow continuous variables were adopted together with the class variables genetic group, year of calving, stage of lactation, and parity as independent variables. The continuous variables were age of cow, lactation length, and previous milk yield (milk yield recorded in the 28-day period preceding that during which milk yield being analysed as response variable was recorded).

Fourteen weather variables were available as possible independent variables for use in models for covariance analyses of the 28-day milk yield. These comprised of two identical sets of the seven weather variables recorded in consecutive 28-day periods. One, to be described as "previous weather variables", was recorded during the period preceding that of recording the 28-day milk yield being adopted as response variable. The other was recorded during the same period as the response variable, and is referred to as "current weather variables".

Each set consisted of the following variables (average daily temperatures and total rainfall):

Dry-bulb temperature at 0900 h (DBtemp am)

Dry-bulb temperature at 1500 h (DBtemp pm)

Wet-bulb temperature at 0900h (WBtemp am)

Wet-bulb temperature at 1500 h (WBtemp pm)

Maximum temperature (Max temp)

Minimum temperature (Min temp)

Rainfall (Rain)

In addition, for each set of weather variables, six derived variables were computed. These were the indexes obtained from the formulae described in Chapter 3 as listed hereunder with their acronyms in parentheses.

Average effective temperature at 0900 h (ETam)

Average effective temperature at 1500 h (ETpm)

Average effective temperature for the day (ETday)

Average temperature-humidity index at 0900 h (THIam)

Average temperature-humidity index at 1500 h (THIpm)

Average of the THI index for the day(THIday).

The indexes were used to replace dry- and wet-bulb temperatures in the models for initial analyses to determine the relative importance of the indexes and the temperatures.

The models adopted at different stages of analyses are summarised in Table 1 and briefly described in the ensuing paragraphs as models 1 through 12.

(a) Initial model for analysis of 28-day milk (Model 1):

For the analyses of 28-day milk yield across genetic group utilising all recorded weather information in the same period as the response variable, a model with five class variables and 11 other independent variables was used. Stepwise regression model selection procedures and knowledge of the biological situation favoured the adoption of current weather variables. The list of independent variables included three cow continuous variables (age of cow, lactation length and previous milk yield) and four cow class variables, genetic group, year of calving, stage of lactation, and parity. The set of seven "current" temperatures and rain was used as independent variables along with previous rain. Previous rain was included in its own right as a factor strongly believed to have influence on the response variable through its effect on pasture growth.

Table 1. List of terms included in models adopted for investigating the effects of various weather and some non-weather variables on cumulative 28-day milk yield, afternoon milk yield, rectal temperature and milk components as dependent variables using the GLM procedure of SAS[1].

Independent variables[2]	Model No (see description in text)[3]											
	1	2	3	4	5	6	7	8	9	10	11	12
Genetic group	x	x	x	x	x	-	x	x	x	-	x	-
Calving year/period	x	x	x	x	x	x	-	-	-	-	-	-
Lactation stage	x	x	x	x	x	x	-	-	-	-	-	-
Parity	x	x	x	x	-	-	-	-	-	-	-	-
Pregnancy status	-	-	-	-	-	-	x	-	-	-	-	-
Coat colour	-	-	-	-	-	-	x	-	-	-	-	-
Rectal temperature[4]	-	-	-	-	-	-	x	-	-	-	-	-
Age of cow	x	x	x	x	x	x	x	x	x	x	x	x
Lactation length	x	x	x	x	x	x	-	-	-	-	-	-
Previous yield	x	x	x	x	x	x	-	-	-	-	-	-
DBtemp at 0900 h	x	-	-	-	-	-	-	-	-	-	-	-
WBtemp at 0900 h	x	-	-	-	-	-	-	-	-	-	-	-
Maximum temp	x	x	x	x	x	x	-	-	-	-	-	-
Minimum temp	x	x	x	x	x	x	-	-	-	-	-	-
DBtemp at 1500 h	x	-	-	-	-	-	x	x	-	-	-	-
WBtemp at 1500 h	x	-	-	-	-	-	x	x	-	-	-	-
Previous rain	x	x	x	-	-	-	-	-	-	-	-	-
Concurrent rain	x	x	x	x	x	x	-	-	-	-	-	-
THI at 0900 h	-	x	-	-	x	x	-	-	-	-	x	x
THI at 1500 h	-	x	-	-	x	x	-	-	x	x	x	x
Daily avge THI	-	-	x	x	-	-	-	-	-	-	-	-

[1]SAS Institute Inc (1990).

[2]The first six variables listed were class(or group) variables, while the rest were continuous variables.

[3]Where a variable was included in model it is indicated with an x; if not included, it is shown by a dash (-);

[4]Rectal temperature used as independent variable where afternoon milk was the dependent variable.

The algebraic form of the initial linear model for the analyses of 28-day milk yield was as shown in the following equation:

$$Y_{ijklm} = \mu + A_i + P_j + Q_k + R_l + \sum_{n=1}^{11} b_n(X_{nijklm} - X_n\textit{mean}) + e_{ijklm}$$

where:

Y_{ijklm} = value of response variable recorded on the mth animal in the lth parity, kth stage of lactation, jth year of calving, and ith genetic group

μ = overall mean of the response variable

A_i = effect of ith genetic group, $i=1,2,\ldots,5$

P_j = effect of jth year of calving, $j=1,2,\ldots,24$

Q_k = effect of kth stage of lactation, $k=1,2,\ldots,10$

R_l = effect of lth parity, $l=1,2,\ldots,9$

X_{nijklm} = value of nth covariate, where n defines a particular covariate out of a total number of 11 covariates in the model.

$X_n\textit{mean}$ = overall mean of the nth covariate

b_n = regression coefficient of response variable on the nth covariate;

e_{ijklm} = random error effect peculiar to the record Y_{ijklm}, assumed to have constant variance and mean zero; and, for hypothesis testing, further assumed to be normally distributed.

(b) Subsequent models:

Through modification in Model 1 by replacing wet- and dry-bulb temperatures with the respective temperature-humidity index values (THIam and THIpm), a different model was built for similar analyses. This gave results to be used in judging if temperatures could be replaced by THI. The model was designated Model 2.

In an effort to see the effect of replacing the two values of temperature-humidity index with a daily average value, a reduced model was used. This was obtained by reducing the number of covariates by one, when THIam and THIpm were replaced by THIday. The new model was defined as Model 3.

By dropping one independent variable, previous rain, from Model 3, it was possible to investigate the importance of previous rain in contributing towards variation in 28-day milk yield. This gave rise to a model defined as Model 4. Adoption of this model showed that dropping previous rain slightly changed the R^2 value from 87.18% to 87.12%. Use of THIday also slightly reduced the R^2 value from 87.18% to 87.16% (comparing Model 2 and Model 3 analyses). In order to find out which of the two THI values (am or pm) was more relevant, subsequent tests adopted THIam and THIpm. Further analyses also excluded previous rainfall, in view of its barely marginal contribution to variation in 28-day milk yield.

Based on the knowledge that parity and age of cow effects would be related from the nature of their definitions, it was deemed necessary to determine which of them would be retained in the model for final data processing. Initial analyses (Model 1, Model 2, Model 3 and Model 4) showed that when both were in the model they were nonsignificant in explaining variation in 28-day milk yield. Parity was found to be significant only in test cases where previous milk yield was excluded from the model, while age of cow assumed more importance if parity was excluded. Parity was left out in subsequent analyses.

Year as a factor had many sub-classes, some of which did not have cows representing some genetic groups. Years were grouped into 5-year periods for further test analyses. A different model defined as Model 5, having three class variables and eight independent continuous variables, was therefore adopted.

Final analyses of variation in 28-day milk yield for each genetic group separately made consideration of the results of analyses carried out using Models 1 to 5. In order to include records of animals which would be considered contemporaries, the analyses included only years that had all genetic groups represented. This also ensured that records from earlier years which were less reliable because they had been converted from pounds to kilos and their originals were not available for verification by the author were excluded. The analyses were carried out using a model that included year and stage of lactation as factors, and the same covariates in Model 5. The final model analyses was described as Model 6.

(c). Models for analyses of afternoon rectal temperature and milk yield

Initial test analyses of rectal temperature as a response variable using all information available adopted genetic group, pregnancy status and coat colour (factors) and age of cow and concomitant dry- and wet-bulb temperatures as the independent variables. The same set of factors and independent variables was adopted in investigating their effect on afternoon milk recorded at the same time as rectal temperature. An equation of the situation was defined as Model 7, specifying the terms as explained in the following algebraic expression.

$$Y_{ijkl} = u + A_i + B_j + C_k + \sum_{n=1}^{3} b_n(X_{nijkl} - X_n mean) + e_{ijkl},$$

where,

Y_{ijkl} = value of response variable recorded on the lth animal in the kth coat colour, jth pregnancy status, and ith genetic group

μ = overall mean of the response variable

A_i = effect of ith genetic group, i=1,2,...,5

B_j = effect of jth pregnancy status, j = 1 or 2

C_k = effect of kth coat colour, k= 1 or 2

X_{nijkl} = value of nth covariate, where n defines a particular covariate out of the three covariates in the model.

X_n*mean* = overall mean of the nth covariate

b_n = regression coefficient of response variable on nth covariate;

e_{ijkl} = random error effect peculiar to the record Y_{ijkl}, assumed to have constant variance and mean zero; and, for hypothesis testing, further assumed to be normally distributed.

Tests from analyses using Model 7 showed that the effects of pregnancy status and coat colour were unimportant. Most animals were found to have been empty and coat colour was light in most cases. Pregnancy status and coat colour were therefore left out of the model in further tests as comparisons on these criteria were unjustifiable. Additional analyses adopted as terms in the model only genetic group as a class variable and three other independent variables, age of cow, dry-bulb temperature and wet-bulb temperature. This was referred to as Model 8.

When the values of THIpm were used in the place of dry- and wet-bulb temperatures, a slightly different situation arose in which only two continuous variables were used together with genetic group as independent variables in the model. This model was referred to as Model 9.

Final analyses of rectal temperature for each genetic group separately were carried out using THI in the place of wet-bulb and dry-bulb temperatures. The regression model envisaged was described as Model 10, which described a multiple regression with independent variables being age of cow and THI at afternoon milking.

(d). Models for analyses of milk components

Analyses to determine relative importance of various factors on milk components included genetic group and pregnancy status(class variables) and age of cow and weather variables as the independent variables. Initial analyses using the model showed that pregnancy status was unimportant as a source of variation in milk components. Furthermore, most of the cows were empty, making comparisons on the basis of pregnancy status unjustifiable. Additional tests left out pregnancy status and used a reduced model for analyses of data pooled across genetic group and containing only age of cow, and the two THI values(morning and afternoon) as covariates. The model for these analyses was described as Model 11.

Separate analyses of milk components for each genetic group adopted a different model obtained by leaving out the term for genetic group effects, from the situation described in Model 11. It was, in effect, a multiple regression model. This regression model will be referred to as Model 12.

Spe