STUDIES OF VARIATION IN THE RECTAL TEMPERATURE, PULSE RATE, RESPIRATION RATE AND SKIN TEMPERATURE OF SOME NEW ZEALAND JERSEY COWS WITH PARTICULAR REFERENCE TO SUMMER CLIMATIC CONDITIONS

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by
A.R. Quartermain
Massey Agricultural College

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Animals are such agreeable friends -
they ask no questions, they pass no
criticisms.

George Eliot

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CHAPTER I

INTRODUCTION

The field of research known as Environmental Physiology covers studies on the physiological responses of animals to variations in their immediate environment and on the adaptation of animals to environment. Generally, studies with cattle in this field have been pursued either in tropical environments or, lately, in very cold climates (see series of papers by MacDonald and Bell, 1958). The use of climatic chambers, such as those described by Brody (1948) and by Findlay (1950), has enabled research workers to study the effects on animals of a wide range of climatic variables but the results have a restricted application in the field. The following broad questions have been posed:

1. With global transportation of livestock, is there a problem of adaptation to new environments and to what extent can such a problem be solved by the physiologist, geneticist and engineer?
2. To what extent is animal production affected, directly and indirectly, by extremes of climate?
3. How can animal breeders select animals that will thrive in a particular variable climate?
4. Is it necessary to shelter, or otherwise protect livestock against the direct effects of a particular climate?
5. What mechanisms are employed by an animal to regulate its own "private" climate?

Excellent reviews have been published on progress in seeking the answers to such questions, e.g. those of Findlay (1950), Findlay and Beakley (1954), Payne (1955) and McDowell (1958), to cite a few of the most comprehensive.

Scope of This Study

In general, studies in environmental physiology have not had any wide application in temperate countries such as New Zealand and no work has been done locally except for the pioneering study by Patchell (1951, 1954) and the studies by Hancock and Payne (1955) and Payne and Hancock (1957) which were made in Fiji and New Zealand. Apart from the fact that studies in this field are worthy, in their own right, of a place amongst physiological investigations, there are two major aspects of direct interest to New Zealand animal husbandmen.

The first concerns the possibility that the New Zealand climate may have a direct effect on the productivity of livestock and hence, that shelter and shade may be valuable. The second (touched upon in the twin papers of Hancock and Payne (1955) and Payne and Hancock (1957)) concerns the export of livestock from temperate to tropical environments. Many writers have stressed (Turbet, 1949; Payne and Hancock, 1957; Lecky, 1949) that some individuals among European-type cattle (<u>Bos taurus</u>) can thrive, and out-produce locally adapted cattle, in the tropics. As a general rule however, temperate-bred cattle fail upon exposure to tropical climates (Maule, 1952).

Four physiological variables (rectal temperature, pulse rate, respiration rate and skin temperature - indicators of the general physiological status of the animal) and one climatic variable (air temperature) were studied with the following types of question in mind:

1. What are the best ways of measuring, in the field, the variables concerned?

2. What variations are there in these variables (particularly diurnal and between animals) and what relationships exist among them?

3. What constitutes "normality" as regards the physiological variables and does the New Zealand summer climate cause any gross departures from normality (i.e. are the animals subjected to any direct climatic stress)?

4. What influences do various animal characteristics and managerial factors have on these physiological variables?

Also, is it possible to select on some physiological basis and in New Zealand, those animals that are likely to thrive if exported to a tropical country?

New Zealand Jersey cattle (B. taurus) were chosen for study since over 85% of the Dominion's dairy cow population is high-grade or purebred Jersey, (Primary Production in New Zealand, 1957).

Chapter I is introductory and explanatory in nature. Chapter II contains a review of the more recent literature pertinent to this study. Chapters III to VI inclusive describe experiments carried out in an attempt to answer some of the above questions while Chapter VII contains a summary of these experiments and the conclusions drawn therefrom.

Note on the Climatic Environment of the Manawatu

Kidson (1950) gives the three principal factors controlling the climate of New Zealand as:

1. Latitude.
2. Oceanic surroundings.
3. High relief.

New Zealand lies within the latitudes 34° 4'S and 47° 2'S and is therefore regarded as a temperate country. Within this latitude zone, westerly winds prevail and the country is subjected to rapid fluctuations in weather produced by a series of anticyclones and depressions moving continuously from west to east. The climate is predominately insular with an absence of extreme, short-term and seasonal variations in temperature. The high relief is responsible for important local modifications to the climate and the main mountain chain, which runs in a north east-south west direction, causes upward movements of air and, consequently an irregular rainfall distribution.

The Manawatu district and the city of Palmerston North lie in "Middle New Zealand", the climate of which, states Garnier (1958), typifies that of New Zealand as a whole. Salient points of interest regarding the local climate are as follows:

1. The annual variations in mean monthly temperature is small (Climagraph - figure 1). However, there is an extreme temperature range from above 80°F to below freezing point.
2. The mean diurnal range of temperature is surprisingly large due to a transparent atmosphere and clear skies. In Palmerston

North, the mean daily range is 15.3°F.

3. Low cloud can seldom form in extensive, continuous sheets.

4. The average precipitation is high (30 inches per year) and evenly spread but with some very intense rain over short periods.

5. In spite of the high rainfall and temperate climate, a high percentage of days have bright sunshine, due mainly to the periodicity of the rainfall and to the prevalence of wind. Palmerston North has, on average, 1,839 sunshine hours per year or 41% of the total possible hours.

6. A high proportion of the winds are strong.

7. Snow rarely occurs but frosts are quite common.

In general, because of the prevailing westerly winds and the central mountain chain, the western districts are wetter than the Eastern districts. This difference is most pronounced in spring when westerly winds prevail most persistently. Climatically and topographically, the western districts of the North Island (North Auckland, South Auckland, Taranaki and Wellington - including the Manawatu) are favourable for dairying and these four land districts between them pasture 85% of the National dairy herd (Farm Prodn. Statistics of New Zealand, 1958). Cattle in these dairying districts are subject, however, to raw westerly and south-westerly winds when no shelter is provided.

Use of the Climograph

The climograph is a method for comparing between climatic areas as to their suitability for a particular type of livestock (e.g. are two areas homoclimatic or heteroclimatic?). The origins of

CLIMOGRAPHS

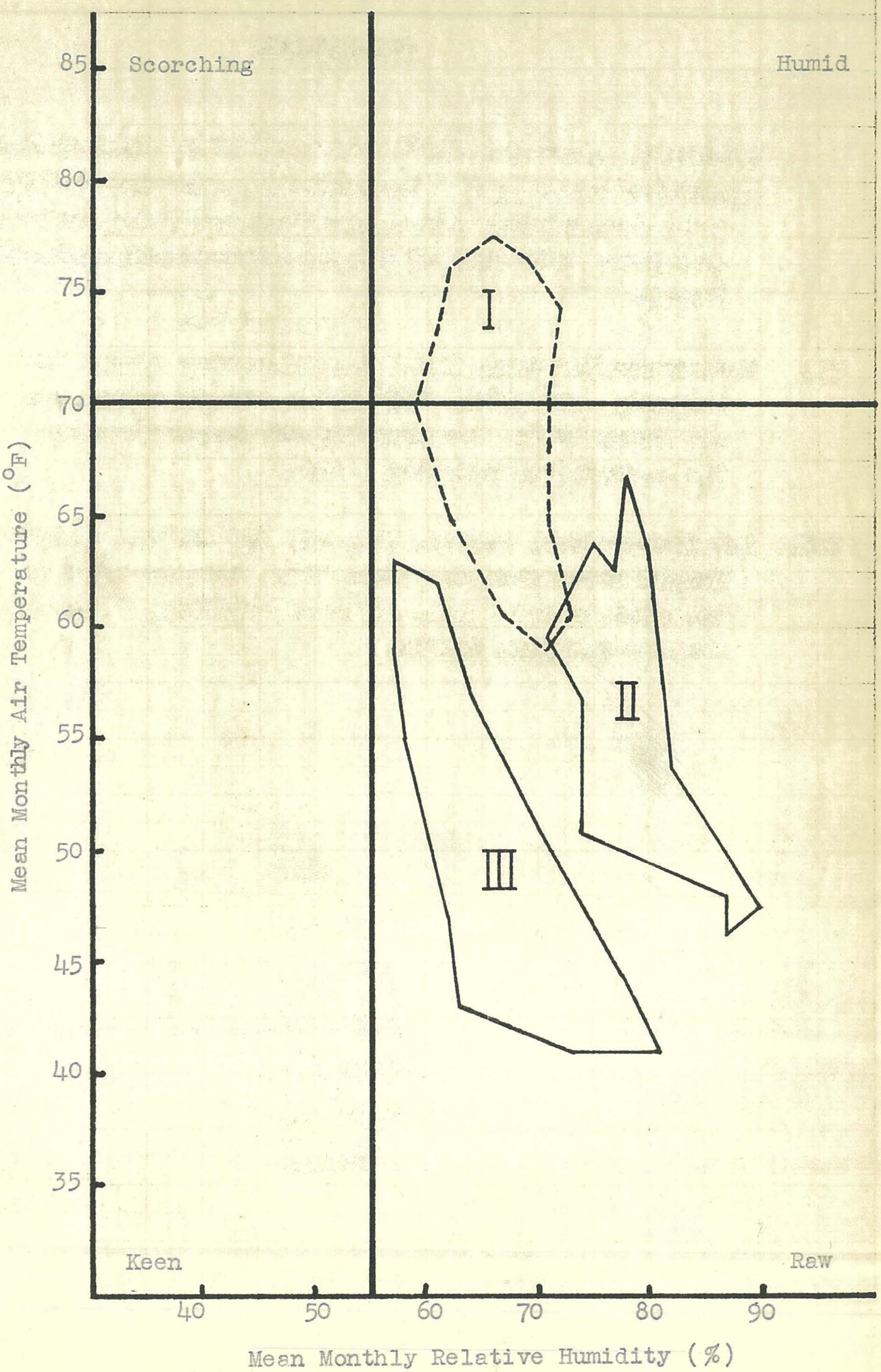
I. Brisbane, Australia; 27° 28' S, 153° 2' E; Height above mean sea level 134'; Standard 30 years' normal (1911-1940) mean monthly air temperature and 9 a.m. relative humidity; Year Book of the Commonwealth of Australia, (1957).

II. Grasslands Division, D.S.I.R., Palmerston North, New Zealand; 40° 23' S, 175° 37' E; Height above mean sea level 110'; Mean monthly air temperature and 9 a.m. relative humidity (1958).

III. Kew Observatory, Surrey, England; 51° 28' N, 0° 19' W; Height above mean sea level 18'; Mean monthly air temperature and 1 p.m. relative humidity; Your Weather Service, (1950).

FIGURE 1

CLIMOGRAPHS COMPARING THE MANAWATU WITH BRISBANE, AUSTRALIA AND SURREY, ENGLAND



the climograph have been given by Wright (1954). On a single graph are plotted the mean monthly air temperatures against the mean monthly relative humidities and the plots joined to form a figure, the position, shape and area of which reflects the summated environmental conditions. Figure 1 pictures climographs comparing the Manawatu with Brisbane (Australian tropics) and with South England (as an example of the climate from which New Zealand's cattle originally came).

Homeostasis and Normality

Homeothermic or "warm-blooded" animals, such as those of the Bos genus, require to maintain homeostasis in the face of fluctuating external climatic conditions. Homeostasis has been defined by Cannon (1929) as the maintenance of steady states in the body by means of complex, co-ordinated physiological reactions.

Hence, since cattle are homeothermic, their homeostatic mechanisms are utilised in the maintenance of a "normal" body temperature, the deep body temperature at which productive processes are most efficient. Measurements of rectal temperature, respiration rate, pulse rate, skin temperature and other, more or less, readily measureable variables have been made by physiologists and used as indicators of the physiological status of the animal. Any gross departures from "normality" have been interpreted as indicating some form of stress with implied adverse effects on production.

Many workers have used the term "normal" rather loosely in this context. In view of the large number of factors which have been shown to influence these variables, no one figure can be cited as normal for any cow in any normal situation when the cow is not under stress. Possibly, measurements taken when air temperatures are within the range for thermo-neutrality (40-60°F), as defined by Kibler and Brody (1949), should be regarded as normal. Beakley and Findlay (1955a) have suggested that measurements taken between 59°F and 68°F (15-20°C) air temperature are normal.

For rectal temperature, Dukes (1953) gives a range of 100.4-102.8°F as normal for a dairy cow, with a mean of 101.5°F. Wirth (1956) gives a range of 100.0 - 103.0°F for the ox and Brody (1945) gives a normal mean value of 101.0°F. From reports of work carried out on the mature Jersey cow within the approximate air temperature range of 40-80°F (Patchell, 1954a; Arrilaga et al, 1952; Badreldin et al, 1951; Riek and Lee, 1948a; Gaalaas, 1945; Regan and Richardson, 1938), the suggestion is made that Wirth's range could hold for the Jersey cow with possibly, an extension of the lower limit to 99.0°F. Any rectal temperatures falling outside the range of 99.0 - 103.0°F would then be considered abnormal. 101.1°F could be regarded as a mean value of rectal temperature but, as will be seen later, a mean value is of little significance in this work.

For pulse rate, Dukes (1953) gives a range of 60 - 70 beats/minute, Wirth (1956) 45-80 beats/minute and Findlay (1950) 60-70 beats/minute. Again, from a study of the same literature, Wirth's range could probably be accepted as normal for the mature Jersey cow with the reservation that rates above this range may not indicate thermal stress.

For respiration rate, Dukes (1955) gives a range of 18-28 respirations/minute and Wirth (1956) 10-30 respirations/minute as a normal range. In view of the gross changes seen in respiration rate at the higher air temperatures and the role of these changes in the maintenance of thermal equilibrium (Findlay and Beakley, 1954), elevated rates should, perhaps, not be considered abnormal unless they rise above rates measured at 70°F air temperature when these can be double the upper limit of Wirth (1956).

Patchell (1954a) gives a range of 80.0 - 100.1°F for the hip skin temperature of the Jersey two-year-old heifer and a mean of 93.8°F, within the air temperature range 36-68°F. Johnston et al (1958) found the mean skin temperature of three Jersey cows (five positions) to be 91.5°F, 95.1°F and 99.4°F at maximum air temperatures of 70°F, 85°F and 95°F respectively.

Heat Tolerance

The ability of an animal to withstand thermal stress (caused by the thermal elements of the climatic environment) determines the heat tolerance of the animal. Stress is defined as a condition of things compelling or characterised by a strained effort and it should be possible to see and measure such a strained effort. In attempting to discover the heat tolerance of cattle, workers have looked for evidence of a strained effort and associated effects on production.

Lee (1955) has pointed out that although strict, quantitative methods are demanded in animal breeding, an intuitive assessment might be more desirable in judging an animal's ability to control its internal homoeostatic environment in the face of climatic stress. Heat tolerance is a function of all the reactions of an animal body and thus, although quantitative information might be available, the final synthesis into some form of index will be largely intuitive.

Payne and Hancock (1957) have defined heat tolerance as the ability to maintain normal physiological function under heat stress. With adequate management (including nutrition and disease control) a normal animal in this sense should produce as well in a hot environment as in a temperate environment and the question naturally arises as to whether or not production per se is an adequate index of heat tolerance. Bonsma (1940) has pointed out that there is a tendency for species to develop to an optimum in a constant environment, leading to adaptation. An assessment of heat tolerance then, is an assessment of the ability of an animal to become adapted to a hot environment. The same author (1949) has stated that the reaction of any animal to a particular environmental stimulus is closely correlated with efficiency of production. An adapted animal should be an efficient producer (in terms of energy intake), with such factors as longevity and reproductive performance taken into consideration, as well as, in the case of dairy cattle, milk or butterfat production. A difficulty lies in measuring this productive efficiency. Perhaps the best that can be done at present is to measure production and measure heat tolerance, by the conventional means considered in the following section, and then to use some form of intuitive reasoning. Cattle do exist that combine both high production and heat tolerance (Maule, 1952).

Lee (1953) has listed the following factors as influencing heat tolerance:

Colour of coat and skin.

Depth and properties of coat.

Body form and surface area.

Wetness of coat and sweating ability.

Breed, age and sex.

In this study, colour, body form, age and productive performance have been considered with breed and sex constant.

The Measurement of Heat Tolerance

Lee (1953) has pointed out that some physiologists regard changes in rectal temperature as the sole criteria of heat tolerance, assuming that other physiological disturbances parallel disturbances to rectal temperature. Other workers have laid stress on production as the index of heat tolerance. Respiratory activity, fertility, coat character and blood composition have all been postulated as valid criteria in the assessment of heat tolerance in cattle and all have their proponents. Lee lists respiration rate, rectal temperature, surface temperature, yield, work capacity, reproductive activity, behaviour, growth and condition as animal reactions indicating the presence or absence of heat tolerance. Every physiological function of the animal must be considered when an attempt is being made to assess the ability of animals to thrive and produce under tropical conditions.

Rhoad (1944) pioneered the measurement of heat tolerance with his Iberia Heat Tolerance Coefficient, a field test under semi-standardised hot conditions and making use of changes in rectal temperature. The assumption is made that the normal rectal temperature is 101.0°F, but this is not necessarily true for every animal and later climatic chamber studies with account taken of the initial rectal temperature before exposure to heat (McDowell et al, 1955) are perhaps more valid. The field tests are not strictly comparable except to compare between animals within a set of readings. Respiration rate is utilised to separate animals which tie on the rectal temperature test and this idea has been further pursued by Benezra (1952) in his modification which takes respiration rate (assumed normal for cattle: 23 respirations/minute) into account. The assumption is that one animal, by reason of a lower respiration rate, may be equally well acclimatised as another with a lower rectal temperature. McDowell et al (1953a) have concluded in like manner, that increased respiratory activity is a compensatory response in the less tolerant animal.

De Alba and Sampaio (1957) have pointed out that short term climatic chamber tests are vitiated by nutritive conditions and the general adaptation of the animals to conditions outside the chamber. Environmental conditions during the intervals between tests seem to be important in the assessment of test results (Lee and Rick, 1951; McDowell et al, 1953b). Dowling (1956) has suggested that because of the high solar radiation heat load in parts of Australia, Rhoad's three-day exposure test simply becomes a measure of the time taken for the animal to lose control of temperature regulation rather than a measure of adaptive ability. This worker used exercise to raise the rectal temperatures of cattle for comparative purposes, taking care not to push the temperatures above 104°F. The results became available in a few hours and the tests were independent of weather conditions.

The effects of thermal stress may be seen in such physiological characteristics as the acid-base balance of the blood, blood composition and respiratory activity (other than rate). Rusoff et al (1951 and 1955) have studied the haemoglobin content, packed blood cell (haematocrit), plasma calcium and plasma inorganic phosphorous contents of the blood and Walker (1958) the haemoglobin index with the idea of utilising changes in blood composition as indices of heat tolerance. The results have been indefinite although the latter worker found an association between a high haemoglobin index and a high heat tolerance. Bianca (1955a) has studied the blood volume, plasma volume, blood cell volume and plasma total solids of calves in order to ascertain the effects of moisture loss during exposure to heat but could find few applications of this work to heat tolerance studies.

Findlay (1955) and McDowell et al (1953a) have suggested that the ability of an animal to decrease tidal volume with increasing respiration rate under hot conditions is a sign of heat tolerance since this results in less disturbance to normal alveolar ventilation and a reduced risk of inducing alkalosis of the blood by the "washing out" of carbon dioxide. Bianca (1955b), in a study of the acid-base balance of Ayrshire calves under thermal stress, concluded that increasing respiration rate causes a deficit in the blood carbon dioxide which is compensated for by a rise in the pH of the urine. This compensation is not affected by increases in lactic acid production by the respiratory muscles.

McDowell et al (1953a) have suggested the use of respiratory volume as an index of heat tolerance rather than respiration rate because of a high positive correlation between the former and rectal temperature changes. However, rectal temperature is comparatively easy to measure and since it reflects the mean body temperature of the animal, it is a reasonable criterion of heat stress (Beakley and Findlay, 1955a).

Bonsma (1955) has stressed the use of coat characters and pigmentation as indicators of an animal's adaptability to a hot climate.

CHAPTER II

REVIEW OF THE LITERATURE

The Heat Tolerance of Jersey Cattle

The importance of variation between breeds, and between individuals within breeds, in the adaptability of cattle has been stressed (Phillips, 1953; Lee, 1953). Many studies have proven the ability of the Jersey breed to withstand the effects of a tropical climate without undue physiological stress. Phillips (1953) has reviewed some of the comparative heat tolerance studies which confirm this conclusion.

Under natural tropical conditions, the Jersey has been shown to be the most heat tolerant of the European breeds (Badreldin et al, 1951; Arrilaga et al, 1952) and consistently more tolerant than the Friesian (Holstein) as judged by rectal temperature changes (Branton et al, 1953; Quazi and Shrode, 1954; Seath and Miller, 1947a), by changes in milk production (Ittner et al, 1954b) and by the use made of artificial cooling (Miller et al, 1951).

Johnston et al (1958) have reported data from chamber studies that indicate that the Jersey is superior to the Friesian in tolerance on account of a lower heat production per unit weight and per unit surface area, the difference being associated with basal heat production rather than with lactation. Robinson and Klemm (1953) compared four lactating Shorthorn cows with the four comparable Jerseys studied by Riek and Lee (1948a) two years previously but under identical conditions. They concluded that the Jersey was more heat tolerant under all combinations of wet and dry bulb temperatures, which they attributed to a greater ability to sweat and to remove heat from the interior of the body to the skin surface on the part of the Jersey.

Heat tolerance coefficients (Rhoad, 1944) have been determined for the Jersey cow and found to lie within the range of 61% to 92% (Gaalaas, 1947; Rhoad, 1944; Asker et al, 1952). In a climatic chamber study, Robinson and Klemm (1953) calculated heat tolerance coefficients in the range of 66% to 94% from the data of Rick and Lee (1948a). These results emphasise the variation found within the Jersey breed, stressed by Gaalaas (1947) and by Johnston and Branton (1953).

Beltsville workers (McDowell et al, 1952; 1955) have shown the heat tolerance of the Jersey to be inferior to that of Red Sindhi (B. indicus) - Jersey (F_1) crossbred cattle but that some individual Jersey cows have a higher tolerance than some individual cross-bred cows. In relation to this, Payne and Hancock (1957) have pointed out that individual temperate-zone cattle may possess heat tolerance coefficients of as high or higher value than many tropical-zone cattle. There is some doubt as to the validity of extrapolating results from climatic chamber studies on small numbers of animals to cover whole populations. Maule (1952), Lecky (1949) and Turbet (1949) have all recommended the use of the Jersey breed in tropical climates.

Table 1 summarises some of the information from a breed comparison made during the course of the Missouri climatic

TABLE 1

The Critical Temperature* (°F) for Various Physiological Reactions.

Lactating Cow Breed Averages

Reaction	Jersey	Friesian	Brown Swiss	Brahman
Food consumption decreases above	75	70	80	95
Milk production decreases above	85	85	85	95
Pulse rate decreases above	80	80	85	95
increases above	100	90	95	100
Body weight decreases above	85	80	80	-
Respiration rate increases above	60	60	60	75
decreases above	85	80	90	-
Evaporated moisture				
increases above	60	60	50	85
decreases above	70	70	85	95
Rectal temperature				
increases above	75	70	80	95
Numbers of Cows	3	4	3	2

From Missouri Work (Worstell and Brody 1953)

* "Critical Temperature" refers to the approximate environmental temperature at which marked changes occur in the slopes of the curves of the physiological variables in animals subjected to rising environmental temperatures from 50 - 105°F.

chamber work (Worstell and Brody, 1953). Although these results may not be applicable as such to field conditions and are based on small numbers of animals, the generalisation can be made that the Jersey is more tolerant than the Friesian but not as tolerant as the Brown Swiss or Brahman (Zebu-type cattle) on the basis of these figures.

Summary

The Jersey is among the most heat tolerant of the European breeds of dairy cattle but there is a wide range of tolerance among individuals within the breed. Individuals and strains have been found which are well suited to tropical conditions.

Diurnal Variation in the Physiological Variables.

Few studies have been made which were planned to investigate diurnal patterns of variation in any of the four variables (rectal temperature, respiration rate, pulse rate, skin temperature). Fatchell (1954c) has reviewed the literature prior to 1950 and has concluded that the rectal temperature of cattle is high in the early evening and lower in the early morning.

Hutchison and Mabon (1954), studying ten adult Zebu-type cows, found a marked variation between recordings of rectal temperature made at 7.30 a.m. and 3.30p.m. The afternoon reading was usually more than 3°F higher than the morning reading and this difference was highly significant. There was a parallel difference of 12°F in air temperature. Part of this variation in rectal temperature they attribute to lactation which, during the season of poor nutrition, causes a priority demand for calories resulting in an inability of the cattle to maintain body temperature during the cooler morning hours. Cows on supplemented rations had higher minimum temperatures and a lower variation. Also, total variation appeared to be lower in the afternoon. This type of hypothesis could only be investigated on a theoretical energy input-output basis at present and it will have to remain as a possibility only. Working with similar Zebu and Zebu-crossbred cattle within a mean air temperature range of 59.0 - 103.8°F, Pagot (1956) found differences of 1.19 - 1.21°F between mean morning and afternoon rectal temperature readings. No further details were given.

Kendall (1948) has reported differences of 0.5 - 1.6°F between the rectal temperatures of European-type cattle as recorded at 5.30 a.m. and 2.30 p.m. when air temperatures averaged 68.6°F and 80.6°F respectively. Differences of up to 2.1°F were found when air temperatures averaged 70.8°F and 86.5°F. Similarly, Ittner et al (1954b) have reported differences of up to 1.7°F between the rectal temperatures of purebred Friesian cows as recorded at 3-5 a.m. and at 3-5 p.m. with the higher temperatures in the afternoon. Respiration rate was, on average, higher at 10 - 11 a.m. and at 1 - 2 p.m. than at 3 - 5 a.m. or 3 - 5 p.m. Air temperature ranged from 50°F to 112°F during this trial.

In general, these diurnal changes take the form of gradual trends, following air temperature trends with a variable degree of lag. In the course of a study on the effects of diurnal temperature cycles on cattle carried out in the Missouri psychrometric laboratory, Kibler and Brody (1956) found that in the 50°F - 110°F air temperature cycle, rectal temperature lagged behind air temperature by up to three hours when air temperature was rising. When it was falling, rectal temperature returned to normal after five to nine hours. Respiration rate also followed air temperature with a variable time-lag. Although pulse rate also tended to follow air temperature, the diurnal patterns were confused by the effects of feeding and by random fluctuations.

Hutchison and Mabon (1954) found that the rectal temperatures of ten Zebu cows, recorded every two hours from 2 a.m. to 9 p.m., followed air temperature with a lag of about four hours. Minimum rectal temperatures were recorded at 7 a.m. and maximum at 5 p.m. Rain caused a marked temporary depression in rectal temperature. Recording the rectal temperatures of five mature Hariana cows every three hours, Minett and Sen (1945) found that in most months, mean rectal temperature rose from 7 a.m. until 7 p.m. after which time it fell until 4 a.m. These workers have shown by means of graphs that these trends largely follow air temperature trends with a lag of about three hours.

Dowling (1956) found that the rectal temperatures of 40 Shorthorn bulls in the shade rose steadily from 8 a.m. until 3 p.m. then fell until 6 p.m. (recordings every hour). At these times, air temperatures were 70°F, 101°F and 84°F with relative humidity at 55%, 34% and 48% respectively. The same general pattern occurred in the sun but at a higher level. This study, and the one mentioned later by Patchell (1954c), would suggest that air temperature is a more important causative factor in physiological diurnal cycles than solar radiation.

It is impossible in these studies to separate out the effects of fluctuating air temperatures from the effects of other factors known to affect the animal variables (e.g. feeding, watering, activity) and from any innate diurnal rhythms. Beakley and Findlay (1955a) mention that a large number of physiological variables show relatively fixed diurnal rhythms. The question arises as to whether or not these are independent of air temperature changes. Minett and Sen (1945) housed ten Kumauni hill bulls in a shed at a constant air temperature of 70-75°F and recorded rectal temperature at hourly intervals. The mean rectal temperature began to rise at about 6 a.m. and followed an upward trend until late afternoon when it slowly fell to reach a minimum in the early morning. Thompson (1954), working in the Missouri psychrometric laboratory, has calculated the heat production per hour of six cows over three 24 hour periods. The heat produced was primarily due to the animals, litter and bedding. Air temperature was held constant at 50°F and variations in radiation, air movement and humidity were minimised. Heat production reached a peak at 6 p.m. (after feeding at 3 p.m.) and reached a minimum at 6 a.m. (in spite of feeding at 5 a.m.). These two studies appear to be the only evidence of diurnal rhythms in cattle independent of air temperature fluctuation.

Most of the above workers have utilised mean values for each time of day in describing their results. In view of variation between animals and possible interaction it seems desirable to use more refined analysis to investigate anything other than general trends. Patchell (1954c) investigated his results from an indoor trial, using three pairs of identical-twin Jersey heifers over seven 24 hour periods, by analysis of variance and by means of graphs. His graphs showed distinct diurnal trends with all heifers having a peak rectal temperature at about 7 p.m. and a minimum about 8 a.m. Respiration rates fluctuated about a common level from 11 a.m. until after midnight but appeared to be low at 8 a.m.. Pulse rates rose from 8 a.m. to 6 p.m. then fell until 6 a.m.. The analysis showed significant differences between the means for the different times of day for the three variables. Interactions between readings (times of day) and animals and between readings and days were significant in some cases suggesting that the diurnal patterns were not identical for all animals and all days. This would not have been noticed in graphs drawn by plotting average values for the variables against time of day. Alim and Ahmed (1957) carried out a similar study on ten buffalo cows and also obtained significant differences between the means of the times of day. In this case, the diurnal pattern was similar for all animals but not for all days due to differences in the climatic conditions at any one time on different days.

In both of these studies there were significant differences between the means for the individual animals and a study of the data from some of the other investigations shows some variation between animals; e.g. Kriss (1921) attributed unexplainable fluctuations from day to day to the "individuality" of the cows.

Summary

There appears to be an innate diurnal rhythm in cattle, at least for the variables rectal temperature and heat production, and this rhythm is augmented or subjugated by variations due to changes in air temperature and solar radiation. There is a distinct diurnal trend in rectal temperature, respiration rate and pulse rate with generally high values in the afternoon and low values in the early morning. These variables tend to follow air temperature changes with a certain time-lag. Individual animals may differ in their diurnal rhythms.

Relationships Among the Variables

Much of the research work in environmental physiology has been conducted on the relationships between the climatic variables on the one hand and the physiological variables on the other. Inter-relationships among the latter variables have also been investigated. The results of both controlled climate chamber and field studies on these subjects have been comprehensively reviewed by Lee and Phillips (1948), Findlay (1950), Findlay and Beakley (1954) and most recently, by McDowell (1958).

McDowell has pointed out that air temperature changes have the greatest effect of all the climatic variables on rectal temperature. Under field conditions, the rectal temperature of European cattle increases with increasing air temperature above about 70°F with a much greater effect above 80°F. The degree of effect is dependant on breed, age, production level and nutritive level with the largest effect in the less heat tolerant animals and in calves. Adaptation to climate seems to be an important factor influencing the responses of rectal temperature to heat. Significant positive correlations between air temperature and rectal temperature, of variable magnitude depending on the conditions and class of animal, have been reported by Seath and Miller (1946b), Johnston and Branton (1952), Gaalaas (1945) and Asker et al (1952) from recent field studies and by Riek and Lee (1948a), Casady et al (1956) and Beakley and Findlay (1955a) from climatic chamber studies on dairy cattle. Gaalaas (1945) only obtained a significant correlation when air temperatures were greater than 70°F. Hutchison and Mabon (1954) and Minett and Sen (1945) have reported a lag phase between change in air temperature and rectal temperature response of three to four hours.

McDowell (1958) has also pointed out that an increase in respiration rate is one of the first visible responses that cattle make to increasing air temperature. Respiration becomes very rapid and shallow (panting) above air temperatures of 70-80°F. It is generally agreed that the function of the increase in respiration rate is to increase evaporative cooling from the respiratory mucosae. Kibler and Brody (1950) reported a slow rise in the respiratory evaporation of cattle as air temperature rose from 5°F to 95°F, accounting for from 4% to 30% of the total heat dissipation. This cooling may be somewhat countered by increased heat production from the work of panting (Brody, 1956). Panting may also lead to the development of a respiratory alkalosis with a decline in the carbon dioxide combining power of the blood serum and a latent ketosis. A high respiration rate may be an indication of lack of thermal control and, if panting has reached an extreme level, there may thereafter be a decline in respiratory activity due to muscular fatigue (McDowell, 1958).

Significant positive correlations between air temperature and respiration rate have recently been reported by Gaalaas (1945), Seath and Miller (1946b), Johnston and Branton (1952, 1953), Mullick and Kehar (1951), Alim and Ahmed (1956) and Asker et al (1952) from field studies and by Riek and Lee (1948a), Casady et al (1956) and Beakley and Findlay (1955c) from chamber studies on dairy cattle.

Kibler et al (1949) have reported that the pulse rate of cattle tends to decline slightly with increase in chamber air temperature up to 90 - 105°F when the rate might increase in association with abnormally high rectal temperatures. McDowell (1958) has stated that most reports appear to concur with these findings. Seath and Miller (1946b), Arrilaga et al (1952), Riek and Lee (1948a), Casady et al (1956) and Asker et al (1952) found that pulse rate was only slightly and inconsistently related to air temperature while Beakley and Findlay (1955d) found that pulse rate increased with air temperature above 68°F in the Ayrshire calf and could decline after prolonged exposure to temperatures above 77°F. Johnston and Branton (1952) found that the pulse rate of the dairy bull was significantly correlated with mean daily temperature only at temperatures above 85°F.

Increasing air temperature causes an increase in skin temperature (McDowell, 1958). Beakley and Findlay (1955b) found that the trunk skin temperature of the Ayrshire calf rises with increasing temperature, humidity and time. Casady et al (1956) have reported high positive correlations between the rump skin temperature of the dairy bull and air temperature and also between skin temperature and rectal temperature.

The effect of humidity on the physiology of cattle is not so clearly defined but at high temperatures, high humidity is no doubt an added factor causing distress to the animal (McDowell, 1958). Many recent workers have pointed out the smallness of the effect of humidity on the physiological variables (Seath and Miller, 1946b, 1947a; Arrilaga et al, 1952; Riek and Lee, 1948a; Dobinson, 1951). Others have stressed the point that humidity can be important in certain situations (Johnston and Branton, 1953; Asker et al, 1952; Robinson and Klemm, 1953; Beakley and Findlay, 1955a b c d).

Asker et al (1952) found a significant correlation between the rectal temperature and respiration rate of cattle at high air temperatures. Casady et al (1956) found only small and inconsistent relationships between rectal temperature and respiration and pulse rate of dairy bulls, even at high air temperatures. They also found that increases in respiration rate, pulse rate and skin temperature with air temperature preceded changes in rectal temperature which was apparently controlled for a time.

Summary

All four physiological variables are apparently related to air temperature, at least above certain "critical" air temperatures. The effects of humidity changes on dairy cattle are considerably less than the effects of changes in ambient temperature but it should be stressed that there is always a combination of variables affecting any one physiological variable and hence the picture obtained from correlation analysis might always be somewhat confused.

The Influence of Coat Colour on the Physiological Variables

> "Colour is important to considerations of heat tolerance in that it determines, to a certain extent, the proportion of the sun's radiation falling upon the animal which is absorbed." (Lee, 1953).

Bonsma (1949) has partitioned solar radiation into

1. Long wave rays - the infra-red or heat rays.
2. Medium wave rays - the light or visible rays.
3. Short wave rays - the ultra-violet rays.

The proportions of these components in the total radiation varies with climatic conditions, latitude and altitude. Findlay and Beakley (1954) have pointed out that about 50% of the energy in the solar spectrum is in the visible portion. A white surface may absorb only 20% of the visible radiation while a black surface may absorb up to 100% of the energy. The role of coat colour in the absorption of radient energy has been reviewed by Findlay (1950). He has suggested that a white, yellow or red coat, with smooth or glossy texture will result in a minimal heat load. Bonsma (1949) has pointed out that long infra-red and light rays are reflected by white, yellow or reddish-brown hair while yellow, reddish-brown or black skin colours resist the damaging effects of short-wave radiation. Theoretical studies made by Stewart (1953), Stewart and Brody (1954) and Nelson et al (1954) have confirmed the above findings.

Wright (1954) has referred to the principle that animals inhabiting warm and humid regions show greater melanin pigmentation than the same species in cooler and drier regions and that, in arid desert regions, the skin is characterised by the accumulation of yellow and reddish-brown phaeo-melanin pigment. The reasons behind this general ecological pattern, enunciated as Gloger's rule, are not clear but a dark hide may be protective and also, as Bonsma (1949) and Badreldin and Ghany (1954) have pointed out, a black pigmented hide aids in heat disposal when cloud or shade shield the animal from direct radiation.

Stewart et al (1951) have discussed changes in coat colour on exposure to hot atmospheres. They found that the reflectivity of the hair of cattle increased with rise in environmental temperature and time. This seems to be an adaptive mechanism with similarity to the changes in coat character discussed by Yeates (1955).

Three studies have been made on the effects of coat colour differences on the responses of physiological variables to temperature. Seath and Miller (1947a), working with Friesian cows in the milking shed, could find no consistent relationships between the percentage of surface area (total and above belly) that was white and rectal temperature, respiration or pulse rate changes Ittner et al (1954b) however, carried out trials in the sun at an air temperature of 102°F and found that nine cows which were 80%

or more white had an average respiration rate of 105 per minute while five cows which were 80% or more black had an average rate of 118 per minute. In the shade, the respective rates were 76 and 70 respirations per minute for ten cows of each type. Cartwright (1955), in a climatic chamber study on beef cattle, tried to correlate coat colour (scored subjectively from 0 - 100) with the other physiological variables studied (such as chamber rectal temperature and chamber respiration rate) but could find no significant relationships with the available variability in colour.

Patchell (1954a) could find no significant differences between the mean skin temperatures of individual Jersey heifers of variable coat colour. He stated that:

> "Any difference there may be due to colour and type of coat did not show up on the basis of this evidence."

Summary

Coat colour seems to be important in determining the heat balance of cattle exposed to solar radiation but colour differences contribute to the variation between animals in the variables mentioned apparently only when air temperatures or colour differences are extreme.

The Influence of Production Level and Stage of Lactation

Studies on the influence of climatic factors on yield in dairy cattle have been adequately reviewed (Findlay, 1950; Hancock, 1954; Johnston, 1958). However, information on the contributions of differences between cows in level of production, stage of lactation and lactational state (i.e. lactating or dry) to variations in rectal temperature, pulse rate or respiration rate between cows is meagre.

Brody (1948) has cited observations that resting dairy cows produce heat at the rate of 400-500 calories per hour when dry and about double this amount when lactating. It could therefore be expected that lactating animals would have higher rectal temperatures, pulse and respiration rates when under thermal stress and might even have different reactions from dry cows under normal conditions. Lee (1953) has stated that rectal temperature will generally be higher and heat tolerance lower at times of high milk production that at times of low milk production.

Studying Jersey and Red Sindhi-Jersey crossbred cattle in a standard hot atmosphere, Beltsville workers (McDowell et al, 1955) found that stage of lactation had little effect on the responses of rectal temperature to air temperature. Although in the Jersey the rectal temperature was higher before exposure to the hot atmosphere in early lactation than in later months, it rose to higher levels on exposure resulting in a similar rise at all stages of lactation. By contrast, level of production had a significant influence on both the mean rectal temperature during exposure and the rise in rectal temperature in both breeds although in the crosses, there was no additional effect above a certain production level. There were no significant differences in initial rectal temperature between cows of different production levels but lactating cows had higher initial temperatures than dry cows. The only significant effect on respiration rate was a difference between the production level groups in rate before exposure. Under these severe exposure conditions (105°F, 60% relative humidity), respiration rates had reached ceiling values and differences due to differences in production level may have been obscured.

In a similar study, Schein _et al_ (1957) found that there were no significant differences between production level groups in initial rectal temperature and respiration rate but that, on exposure, there was an orderly increase in the amount of change in rectal temperature from 2.6°F in the 15 lbs. F.C.M. per day class to 3.1°F in the 45 lbs. F.C.M. per day class (Jerseys). No similar trend was noted in respiration rate.

Gaalaas (1947) could find no significant differences between the heat tolerance coefficients of 29 mature Jersey cows determined at various stages of lactation and when the cows were dry, indicating a stable rectal temperature response to heat stress. On the other hand, Ittner _et al_ (1954b) found that when air temperature ranged from 71 - 112°F, high producing Friesian cows had consistently higher rectal temperatures (0.3 - 0.8°F) than low producing cows. There were no definite differences in respiration rate. However, when air temperature ranged from 50 - 86°F, the two groups differed little in either variable. They concluded that dry cows (or low producers) suffer less than lactating cows (or high producers) during the hotter months although they admitted that their data were limited.

Two brief reports from Russian workers suggest that pulse and respiration rates could be higher in high producing than in low producing cows (Arsumanjan, 1950) and higher in lactating than in dry, non-pregnant cows (Sementovskaja and Garkavi, 1950).

Summary

Level of production (including lactational state) seems to be an important contributor to differences between cows in the levels of their physiological variables and the responses of these variables to heat stress. Stage of lactation, which includes an element of production level since cows in early lactation are producing at higher levels than in later lactation, seems to be of lesser importance although there are some inconsistencies in the reports.

The Influence of Body Weight

Lee (1953) has suggested that not only may body weight be affected by the environment, through growth and the gain or loss of condition, but may itself influence an animal's response to the climatic environment. Brody (1948) has pointed out that the larger the surface area of an animal, the greater the rate of heat dissipation by all avenues of physical heat loss (conduction, convection, evaporation and radiation) when the animal is under heat stress. Since geometrically, the smaller the animal the larger the surface area per unit weight, it is logical to assume that small (and more angular) animals would be best adapted to tropical environments, other factors being equal. The conductivity of the tissues is involved in the transfer of heat from the internal organs to the surface for dissipation and the smaller animal would be less likely to have an insulating fat layer under the skin. These ideas are supported by ecological considerations (Wright, 1954) which suggest that homeotherms evolved in colder climates tend to be larger than strains evolved in hotter climates, at least within a species (Bergmann's Rule).

On this basis, body weight should have some effect on the general level of rectal temperature, respiration rate or pulse rate in cattle, especially when under climatic stress. Apparently no satisfactory studies have been made on this subject and this is a serious deficiency. Arzumanjan (1950) studied 311 cows and 290 heifers of dairy breeds and found that liveweight had no appreciable effect on pulse or respiration rate. This study may have been important but no statistical analyses or climatic data were given in the abstract. Recording the rectal temperatures of nine buffalo bullocks (Bos genus) when shade temperature ranged from 95 - 109°F, Minett (1955) found that the rectal temperatures of the three heaviest (900 - 1,040 lb) were lower than those of the three smallest (700 - 740 lb.) throughout the day, but the difference was not statistically significant.

Summary

Although an adapted animal might attain larger size than a less well adapted animal through better growth, small strains of animals are likely to be more heat tolerant than larger strains within a species. However, it has not been shown that body weight differences contribute any variation to differences between animals in the physiological variables.

The Influence of Age

Lee (1953) has pointed out that young animals often differ in their heat tolerance from adults although the reasons for this have not been established. Riek and Lee (1948b), in the discussion on their two papers regarding the reactions of Jersey cows and calves to hot atmospheres (1948a,b) have stated:

> "The body temperature response of the calves to hot conditions varies markedly from those of the cows in three respects - more rapid initial rise; higher equilibrium values, especially under less severe conditions; and reduced effect of alterations in absolute humidity. These differences are even more striking in the response of the respiratory rate. Calves, therefore, may be said to suffer a greater strain than cows in response to a given heat stress."

However, in a comparison of Brown Swiss heifers with Brown Swiss cows, Worstell and Brody (1953) have stated that the heifers showed a greater percentage increase in cardio-respiratory activities in response to heat and had higher "critical temperatures" (see table 1 for definition) and were therefore more heat tolerant than the cows. This was in accordance with the generalisation that the heat dispersal efficiency of the smaller animal is greater than that of the larger because of a greater surface area per unit weight. Support for the conclusions of these Missouri workers came from Seath and Miller (1946) who have produced evidence from a trial in which two yearling heifers and four lactating Jersey cows had access to shade and sprinkling. In the sun, rectal temperature averaged lower in the heifers than in the cows but the reverse was true in the shade. The heifers did not avail themselves of the ameliorative treatments to the same extent as the cows which seemed to suggest that the former were not under the same heat stress as the latter.

McDowell et al (1955) and Schein et al (1957), working with Jersey and Jersey-Red Sindhi crossbred heifers, have reported higher rectal temperatures before exposure to heat among the younger animals than among the older but not higher respiration rates. The latter group of workers reported higher test rectal temperatures and respiration rates among the younger heifers as well. Arsumanjan (1950) reported higher pulse and respiration rates among his young dairy stock than among older cows but no further details were given in the abstract of his paper. By grouping their female cattle into age groups, Badreldin et al (1951) found that rectal temperature, pulse and respiration rate decreased as age increased within the air temperature range of 51.8 - 82.0°F.

Summary

There is some controversy as to whether younger animals are more or less heat tolerant than older stock but many workers have produced evidence that suggests that heat tolerance increases with age among heifers (Bonsma, 1949; Klemm and Robinson, 1955; Asker et al, 1953), cows (Gaalaas, 1947) and bulls (Casady et al, 1956). Young animals such as active, growing calves appear to have higher rectal temperatures, pulse and respiration rates under normal conditions than older cows and this could be misleading in an assessment of heat tolerance.

<u>The Influence of Pregnancy</u>

The pregnant condition and the onset of parturition would be expected to have some influence on an animal's physiological reactions to fluctuating air temperature, but only three studies contain much information on this problem. Thomas (1949) found that the heart rates of forty dry, pregnant cows increased rapidly as calving time approached. The average rates were 65, 72 and 92 beats/minute at 70-90, 30-50 and 0-10 days pre-partum respectively. No further data were available in the abstract of this paper so that it is not known whether or not any other factors were involved. Wrenn <u>et al</u> (1958) followed the changes in rectal temperature of nine dairy cows both pre- and post-partum. The mean rectal temperature for the period 10-3 days pre-calving was in the order of $\frac{1}{2}^{o}$F higher than that of normally cycling cows, but the significance of this is doubtful since the two lots of temperatures were obtained from separate studies. There was a sharp decline in rectal temperature during the period 1-2 days pre-calving of over 1^{o}F and recovery within a day. Gaalaas (1947) could find no significant differences between the heat tolerance coefficients of 29 Jersey cows determined at different stages of pregnancy.

From a study of the rectal temperatures and pulse rates of six pairs of identical twin heifers over a three month period, Patchell (1954a) found significant differences between the means of animals and of days which he explained on the basis of advancing pregnancy rather than on climatic effects in that air temperature range (37-67^{o}F). He suggested that differential calving dates among his animals could explain his significant interaction between days and animals in pulse rate but, if pulse rate increases steadily as pregnancy advances, although an interaction could still occur, the animals would be likely to continue to rank in the same order on successive days. Hickey (1955) cited Patchell as ascribing his high average respiration rate and range of respiration rates to the effects of advancing pregnancy but this is apparently a misquote. He (Hickey) suggested that advancing pregnancy could not have been the chief cause behind the high pulse rates obtained by Patchell but, since Patchell's heifers were supposedly within a month or two of calving, pregnancy could have had a big influence on pulse rate if account is taken of the above study by Thomas (1949).

The only available comparative data between pregnant and empty animals comes from work with buffaloes (Bos genus but not _B. taurus_ or _B. indicus_) by Alim and Ahmed (1957). These workers found that pregnant, dry cows had higher rectal temperatures and respiration rates than open, dry cows when air temperatures ranged from 77.0 - 100.4°F.

Summary

Pulse rate probably rises considerably over the last three months of pregnancy in cattle but it is likely that rectal temperature is only affected near parturition time. The rectal temperatures and respiration rates of pregnant cows could possibly respond more to heat stress than those of empty cows.

The Influence of Shading on the Physiological Variables

The importance of the provision of shade for cattle in tropical areas is emphasised by studies on the solar radiation heat load (Findlay and Beakley, 1954) and its effect on the physiological variables (Stewart and Brody, 1954; Kibler and Brody, 1954). Dairy cattle normally seek shade when subjected to hot, sunny conditions. Seath and Miller (1946a), Payne et al (1951) and Larkin (1954) have demonstrated that cattle graze more at night when temperatures are high and the total grazing time may be reduced. It is difficult to assess the value of shades since, during the daytime, the animals might have been more comfortable in the shade but they might have spent the time more usefully if grazing.

A considerable body of work on cattle shades has been published by Californian workers (Ittner et al, 1954a) and Payne (1955) has reviewed much of the work on practical aspects of shading cattle. Ittner and Kelly (1951) found that air temperatures were of the same order under all types of shades that did not utilise evaporative coolers and they emphasised that the chief function of shade is to reduce the heat load incident to the absorption of radient energy. Seath and Miller (1946a) found that the average rectal temperature of cows when they willfully entered shade was 102.4°F, average respiration rate 64 per minute and average air temperature 80°F. Lee et al (1954) have suggested, on the basis of Beltsville work, that grazing dairy cattle need shade when local mean shade temperatures on two successive days exceed 66°F.

In general, two types of studies have been made on the effects of shading on physiological variables. In the one, the effects are confounded with diurnal trend effects. For example, Seath and Miller (1946a) found that in spite of the provision of shade from 9.20 a.m., the rectal temperatures and respiration rates of their cows continued to rise until 3 p.m. when air temperature was at a maximum. There is no way of telling what the variables would have been without shade. The same authors (1947b) held four grade Jersey cows in bright sunshine (shade temperatures ranged from 83 - 90°F) from midday until 2 p.m. and then placed two in the shade. The other two did not act as controls but underwent another treatment. Although air temperature continued to rise slightly, there were declines (of apparently significant magnitude) in rectal temperature, pulse and respiration rate after one hour in the shade. A study by Rhoad (1938) was also confused in this way but he noted in some cases, a fall in rectal temperature and respiration rate when his cattle were shaded in spite of continued rising air temperature. Badreldin and Ghany (1954) found that the rectal temperatures and respiration rates of their cows fell when the animals were transfered from direct sunlight to shade at 12 noon and at 2 p.m.. Pulse rates appeared to follow a diurnal pattern regardless of sun or shade.

In the other type of experiment, direct comparisons were made between shade and no-shade treatments. Rhoad (1940), using purebred Aberdeen Angus cattle, found that for two temperature ranges (86 - 95°F and 76 - 85°F) mean rectal temperature and respiration rate were greater in the sun than in the shade. At 89.0 - 89.7°F air temperature, Gaalaas (1945) found that the rectal temperatures of Jersey cows averaged 0.7°F higher and respiration rates 20 per minute higher when the cows were recorded in the sun than when recorded in the shade and had access to shade. In a reversal type experiment, Seath and Miller (1948) compared two groups of Jersey cows, one with access to shade from 8-9 a.m. At 11 a.m., when air temperatures were 87-94°F, the mean rectal temperature of cows in the sun was 103.93°F and that of cows in the shade 101.91°F. The respective respiration rates were 109.17 and 85.2 per minute. The ranges of the two variables in the two treatments did not overlap and the range was greater in the shadeless group.

Dowling (1956) investigated the diurnal rectal temperature curves of Shorthorn bulls both in the shade and in the sun. Although shade temperatures were lower on the day that the bulls were in the sun than on the day that they were in the shade, the responses of rectal temperature to air temperature were greater in the former case than in the latter.

Summary

Shade is of proven benefit to cattle when air temperatures are above certain limits and when solar radiation is high. At high air temperatures, rectal temperatures, respiration rates and possibly pulse rates are reduced when the cattle are shaded compared with when they are in the sun.

The Influence of Sprinkling with Water

Studies on the use of sprinkled water to lessen the heat load on cattle by increasing the availability of water for evaporation have been reviewed by Findlay and Beakley (1954), Findlay (1950) and Payne (1955). In general, sprinkling has a beneficial effect on European-type cattle in the tropics when air temperature is high and humidity not too high. The spray results in a decline in rectal temperature and respiration rate and Seath and Miller (1947b) have reported a lowering in pulse rate as well. Most of these studies have been made at air temperatures of over 80°F. Minett (1947) has reported significant decreases of 1.6 - 3.8°F in the rectal temperatures of hill bulls standing in monsoon rain at an average air temperature of 59°F. The temperature of the rain water was 48 - 82°F. Contrary evidence has been given by Ragab et al (1953) who could find no notable delines in the rectal temperatures, pulse or respiration rates of Egyptian cattle and Shorthorn cattle as a result of the sprinkling methods used.

Summary

Sprinkling will generally result in a lowering of rectal temperatures, respiration rates and possibly pulse rates when these variables are elevated because of high air temperatures. Insufficient information was available on the work of Ragab et al to suggest a possible reason for their results.

Some Comments on the Measurement of Rectal Temperature

The various methods available for the measurement of body and skin temperature, pulse and respiration rate, and the environmental variables have been discussed by Findlay (1950) and by Lee (1953). Since the methods used in this study are discussed in Chapter III and the measurement of skin temperature is discussed in detail in Chapter VI, this short review will only deal with four general problems in the measurement of body temperature.

Bligh (1955) has stated:

> "In the bovine animal.......the rectal temperature is generally accepted as a measure of deep body temperature."

To what extent does the relationship between rectal temperature and deep body temperature vary when environmental temperatures are changing? Bligh measured temperature at different depths in the rectum and also the deep body temperature as given by a thermo-couple led into the bicarotid arterial trunk leaving the heart. At any other than the most severe air temperature conditions, rectal was slightly higher than carotid temperature but for all practical purposes, upward changes in rectal temperature in response to heat stress paralleled changes of similar magnitude in deep body temperature. Brody et al (1955) found the rectal temperature of a Jersey cow to be higher over 15 minutes (by 0.81°F) than the temperature of the blood (catheter through right jugular to right ventricle).

Kriss (1921) found a temperature gradient in the rectum with a difference of up to 0.8°F between depths of 4" and 7". Although this worker has suggested that it is unreliable to measure rectal temperature at a depth of less than 6", most workers have taken readings at 3-4". Minett and Sen (1945) also found a temperature gradient in the rectum but Bligh (1955) could find only slight and random variations with depth. Kibler and Brody (1951) concluded that a mercury thermometer at a depth of 4" from the anal sphincter gave satisfactory results.

Patchell (1954c) has pointed out that the standing cow would be expected to have a higher rectal temperature than the lying animal since she is expending more energy but he found a higher rectal temperature in the latter. He offered the explanation that the abdominal organs, with high temperatures, were possibly displaced towards the rear in the lying animal. It could be that the standing animal is simply better placed for physical cooling of the anal region. The differences found (0 - 0.6°F) were small and Kriss (1921) could find no effect of the position of the animal on rectal temperature except, possibly, immediately following a change of position.

Beakley and Findlay (1955a) observed sudden rises in the rectal temperatures of their calves of 0.3 - 0.4°F due probably to changes in the position or surroundings of the thermometer. Defaecation was found to be associated with small changes in rectal temperature and Minett and Sen (1945) found differences of 0.1 - 0.8°F between rectal temperature readings taken immediately pre- and post-defaeciation. Kriss (1921) could find no consistent effect. It is suggested that the passage of the cooler faecal mass over the mucosa could momentarily lower its temperature.

<u>Summary</u>

Even if the rectal temperature differs a little from the deep body temperature, changes in the former would be expected to reflect changes in the latter sufficiently well for the former to be used in experimentation. If the rectal temperature is taken at a constant depth in the rectum, if it is taken when the animal is consistently lying or standing and if temperature taking during defaecation is avoided, then variations in rectal temperature due to these factors should be minimised.

CHAPTER III

EXPERIMENTAL STUDY OF THE VARIABLES

Some Comments on Field Studies.

Most of the fundamental experimentation in environmental physiology has been done in psychrometric rooms under controlled conditions. The two best known laboratories, where much of the pioneering work has been done, are at the University of Missouri and at the Hannah Dairy Research Institute in Scotland. Studies on the relationships among the variables (physiological and environmental) as related to heat tolerance are best done initially in the laboratory but field studies have an important place in this work provided that adequate techniques and plans of study are established. There must be close liaison between laboratory and field workers and also between field workers in different parts of the world (Lee, 1953).

The advantages of field studies can be listed as follows:

1. They are comparatively cheap.
2. They are pursued in the conditions under which the animals are expected to perform and "productivity" can be studied in a broad sense.
3. Animals can demonstrate their degree of ecological adaptation.
4. Fairly large numbers of animals can be studied under a wide variety of natural combinations of environmental variables.
5. Farmers and breeders are more likely to take an interest in this type of research work.

However, there are difficulties inherent in field studies which must be overcome. Some of these can be listed as follows:

1. No control is exercised over the climatic variables and a single climatic variable cannot be studied on its own.

2. Animal behaviour is likely to be more variable and unpredictable.

3. The techniques of measurement might have to be cruder in order to obtain a robustness and portability of the instruments.

There is more likely to be a greater variation between animals and larger errors of measurement in the field than in the psychrometric room. Large numbers of animals and repeated readings may partly overcome these difficulties but there are two other problems that arise both in the field and in the laboratory. The first concerns possible interference with the manifestation of an animal reaction by the technique of measurement (e.g Does the application of a skin temperature measuring device to the skin alter the skin temperature in that localised area?). The second concerns any possible physiological effects of psychological reactions and consequent behaviour patterns (e.g. the effect of excitement on the pulse rate).

A. THE DIURNAL TRIAL

Materials and Methods

Six mature pedigree Jersey cows of the Massey Agricultural College "Production per Acre Project" herd were used in this trial. These cows, described in table 2, were selected at random from the herd except that, in order to ensure that the cows were as normal as possible during measurement, only naturally quiet cows were considered. The herd was grazing freely on a predominately short-rotation ryegrass (*Lolium perenne* x *L. multiflorum*) and white clover (*Trifolium repens*) pasture at a stocking rate of 0.9 cows per acre. During the trial period, the herd was given maize (*Zea mays*) and marrow-stem kale (*Brassica oleracea*) as supplementary feeds. Milk recording and butterfat testing were carried out once every month and the cows were weighed every week at the same time of day as a routine practice. Water *ad lib* and shade (in some paddocks only) were available to the herd.

Rectal temperatures, pulse and respiration rates were recorded on four suitable fine days between 11/2/58 and 22/2/58. Readings were obtained nine times on each day - at 10 a.m., noon, 2 p.m., 6 p.m., 8 p.m., 10 p.m., midnight, 2 a.m. and 4 a.m. 6 a.m. and 4 p.m. readings were not taken because the herd was being milked at these times. 8 a.m. readings were taken on three days only so that these data were used in the graphs but not in the statistical analyses. Skin temperatures were recorded on three suitable days between 21/2/58 and 5/3/58. Readings were obtained five times each day - at 8 a.m., 10 a.m., noon, 2 p.m.,

TABLE 2

Characteristics of the Cattle Used in the Diurnal Trial

Number	Name	Age	Weight	Production	Days in Milk	Calving Date	Colour
3	Love	2 yrs	808 lbs	69 lbs.	224	13/7/58	Fawn-grey
21	Joybell	4	843	72	198	27/8/58	Dark brown
4	Juggler	4	842	98	216	29/7/58	Brown
74	Gerbera	6	935	85	201	11/8/58	Light fawn
1	Ellen	8	741	70	197	28/7/58	Light fawn
29	Dorothy	9	863	86	204	29/7/58	Light brown

Weight Mean of four weighings (4/2/58, 11/2/58, 23/2/58 and 4/3/58)

Production lbs. butterfat for 60 days ending 21/2/58

Days in Milk at 21/2/58

and 6 p.m.. Night readings were not taken because dew interfered with the thermo-couple junction. Skin temperature readings were taken on separate days from the other physiological variables (except on the 21/2/58) because the measuring apparatus and labour were not always available when required.

Seven preliminary sets of recordings of rectal temperature, pulse rate and respiration rate, and two sets of skin temperature, were made between 3/2/58 and 8/2/58 in order to accustom the animals to the routine and to perfect the measurement techniques.

Each set of readings (at any one time of day) took approximately 40 minutes and air temperature was recorded at the beginning and end of each 40 minute period, the two temperatures being averaged to obtain a mean air temperature for the particular set of readings. The recordings were made with a mercury thermometer (0-240°F) hung in a sheltered, shady spot at the site of operations. It was originally planned to take continuous records of air temperature and relative humidity using a clockwork bi-metallic thermograph and hair hygrograph (Middleton, 1942) but this apparatus failed. Meteorological data for the days concerned were obtained from the Grasslands Division, D.S.I.R., Palmerston North, situated within 300 yards of the sites at which the animal measurements were taken.

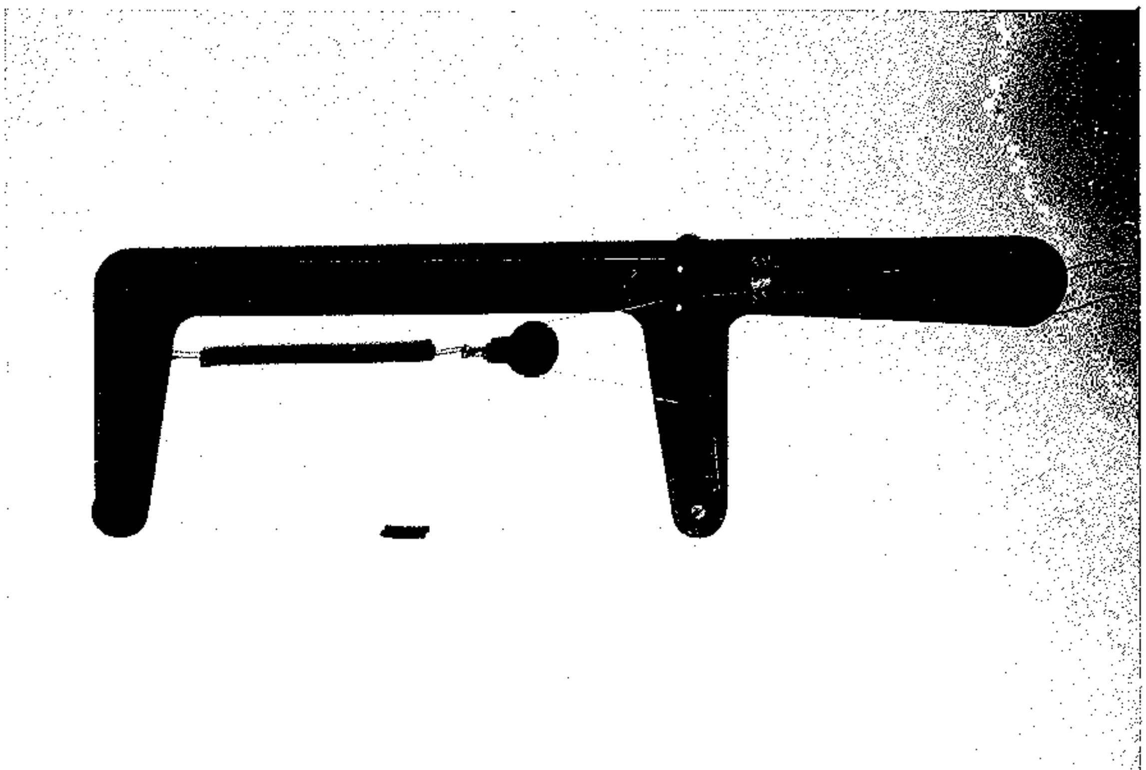
Rectal temperature was measured with a 4", mercury in glass, clinical thermometer (certified correct to within 0.2°F) inserted in the rectum to a constant depth of 3" from the anal sphincter. A 1" long cork on the end of the instrument ensured this constant depth of insertion. Although "½ minute" was given by the makers as the standard time for equilibrium to be reached with this type of thermometer, it was found desirable to leave the instrument in position while pulse and respiration rate were being recorded (on average 1½ minutes). Readings were taken to the nearest 0.05°F.

Respiration rate was measured by counting flank movements (complete respirations) over 30 second intervals, timed with the second hand of a wrist watch. Since interruptions to respiration such as swallowing and eructation were irregular, it was thought desirable to establish a rhythm in counting which was continued through such interruptions in order to have the repeatability as high as possible and to establish a measurement more indicative of the respiratory status of the animal than of its digestive status. Pulse rate was determined by manual palpation of the ventral coccygeal artery (Wirth, 1956) and timed in a similar way to respiration rate.

Skin temperature measurements were made using a copper-constantin thermocouple and a Cambridge Portable potentiometer with the reference junction at 32°F in crushed ice in a thermos flask. The couple was held in a bow-type holder described by Patchell (1954b) (see figure 2) and, in accordance with his findings, applied to the skin surface beneath the hairs in the region of the hip bone. The area was shaded with the hand while the potentiometer was read. The thermocouple had been calibrated in a water bath by several runs (up and down the temperature scale) over the temperature range in which it was to be used and the regression of temperature (°F) on potentiometer reading

FIGURE 2

BOW TYPE THERMOCOUPLE HOLDER.



(millivolts) determined.

$$Y(^{o}F) = 35.363 + 42.386 X (mV)$$

This regression line (highly significant by "F" test for 1 and 29 degrees of freedom) was then used to convert all potentiometer readings to the temperature scale. Readings were taken to 0.01°F.

All four of these measuring systems have a scale which is additive and monotonic and all are reasonably simple except the method for skin temperature measurement which is discussed further in Chapter VI.

The six cows were separated from the herd 5-10 minutes before readings were commenced and enclosed in a small, portable netting pen erected in the paddock. Each cow was haltered and tied to the fence before reading. All care was taken to see that the animals were excited as little as possible when walking to the pen, when penned and especially when readings were being made. There was however, a degree of excitement and restlessness which must be allowed for in the interpretation of results. The cows were dealt with in random order at any one time on a day with the restriction that the same random order was repeated on successive days. All readings of rectal temperature, pulse rate, respiration rate and air temperature were taken by the author and a number of different assistants were used to work the potentiometer for the skin temperature measurements. The night readings were taken by torchlight. The difficulties caused by flies are discussed in Chapter V but this was a factor causing restlessness in the animals and occasionally making some readings (pulse rate in particular) difficult to obtain.

Three repeated readings were taken for each variable on each cow at each time of day. If one of these three was six beats per minute (pulse and respiration rate) or 0.2°F (rectal temperature) or more different from either of the other two it was automatically discarded as being the least accurate indicator of the state of the animal. No such arbitrary levels were set for skin temperature. If all three readings were within the limits, the odd member of the trio was discarded at random.

This randomised block design (with cows as blocks) replicated in time (days) was analysed in a similar manner to the example given by Wilm (1945). The design is analogous to a "split plot" design with a number of splits (days) within each time of day and cow. All first order interactions were tested with reference to the second order interaction or residual error term. The significances of differences between cow means and between time of day means were tested by the interaction between cows and times which is an estimate of the failure of the diurnal pattern to be repeated from cow to cow. If only one of the first order interactions involving days was significant it was used to test the significance of differences between days. If both or neither were significant, the analysis was handled in the manner which seemed most appropriate from an examination of the mean squares (see discussion on each individual analysis). Although the standard procedure in a split plot experiment is to test the mean squares "within plots" by an error compounded of one of the within plot first order interactions and the second order interaction (Snedecor, 1955), this may not be valid if either of the first order interactions "within plot" is of any magnitude in relation to the residual error term. If the interactions are pooled to give a compound error term there remains the problem of how many degrees of freedom to use. Again, if the cow rankings or diurnal pattern are different from day to day, then the significance of differences between day means is probably of little importance and could, if necessary, be ignored (Glenday, 1959).

A similar type of analysis has been used by Patchell (1954a) and by Alim and Ahmed (1957). The component of variance termed "within readings" in this analysis is an estimate of the error introduced by taking the two repeated readings on each cow at each time and is therefore a measure of the repeatability of the measurement system.

Readings for Cow 4 at noon on 19/2/58 were not obtained because of an instrument breakdown. These missing plots were filled by estimates derived from the following formula supplied by Glenday (1958):

$$X = \frac{24A + 36B + 54F - 6C - 4D - 9T + G}{120}$$

where A = Sum of 8 readings for same cow and day.
B = Sum of 5 readings for same time and day.
F = Sum of 3 readings for same time and cow.
C = Sum of 35 readings for same cow.
D = Sum of 53 readings for same day.
T = Sum of 23 readings for same time.
G = Sum of 215 readings

worked on the means of the repeated readings.

FIGURE 3

DIURNAL AIR TEMPERATURE PATTERN - INDIVIDUAL DAYS AND MEAN

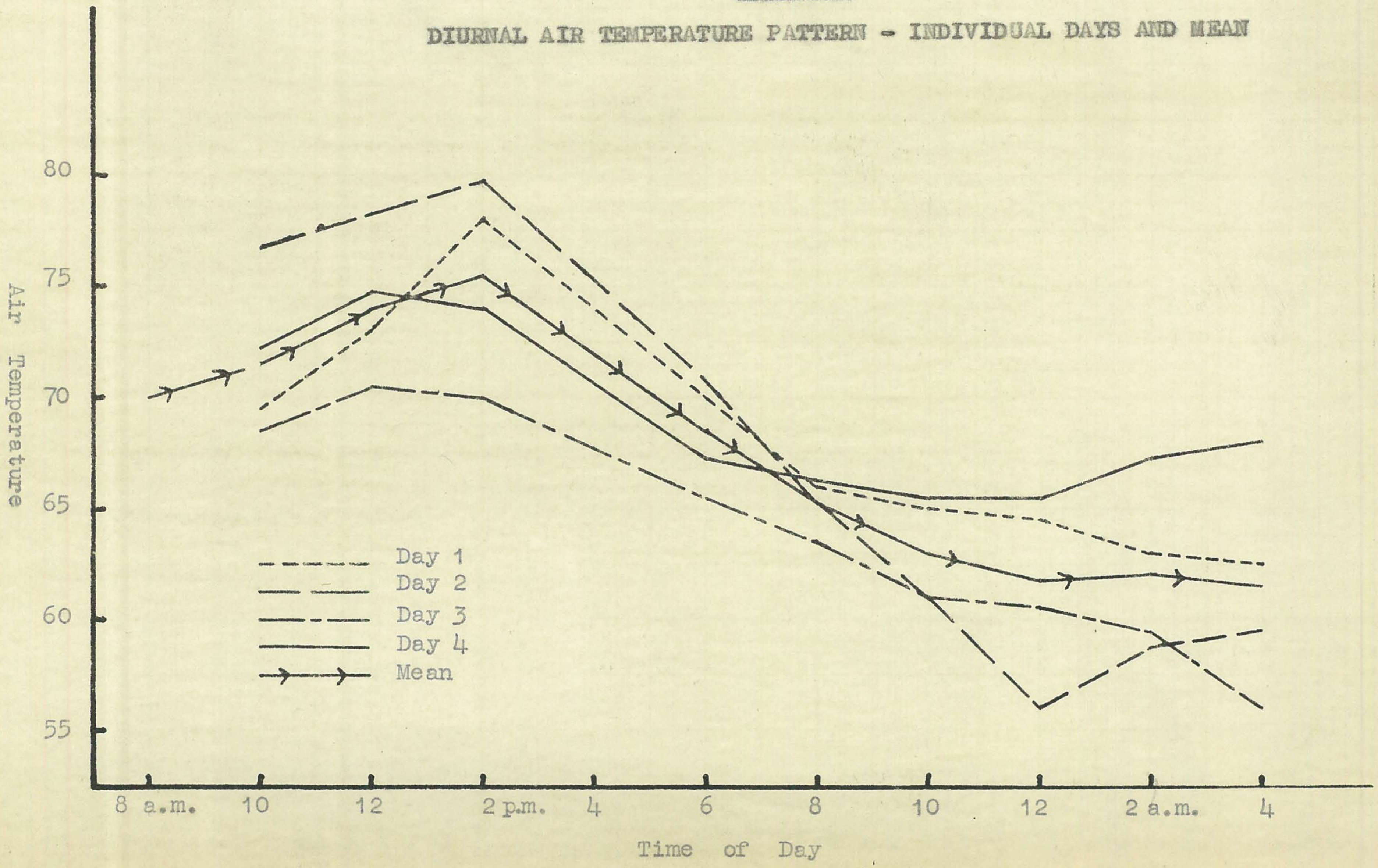
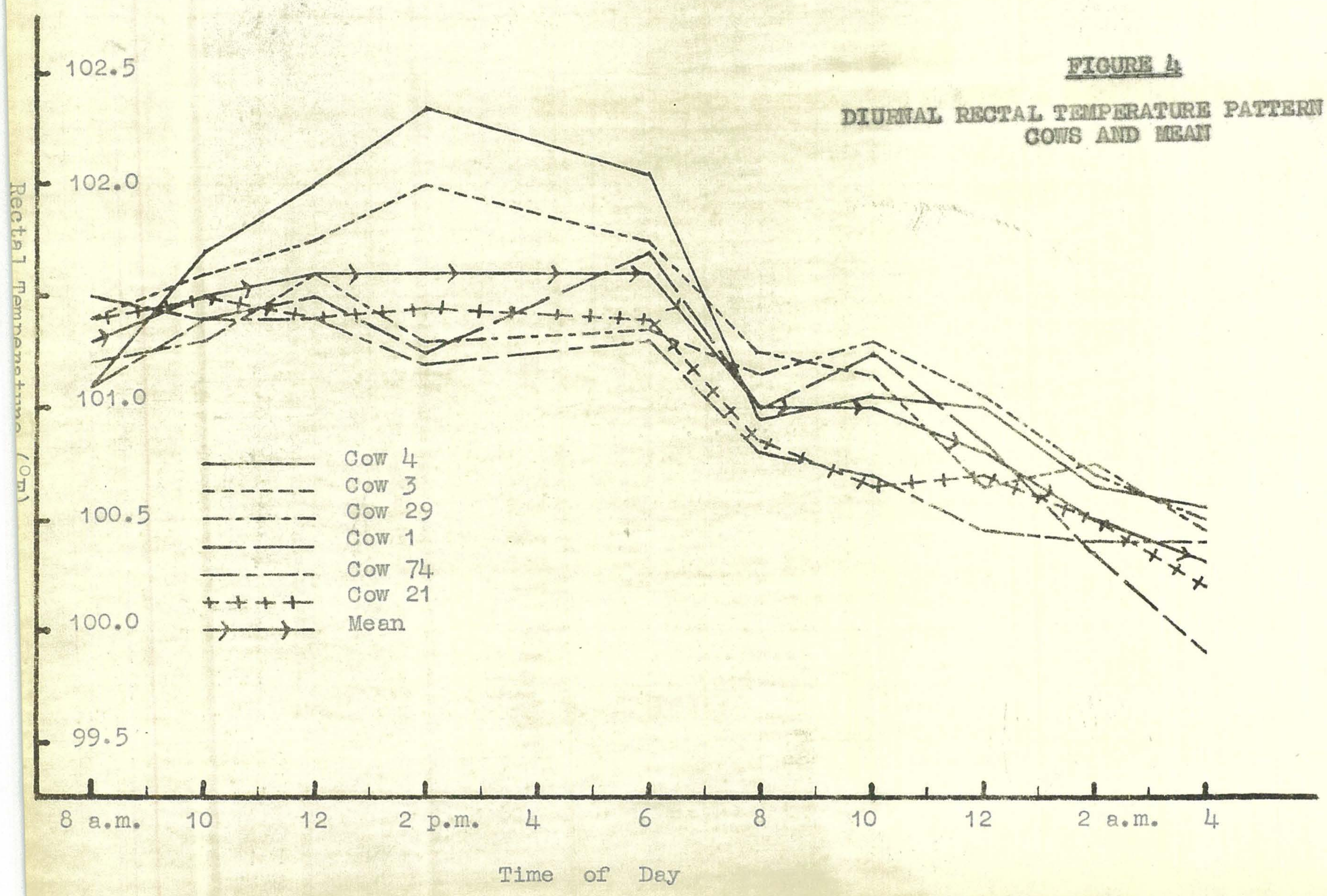


FIGURE 4

DIURNAL RECTAL TEMPERATURE PATTERN - INDIVIDUAL COWS AND MEAN



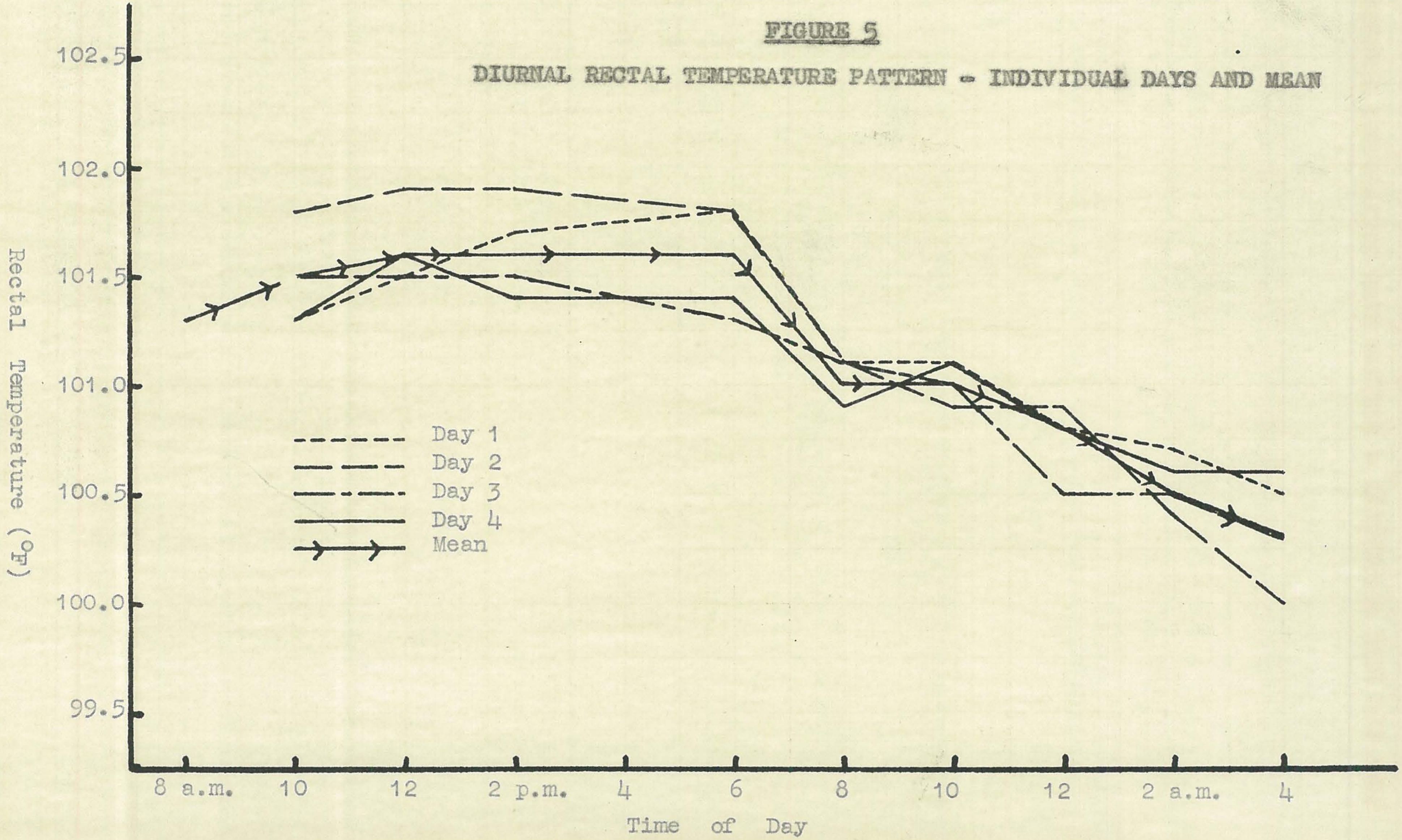


FIGURE 5
DIURNAL RECTAL TEMPERATURE PATTERN - INDIVIDUAL DAYS AND MEAN
102.5
102.0
101.5
101.0
100.5
100.0
99.5
Rectal Temperature (°F)
Day 1
Day 2
Day 3
Day 4
Mean
8 a.m.
10
12
2 p.m.
4
6
8
10
12
2 a.m.
4
Time of Day

FIGURE 6

DIURNAL RESPIRATION RATE PATTERN - INDIVIDUAL ~~DAYS~~ Cows. AND MEAN

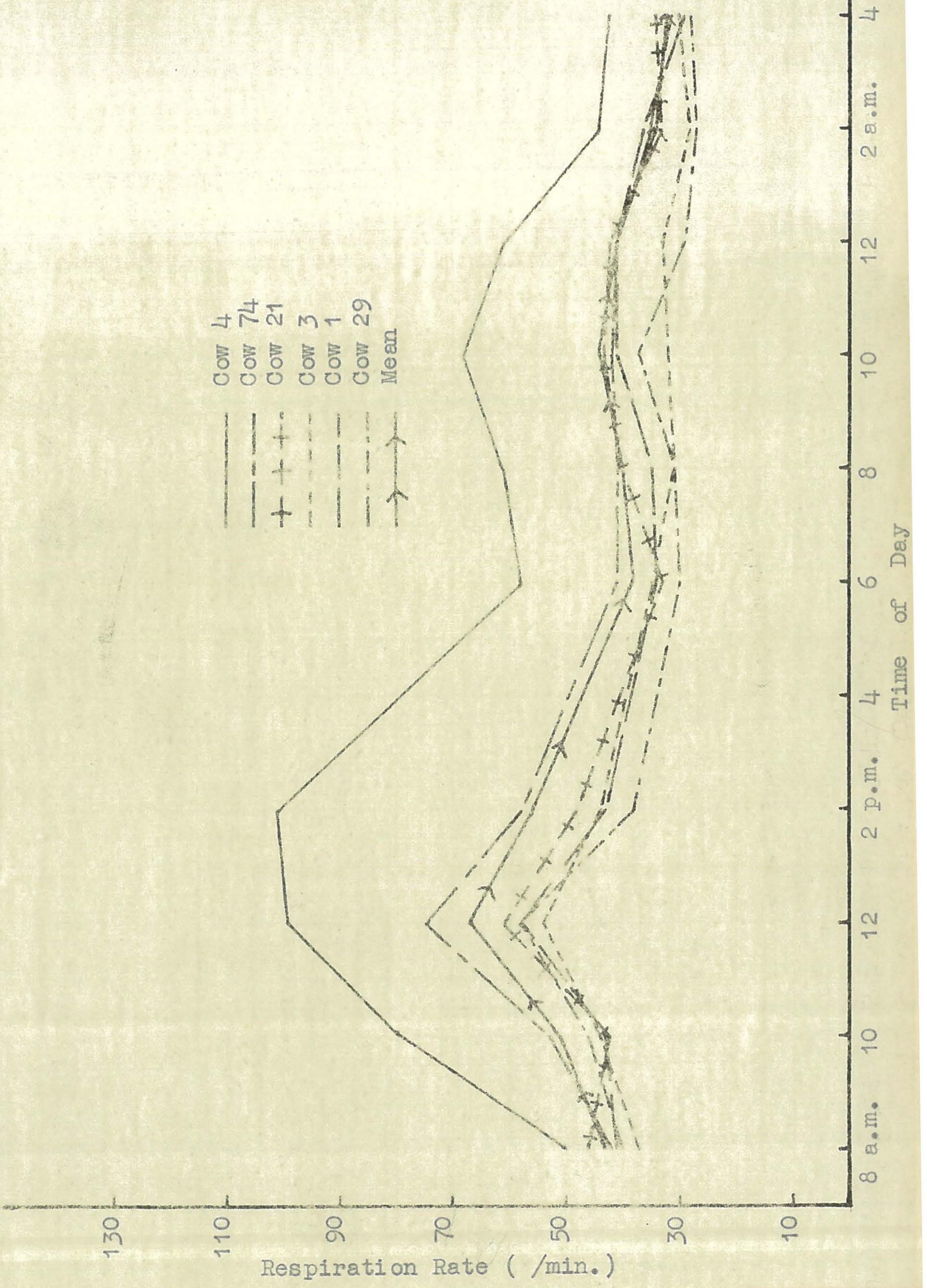


FIGURE 7

DIURNAL RESPIRATION RATE PATTERN - INDIVIDUAL DAYS AND MEAN

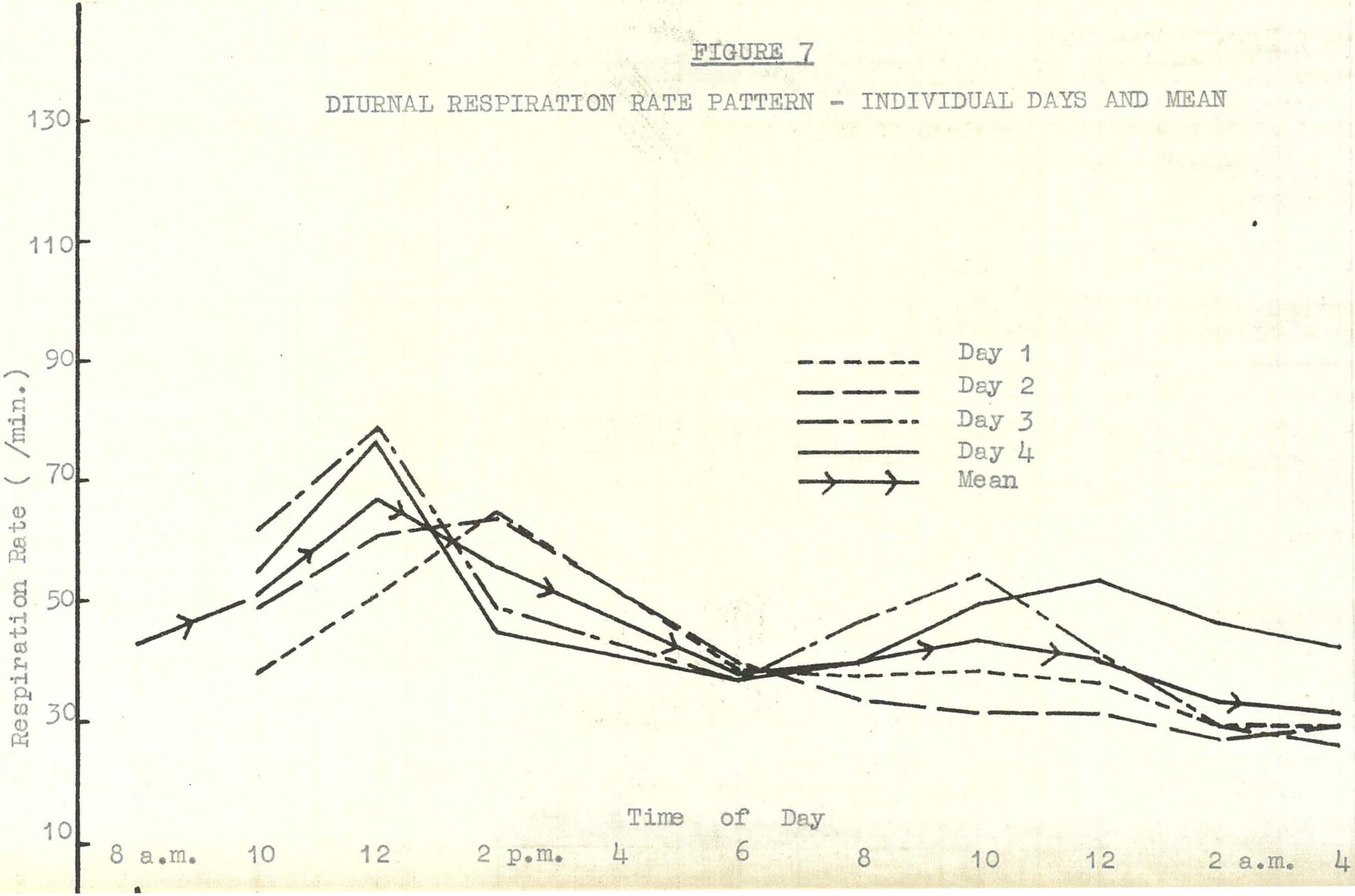
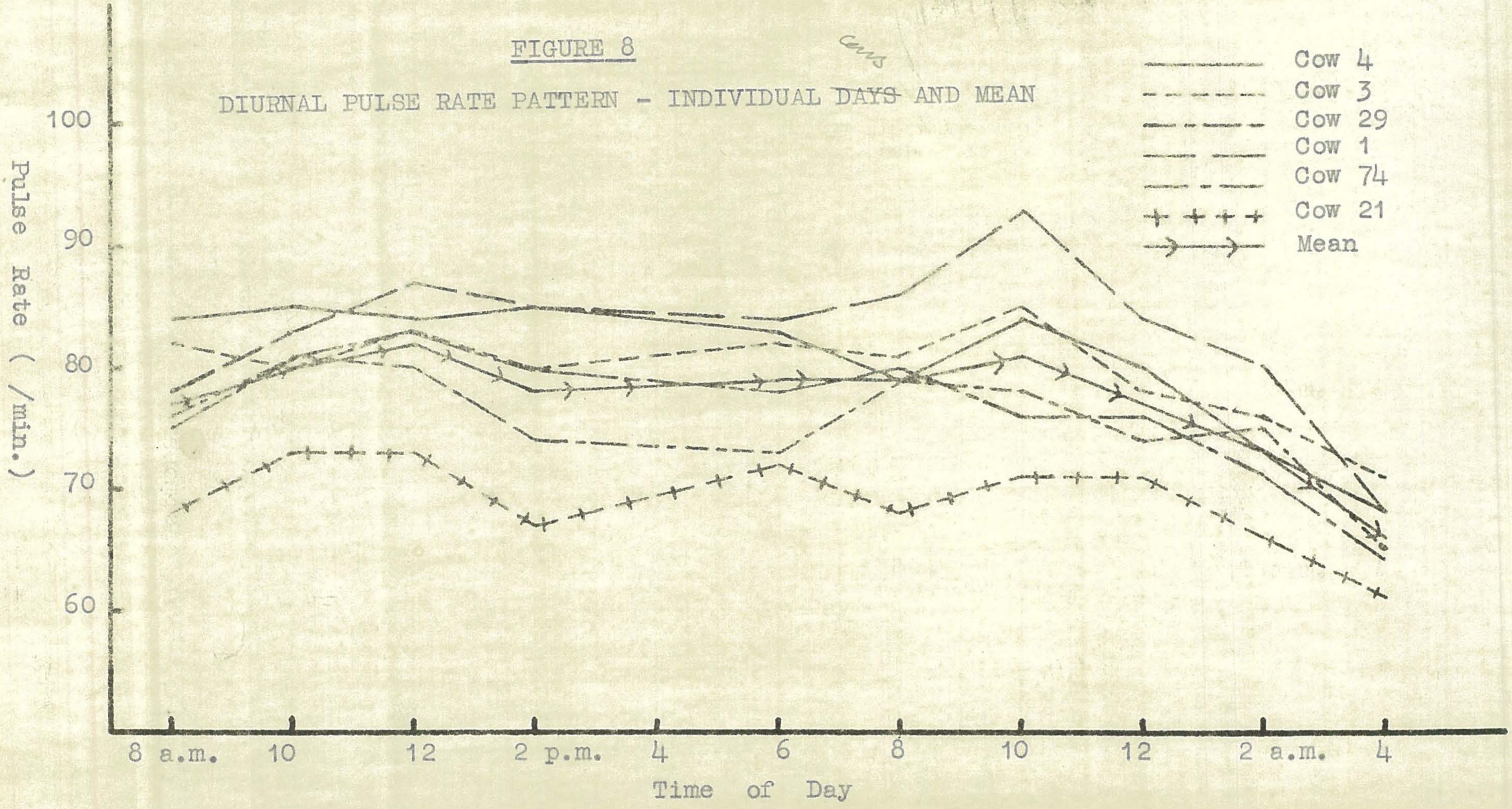


FIGURE 8

DIURNAL PULSE RATE PATTERN - INDIVIDUAL ~~DAYS~~ cows AND MEAN



<u>FIGURE 9</u>

DIURNAL PULSE RATE PATTERN - INDIVIDUAL DAYS AND MEAN

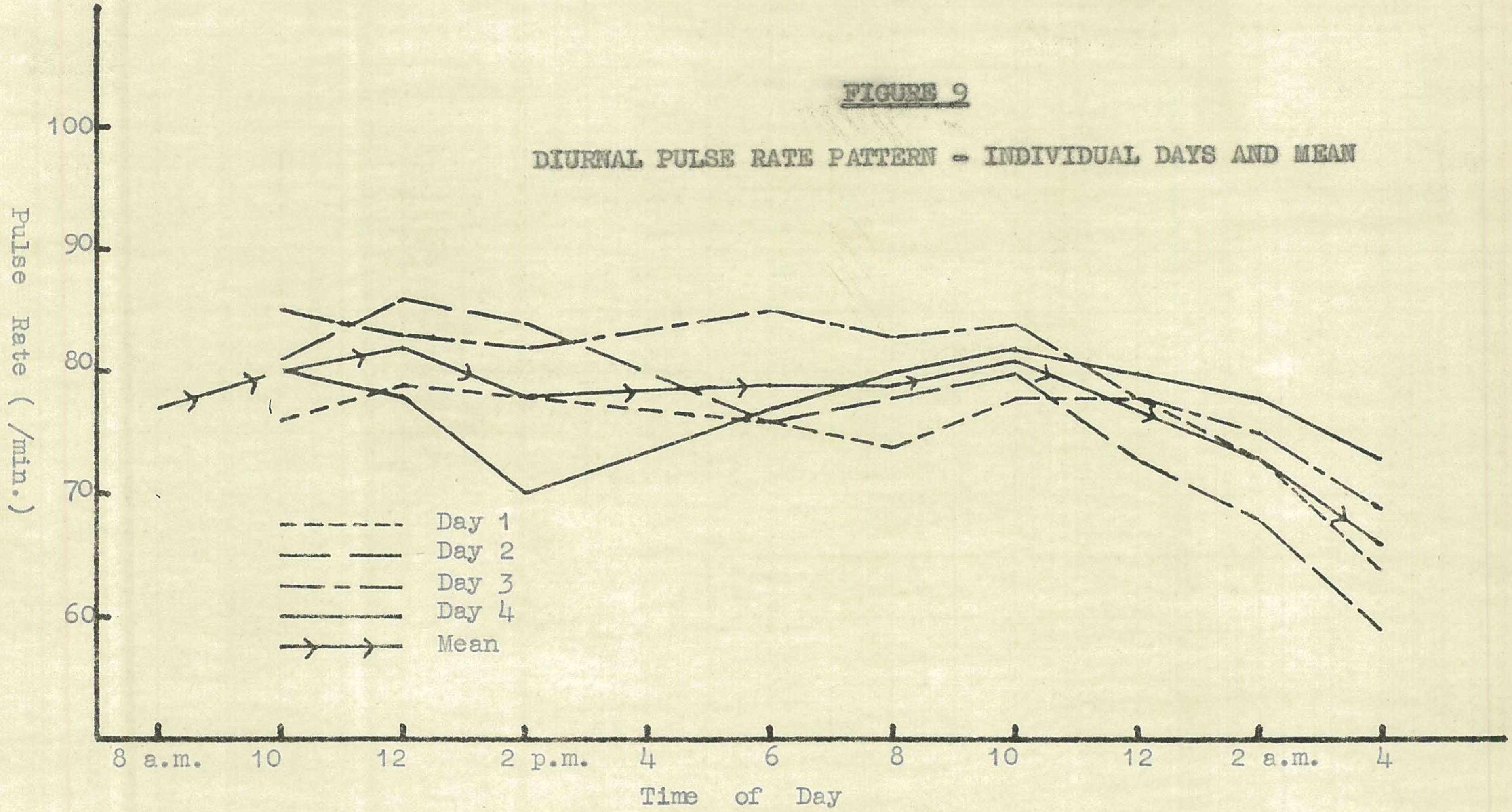


FIGURE 10

DIURNAL SKIN TEMPERATURE PATTERN - INDIVIDUAL COWS, DAYS AND MEAN; AND DIURNAL AIR TEMPERATURE PATTERN - INDIVIDUAL SKIN TEMPERATURE DAYS AND MEAN

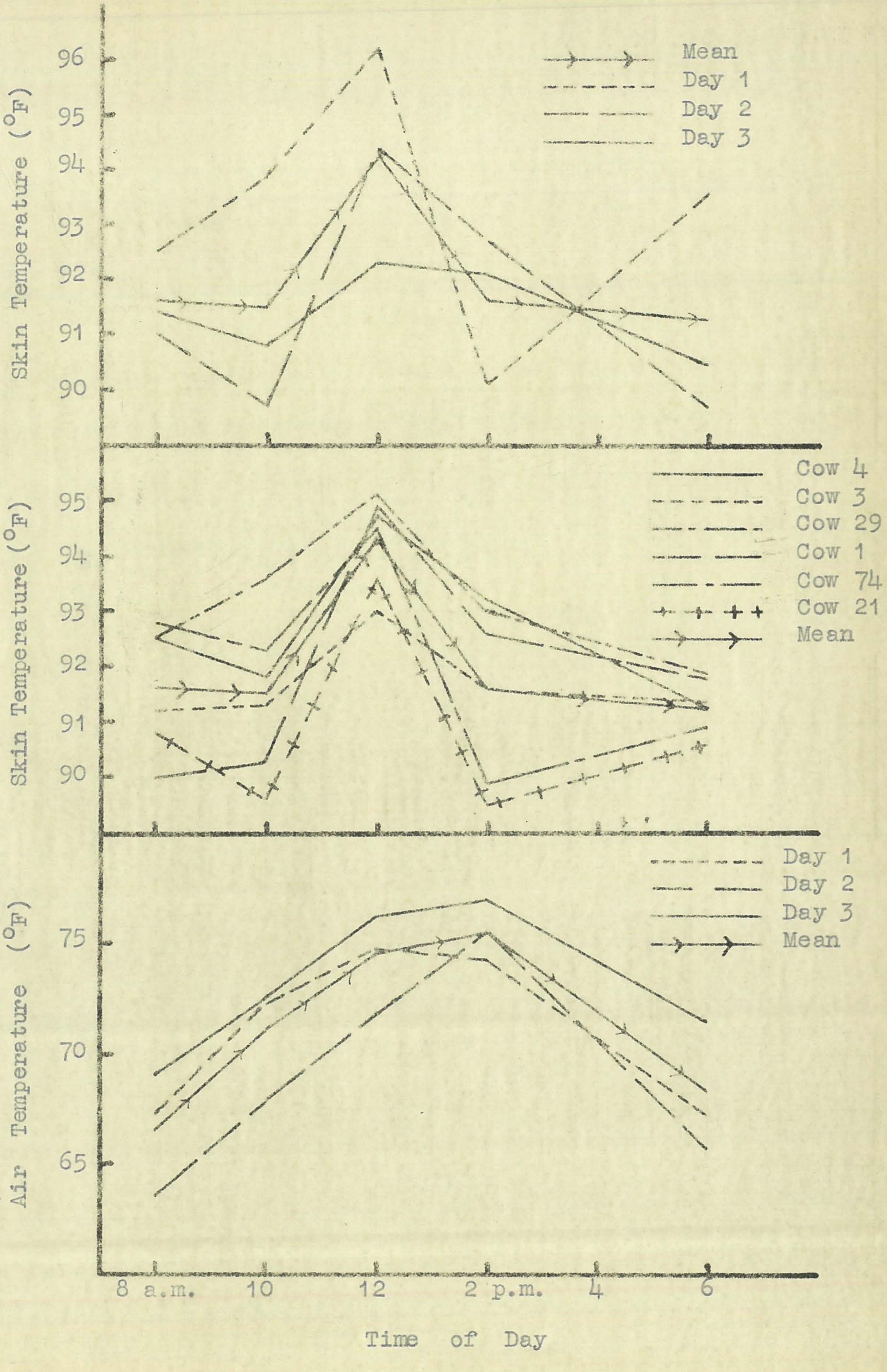


TABLE 3

Results of the Analyses of Variance of the Diurnal Trial Data

Source	df.	S^2	DCT^2	DC^2	CT^2	DT^2	C^2	T^2	D^2	Resp. Rate MS	Resp. Rate "F"	Pulse Rate MS	Pulse Rate "F"	Rectal Temp. MS	Rectal Temp. "F"
Bet. Cows	5	1	2	18	8	-	72	-	-	10,323	34.07**	1,706.4	34.4**	2.6	9.63**
Bet. Times	8	1	2	-	8	12	-	48	-	6,131	20.23**	1,106.0	22.3**	11.5	42.59**
Cows x Times	40	1	2	-	8	-	-	-	-	303	2.07**	49.6	1.6*	0.27	1.36
Bet. Days	3	1	2	18	-	12	-	-	108	2,318	* a	593.3	* a	0.97	a
Days x Cows	15	1	2	18	-	-	-	-	-	256	1.75*	114.8	3.72**	0.43	2.17*
Days x Times	24	1	2	-	-	12	-	-	-	832.4	5.68**	180.1	5.83**	0.45	2.27**
D X C X T	120	1	2	-	-	-	-	-	-	146.6	-	30.9	-	0.198	-
Within Readings	216	1	-	-	-	-	-	-	-	6.6	-	4.5	-	0.008	-
Total	431														

Source	df	S^2	DCT^2	DC^2	CT^2	DT^2	C^2	T^2	D^2	Skin Temp. MS	Skin Temp. "F"
Bet. Cows	5	1	2	10	6	-	30	-	-	20.52	4.11**
Bet. Times	4	1	2	-	6	12	-	36	-	57.08	11.44**
C x T	20	1	2	-	6	-	-	-	-	4.99	1.41
Bet. Days	2	1	2	10	-	12	-	-	60	65.40	2.26
D x C	10	1	2	10	-	-	-	-	-	6.80	1.92
D x T	8	1	2	-	-	12	-	-	-	28.95	8.18**
D x C x T	40	1	2	-	-	-	-	-	-	3.54	-
Within Readings	90	1	-	-	-	-	-	-	-	0.94	-
Total	179										

Source	Air Temp (4 Main Days) df	Air Temp (4 Main Days) MS	Air Temp (4 Main Days) "F"	Air Temp (Skin T. days) df	Air Temp (Skin T. days) MS	Air Temp (Skin T. days) "F"
Bet. Days	3	44.3	4.9**	2	24.21	14.16**
Bet. Times	8	124.3	13.7**	4	44.14	25.81**
Error	24	9.1	-	8	1.71	-
Total	35	-	-	14	-	-

a. See discussion
* Significant ($p < 0.05$)
** Highly Significant ($p < 0.01$)

Results

The results of the trial are presented in the form of graphs in figures 3-10 inclusive. Each point on the individual cow graphs for rectal temperature, pulse and respiration rate is the mean of 8 readings (two repeats and four days) except for the 8 a.m. points in each of which only three days were involved. Similarly in the other five graphs of the animal variables, each point is the mean of a number of readings. The mean graph lines are drawn through the means of all readings for the particular time of day. The air temperature graphs for the individual days are single plots. The skin temperature data is plotted to 0.1°F only.

The results of the analyses of variance are given in table 3 along with the components of variance contained in each mean square. From the latter were estimated the variances given in table 4. As mentioned before, the "within readings" component is an estimate of the variance within the plot made up of two repeated readings on the same animal at the same time on the same day. For comparative purposes, repeatability estimates were derived on the following basis:

$$R = \frac{D \times C \times T^2}{D \times C \times T^2 + S^2 \text{ (Within Rdgs.)}}$$

and are measures of the within plot error as a proportion of the total "unexplained" error variance.

The estimates obtained were:

Respiration Rate	0.91
Pulse Rate	0.75
Rectal Temperature	0.92
Skin Temperature	0.58

TABLE 4

Variances Contained in the Diurnal Trial Data

	Pulse Rate		Respiration Rate		Rectal Temperature		Skin Temperature	
	s^2	%	s^2	%	s^2	%	s^2	%
Within Pigs	4.5	5.56	6.6	1.58	0.008	1.97	0.94	14.18
C^2	21.9	27.04	137.7	33.02	.029	7.13	.41	6.18
T^2	18.9	23.33	107.1	25.68	.229	56.27	.74	11.16
D^2	3.1	3.83	12.7	3.05	.003	0.74	.55	8.30
$C \times T^2$	2.3	2.84	19.6	4.70	.009	2.21	.24	3.62
$D \times C^2$	4.7	5.80	6.1	1.46	.013	3.19	.33	4.98
$D \times T^2$	12.4	15.31	57.2	13.72	.021	5.16	2.12	31.98
$D \times C \times T^2$	13.2	16.30	70.0	16.79	.095	23.34	1.30	19.61
Total	81.0	100.01	417.0	100.00	0.407	100.01	6.63	100.01

TABLE 5

Means and Variances for Individual Times and Cows, and Means for Days, from the Diurnal Trial

	Pulse Rate /minute					Respiration Rate /minute					Rectal Temperature °F				
Time	M	s^2	S	SE	CV	M	s^2	S	SE	CV	M	s^2	S	SE	CV
10 a.m.	80.4	41.57	6.45	1.32	8.02	51.1	323.04	17.97	3.67	35.17	101.5	0.12	0.35	0.07	0.34
12	81.5	40.52	6.37	1.30	7.82	67.1	481.91	21.96	4.48	32.73	101.6	0.20	0.45	0.09	0.44
2 p.m.	78.3	88.83	9.43	1.92	12.04	55.8	566.17	23.80	4.86	42.65	101.6	0.42	0.64	0.13	0.63
6	78.6	45.22	6.73	1.37	8.56	38.3	130.54	11.42	2.33	29.82	101.6	0.18	0.43	0.09	0.42
8	78.7	52.65	7.26	1.48	9.22	39.6	179.90	13.42	2.74	33.89	101.0	0.12	0.35	0.07	0.35
10 p.m	81.0	84.35	9.19	1.88	11.35	43.8	274.09	16.56	3.38	37.81	101.0	0.16	0.40	0.08	0.40
12	77.0	31.57	5.62	1.15	7.30	41.0	241.35	15.53	3.17	37.88	100.8	0.10	0.32	0.07	0.32
2 a.m.	73.3	47.52	6.90	1.41	9.41	33.7	133.17	11.54	2.36	34.24	100.5	0.07	0.27	0.06	0.27
4	66.3	47.13	6.87	1.40	10.36	32.3	106.02	10.30	2.10	31.89	100 3	0.13	0.36	0.07	0.36
8	77.2	71.59	8.46	2.00	10.96	42.8	77.79	8.82	2.08	20.61	101.3	0.27	0.52	0.12	0.51
Cow															
21	69.1	26.51	5.15	0.86	7.45	41.6	171.55	13.10	2.18	31.49	101.0	0.27	0.52	0.09	0.51
74	76.6	44.43	6.67	1.11	8.71	46.1	301.47	17.37	2.90	37.68	100.9	0.25	0.50	0.08	0.50
3	79.4	36.99	6.08	1.01	7.66	36.5	124.03	11.14	1.86	30.52	101.3	0.35	0.59	0.10	0.58
1	83.2	102.14	10.10	1.68	12.14	40.3	143.99	12.00	2.00	29.78	101.0	0.47	0.69	0.12	0.68
4	80.0	59.46	7.71	1.29	9.64	67.9	636.34	25.23	4.21	37.16	101.4	0.55	0.74	0.12	0.73
29	75.3	49.98	7.07	1.18	9.39	35.8	187.48	13.70	2.28	38.27	101.1	0.23	0.48	0.08	0.47

Skin Temperature °F

Time	M	s^2	S	SE	CV
8 a.m.	91.6	2.61	1.62	0.38	1.77
10	91.5	6.80	2.61	0.62	2.85
12	94.3	4.77	2.18	0.51	2.31
2 p.m.	91.6	4.49	2.12	0.50	2.31
6	91.3	4.11	2.03	0.48	2.22

Skin Temperature °F

Cow	M	s^2	S	SE	CV
21	90.8	6.57	2.56	0.66	2.82
74	92.1	5.37	2.32	0.60	2.52
3	91.7	2.00	1.41	0.36	1.54
1	91.9	8.42	2.90	0.75	3.16
4	92.7	5.38	2.32	0.60	2.50
29	93.2	4.41	2.78	0.72	2.98

Means for Days

Day	Pulse	Respiration	Rectal Temp.
1	75.1	40.6	101.16
2	76.0	41.0	101.20
3	80.4	47.5	101.01
4	77.4	49.8	101.07

Day	Skin Temp.
1	93.27
2	91.50
3	91.42

Means and variances for the individual times of day and cows, and means for the individual days, for each of the four animal variables are given in table 5. These statistics were derived from the means of the two repeated readings so that the variances do not include this additional source of variation. Individual time of day and individual day means for both sets of air temperature data are given in table 6. Overall means, ranges and variances from the complete data for all five variables are given in table 7.

Relative humidity data, taken with a wet and dry bulb sling psychrometer (Middleton, 1942), were obtained for two of the 24-hour periods. Diurnal patterns of relative humidity appeared to follow those of air temperature in an inverse manner and ranged from 62% in the afternoon to 92% in the early morning.

Meteorological data obtained from the Grasslands Division, D.S.I.R., and general comments on climatic conditions made in the field, are set out in appendix 1. The raw data for all five variables are given in appendices 2-6 inclusive.

Discussion

(a) Repeatabilities

In order to assess the usefulness of a measurement system for biological investigations it is necessary to determine its accuracy. A repeatability estimate is a measure of the closeness of agreement between repeated observations on the same individual assuming no real change in the variable over the time involved. Even such objective measurements as rectal temperature

TABLE 6

Means for Individual Times and Days from Air Temperature Diurnal Data.

Air Temperature (4 Main Days) °F

Time	10 a.m.	12	2 p.m.	6	8	10	12	2 a.m.	4
Mean	71.7	74.1	75.5	68.4	65.3	63.1	61.6	62.1	61.5

Day	1	2	3	4
Mean	67.9	67.4	63.9	69.0

Air Temperature (Skin Temperature Days) °F

Time	8 a.m.	10	12	2 p.m.	6
Mean	66.6	70.8	74.3	75.5	68.2

Day	1	2	3
Mean	71.1	68.9	73.3

TABLE 7

Overall Means, Ranges and Variances for Each Variable from the Diurnal Trial

	Mean	s^2	s	SE	CV	Range	
Pulse Rate	77.2	81.00	9.00	0.43	11.66	52 – 96	/minute
Respiration Rate	44.7	417.00	20.42	0.98	45.68	18 – 118	/minute
Rectal Temperature	101.1	0.41	0.64	0.03	0.63	99.1 – 103.3	°F
Skin Temperature	92.1	6.63	2.58	0.19	2.80	86.1 – 100.8	°F
Air Temp. (4 Main Days)	67.0	38.44	6.20	1.03	9.25	56.0 – 79.8	°F
Air Temp. (Skin Temp.Days)	71.7	17.05	4.13	1.07	5.81	63.5 – 77.0	°F

determination include a subjective element, an error due mainly to the observer, and although the systems used in this study have been widely used, no accounts of repeatability trials in which these systems were firmly established could be found in the literature. It was therefore necessary to assess the accuracies of the systems in the hands of this observer.

As stated previously, three repeated readings were taken on each cow at each time, one of which was deleted before analysis. The pulse rate sometimes decreased markedly over the three readings if the first reading was elevated because of the effects of excitement (Wirth, 1956). In such a case the highest reading was deleted but this could have been a source of error and probably contributed, along with general difficulties experienced in taking pulse rates if the cows were disturbed, to the lower repeatability estimate obtained for this variable compared with that for respiration rate. The estimates for rectal temperature and respiration rate were satisfactory but the skin temperature estimate was low. This could have been due to inadequacies in the technique for applying the thermocouple to the skin, to very rapid changes in skin temperature with time, or to the fact that some of the assistants were not as skilful as others in the use of the potentiometer.

The effects of sudden excitement on the rectal temperature, respiration rate and pulse rate of a single cow were investigated in order to assess the possible influence of this factor on the repeatability estimates. The pulse rate rose sharply from 83 to 92 beats per minute after the cow had been chased twice around the yard. After five minutes rest, the rate had declined to 82 beats per minute. This abrupt rise seemed to be clearly an effect of the disturbance. The rectal temperature rose steadily by 0.55°F over the whole period while the respiration rate remained virtually unchanged. Although the treatment was drastic, pulse rate (and possibly rectal temperature) could be affected in a similar way during normal experimentation.

(b) Pulse Rate

The graphs show a diurnal trend in pulse rate both for each individual cow and for the means of all cows on individual days. The main feature was a steady fall in rate from 10 p.m. until 4 a.m. when the cows were quiescent and usually lying down. The greatest variation in rate occured at around 2 p.m. and at 10 p.m. (table 5). The greatest variation in air temperature also occurred at 2 p.m. but the general rise and increase in variation at 10 p.m. is difficult to explain. There could be a connection between this and increased metabolic activity following the evening grazing period which usually lasts from the completion of milking at 5 p.m. until 9 p.m. (Hancock, 1948). Since air temperature is normally declining at this time, any effect of air temperature on pulse rate would have been unlikely to obscure any "metabolic effect".

The results of the analysis of variance show significant differences between the means of the six cows, between the times of day and between the different days. The diurnal pattern of pulse rate seemed to be different for each cow (cows by times interaction), the cows reacting differently to the various factors which affect pulse rate. The variation between days was significant whether tested by the highly significant failure of the cows to rank the same on the different days or by the highly significant failure of the diurnal pattern to be repeated from day to day. Variations in the influences of climatic factors and grazing pattern from day to day probably account for the magnitude of these interactions.

Wilm (1945) proposed a method for answering the type of question of which the following are examples. The method uses the components of variance derived from the analysis of variance.

1. On other days, similar to those of the experiment, is the same diurnal pattern likely to occur in other cows from the population of which these cows are a sample?

2. With similar cows to those used in the experiment, is the same diurnal pattern likely to occur on other days from the time population of which these days are a sample?

In other words, the value of the sampling methods used is being questioned. The procedure for question 1 involves subtracting the days by times component of variance from the between times mean square before testing this mean square over the cows by times interaction mean square in the normal way. Similarly for question 2, the cows by times component is subtracted from the between times mean square and the residual tested over the days by times interaction mean square or "time" error in Wilm's terminology. Wilm has pointed out that these calculated values for "F" will not follow exactly the mathematical distribution of "F" and he therefore reduced the number of degrees of freedom involved. The value of the method has not been determined but, for what it was worth, both values of "F" were calculated and found to be highly significant using 6 and 35 degrees of freedom in the one case and 6 and 30 degrees of freedom in the other. This suggests justification for extrapolating these results to other days or to other cows of the same population with similar stock or on similar days.

The greatest proportion of the total variation was caused by variations between cows and between times of day, as well as by the interaction between days and times, as determined from the components of variance.

The overall mean pulse rate was 77.2 ± 0.43 beats per minute with a range of 52 – 96 per minute. This is a little on the high side if compared with the 45 – 60 per minute range considered as normal in chapter 1. Hickey (1955) attributes the high pulse rates found among New Zealand cattle to nutritive imbalance caused by pasture feeding. This could be true, but many other factors such as breed and experimental conditions must be taken into account before an assessment can be made of the effects (if any) on pulse rate of the grass/clover sward as a cattle food.

(c) Respiration Rate

The diurnal pattern in respiration rate was more distinct than in pulse rate, especially the rise in rate as air temperature reached a peak in the middle of the day. Following a steady decline in rate from noon or 2 p.m. until 6 p.m., there was a rise up to 10 p.m. This 10 p.m. rise in both respiration and pulse rate remains unexplained but possibly only operates out-of-doors when the cattle are on pasture since no similar effect was discernible in Patchell's indoor data (1954c). The rate was lowest around 4 a.m.

The results from the analysis of variance are similar to those for pulse rate except that, if the mean square between days is tested by the failure of the cows to rank the same from day to day a highly significant result is obtained but, if it is tested by the failure of the diurnal pattern to be repeated from day to day the result is not significant. It is difficult to interpret this sort of result except to say that, because of the significant sizes of the interactions involving days, differences between day means are of doubtful significance.

As regards the two questions concerning sampling posed in sub-section (b) on pulse rate, the two "F"s were again highly significant with the same numers of degrees of freedom. Variation between individual cows was the largest contributor to the total variation and this factor is discussed further in section C of this chapter. The greatest variation in respiration rate occurred during the hottest part of the day as would be expected if it is assumed that the cows differed in heat tolerance and would therefore respond to air temperature changes by changes in respiration rate at different levels of air temperature. Thus, the more tolerant cows would have lower rates at the higher air temperatures than the others. On days 3 and 4, maximum respiration rate occurred at noon as did maximum air temperature while on days 1 and 2, maxima for both variables occurred at 2 p.m..

Overall mean respiration rate was 44.7 ± 0.98 respirations per minute with a range of 16 – 116 per minute. This wide range is not surprising in view of the frequency with which air temperatures over 70°F were recorded during this trial and in view of the fact that Worstell and Brody (1953) give 60°F as the critical level of air temperature for increases in respiration rate of the Jersey cow.

(d) Rectal Temperature

Rectal temperature followed a steady diurnal pattern from day to day and even from cow to cow with the exception of cows 3 and 4. The rectal temperature pattern of these two cows is discussed in section 8 of this chapter. In general, rectal temperature was steady over the day - light hours with a gradual fall from 6 p.m. until 4 a.m. which appeared to be most rapid between 6 p.m. and 8 p.m. when dusk was falling and could have been largely due to the withdrawal of solar radiation. The decline during this period was less on day 3 which was a cloudy day but this idea was not confirmed on the other cloudy day (day 4). There seemed to be a check to the rate of fall at 10 p.m. if not a slight rise in some cases.

Readings for the three variables (rectal temperature, pulse and respiration rate) at 10 a.m. on day 1 were low and, from the remarks in appendix 1, it can be seen that this set of readings was taken in the shade; similarly at 2 p.m. on day 4. The wet night on day 5 did not appear to have any effect however.

The result of the analysis of variance for rectal temperature differs from the previous two (pulse and respiration rate) in that there was no significant interaction between cows and times. Also, there were no significant differences between day means regardless of which of the two significant interactions involving days was used to test the significance of the mean square between days. Over one half of the total variation was caused by the differences between times of day (table 4), emphasising the strong diurnal trend in rectal temperature noted in the review of literature (Chapter II).

The greatest variation in rectal temperature occurred at 2 p.m., during the heat of the day, and at 8 a.m. but the latter estimate was based on a smaller sample. As far as the two questions regarding sampling are concerned, again both "F"s were highly significant.

The overall mean rectal temperature was 101.1 ± 0.03°F with a total range of 99.1 - 103.3°F. This corresponds very closely with the range and mean given as "normal" in Chapter I.

(c) Skin Temperature

The diurnal pattern of skin temperature appeared to be much more varied from day to day. Day 1 was cloudy at 9 a.m. but the peak skin temperature at noon was probably due to subsequent bright sun. There was a noticeable effect of shade on skin temperature on this day at 2 p.m. The low 10 a.m. skin temperatures on days 2 and 3 are not explained and neither is the low general level of skin temperature on day 3 in spite of the high air temperatures on this day (see review, Chapter II, for effect of temperature on the skin temperature). Nearly one third of the total variation in skin temperature was caused by the interaction between days and times which was significant confirming that the diurnal pattern was different from day to day. The skin temperature is probably sensitive to variations in climatic conditions from day to day but, within the days, variation was similar at each of the five times. There were significant differences between the means of cows and of times of day and there was no significant interaction between cows and times.

If the two questions concerning sampling are again posed and the calculations made, a highly significant "F" is obtained for the first question with 2 and 15 degrees of freedom. However, for the second question, with 2 and 6 degrees of freedom, the calculated "F" was not significant suggesting that there is a lessened likelihood of obtaining the same diurnal pattern with these cows on other days from the same population of days as these three.

Kibler and Brody (1950) noted a sudden rise in surface moisture evaporation in European cattle between 65°F and 80°F air temperature. More recently, Johnson et al (1956) found that between 65°F and 85°F air temperature, the evaporation of moisture from the body surface of cattle increased by 75%, analogous to the onset of sweating in man at 80-90°F. Klemm and Robinson (1955) found that as air temperature approached 100°F with absolute humidity at 12.5 grains/cubic foot, the skin temperature of the Zebu-Hereford crossbred bull calf fell with increased sweating, after having been rising steadily. These workers have stated:

"There is a close relationship between skin temperature and the onset of sweating, the glands becoming noticeably active at a skin temperature of 96°F which may be considered the threshold for sweating in this breed."

There was a steady decline in the mean skin temperature of these crossbreds after it had reached 95°F in spite of increasing air temperatures. Knapp and Robinson (1954) however, could find no sudden fall in skin temperature associated with the onset of sweating in a single Jersey cow. Apart from this latter evidence, the above findings suggest that at air temperatures approaching 80°F, with skin temperature over 90°F, there is a fall in the skin temperature of the European-type cow, even in the face of a continued rise in air temperature. The threshold temperatures would be a little higher in crossbreds (Zebu x Hereford), probably because of higher heat tolerance.

The suggestion is made from a study of figure 10 (along with data in appendix 6) that on days 2 and 3 in the present study, skin temperature fell before air temperature had ceased to rise and that this fall took place at about the skin temperature - air temperature combination mentioned above. Skin temperature could have been affected by sweating above this temperature combination but, because there was no direct evidence of sweating in this study and because the above pattern was only evident in 4 out of the 6 cows on both days (only in one case, cow 29, was the odd cow the same on both days), this might not have been a general pattern. Cow 29 could have been a poorly sweating animal. On day 1, all cows had a maximum skin temperature at noon when air temperature was at a maximum.

The overall mean skin temperature was 92.1 ± 0.19°F with a range of 86.1 - 100.8°F. This corresponds with the range given by Patchell (1954a), taken on the same body position, except that the lower limit is higher than Patchell's (80.0°F). The air temperatures involved were higher during the present trial.

(f) Air Temperature

(i) Four Main Days. The diurnal pattern of air temperature was varied but the general trend was distinct with a peak air temperature at noon or 2 p.m. and a low temperature at midnight or 4 a.m.. Differences between days and between times of day were highly significant from the results of the analysis of variance. The mean air temperature was 67.0 ± 1.03°F with a range of 56.0 - 79.8°F.

(ii) Skin Temperature Days. The results of the analysis of variance showed significant differences between the means for individual days and between the means for the different times of day. Mean air temperature was 71.1 ± 1.07°F with a range of 63.5 - 77.0°F and there was a distinct diurnal trend over the ten hours involved.

B. RELATIONSHIPS AMONG THE VARIABLES

Biological Background

There is a temperature regulating centre in the hypothalamus which is possibly under even higher nervous control from the cerebral cortex and cerebellum. This "heat centre" is activated by the temperature of the blood bathing the centre and by reflex nervous action from the peripheral thermoreceptors (Dukes, 1953).

The frequency of beat of any rhythmically acting tissue such as the heart varies, within limits, almost linearly with temperature which in this case, would be the temperature of the blood bathing the heart (Dukes, 1953). Thus a rise in blood temperature can cause a rise in heart rate provided that this effect is not overridden by other contributing influences. The cardio-motor nervous control of the heart (efferent nerves from the vagus and sympathetic nervous system) ensures co-ordination and adjustment between the heart beat and the body blood requirements. The parasympathetic fibres of the vagus are cardio-inhibitory, probably the main regulation, while the sympathetic fibres are acceleratory and an emergency regulation (Dukes, 1953). The cardio-motor centre of the central nervous system is under some control from the "heat centre". An increase in heart rate with temperature indicates an increased minute volume (output) only if there is an adequate venous return but, with peripheral vasodilation and water loss under heat stress, there may not be a sufficient compensatory increase in blood volume. (Lee and Phillips, 1948). Hence, with a blood deficit, stroke volume may decrease and any increases in rate to increase or even maintain output may become largely futile attempts to supply more blood to the periphery for cooling.

Impulses from the "heat centre" probably influence the balance of the respiratory centres in the medulla oblongata and bring about changes in respiration rate and character through effects on the respiratory musculature. Thus polypnea, as a response to heat, is under neural control (Dukes, 1953).

According to Bianca (1958) the heart rate of his dairy calves increased with time from the beginning of exposure to heat. At the same time, the respiration rate became shallow and rapid (panting). With continued exposure, respiration became slower and deeper while heart rate rose steeply. Bianca has suggested that in both stages, heart rate rose with blood temperature but in the second stage, cardiac acceleration probably resulted from an increased demand for oxygen by the respiratory muscles. The second stage breathing still resulted in some cooling of the body but placed a strain upon the heart as well as adding the risk of induced alkalosis of the blood.

The physiological factors involved in skin temperature regulation and function are discussed in Chapter VI.

The probable sequence of events in the relationships among these variables is as follows:

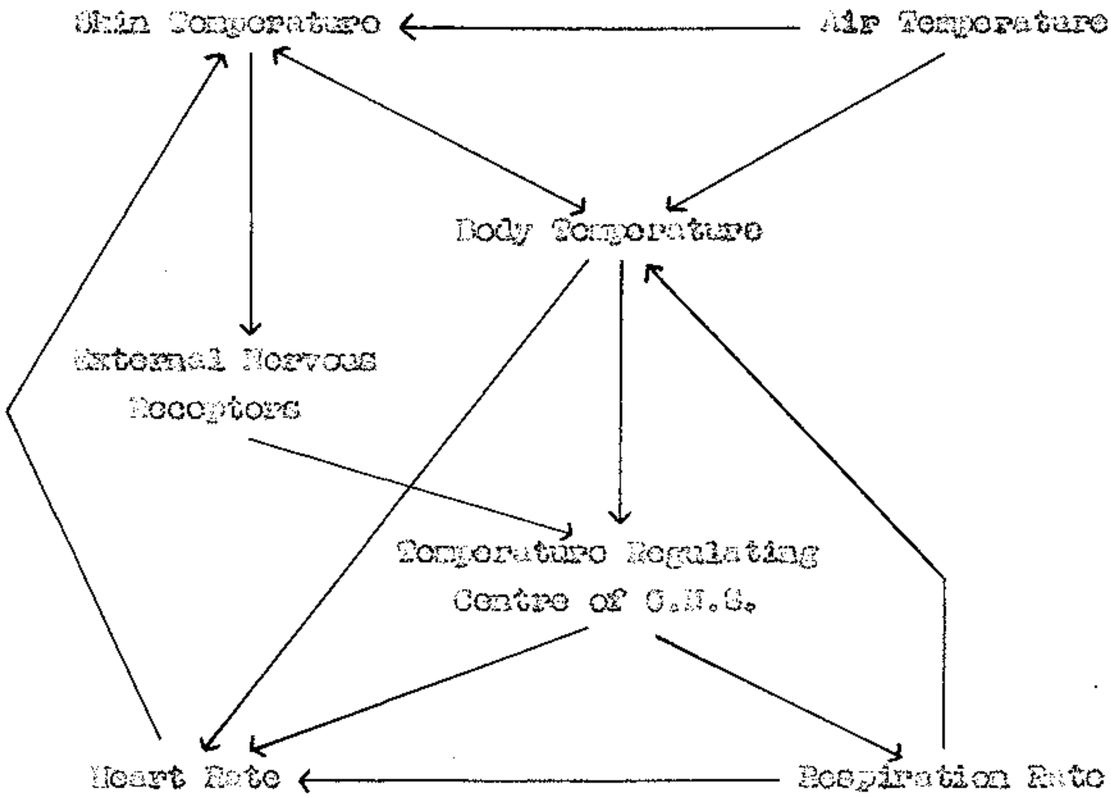
The temperature and humidity of the ambient air influence (along with other climatic factors) the efficiencies of the physical heat loss mechanisms (evaporation, conduction, convection, radiation). This has the effect of raising or lowering body temperature, blood temperature, rectal temperature and skin temperature. Heat may be gained by direct heating of the tissues as well as by the metabolic activities of the animal. The skin temperature is affected by the temperature of the peripheral blood flow and some balancing is achieved by this means as also by the reflex nervous regulation of respiration rate. A rise in blood temperature affects the "heat centre" of the central nervous system and hence, cardio-respiratory activities are called in to control body temperature. The relative importance of each of the two paths of influence on the "heat centre" is not clear. Apparently the influence of the "heat centre" over-rides the direct influence of the blood temperature on the heart since most work suggests that heart rate declines with rise in temperature (see Review of Literature, Chapter II) until a critical temperature is reached when severe heat stress (Bianca held his calves at 104°F air temperature) causes the heart rate to increase, probably coincident with a steep rise in rectal temperature (i.e. when the cooling mechanisms fail to maintain homeostasis). Respiration rate has an influence on pulse rate (Bianca, 1958) and pulse rate has an influence on skin temperature through blood distribution.

These paths of influence are pictured in the biological model (figure 11). This is a simplified model and no attempt has been made to include all the possible mechanisms operative in homeothermic temperature regulation. Under normal conditions the whole system is self-balancing ensuring the maintenance of homeostasis.

FIGURE 11

BIOLOGICAL MODEL OF RELATIONSHIPS AMONG

THE VARIABLES



Materials

The data used in this covariance and multiple correlation analysis were obtained from the diurnal trial (Section A of this chapter). For rectal temperature, pulse rate, respiration rate and air temperature there were nine sets of readings on four days plus data for 8 a.m. on three days and an extra set of readings on 12/3/58 making 40 sets of readings in all. For skin temperature and air temperature there were five sets of readings on three days plus four sets on day 1 of the diurnal trial making 19 sets of readings in all. Simple correlation analysis only was carried out on these latter data. The four variables (rectal temperature, pulse rate, respiration rate and air temperature) were used in multiple correlation analysis and unfortunately insufficient data were available on skin temperature and relative humidity to be able to include them also in this analysis. The raw data used in these analyses are given in appendices 7 and 8.

Methods and Results

(Rectal Temperature, Pulse Rate, Respiration Rate, Air Temperature)

The data for three of the variables were coded to simplify the calculations. Coding was as follows: pulse rate ($X - 50$ beats per minute), rectal temperature ($X - 90^{o}F$), air temperature ($X - 50^{o}F$). These data (respiration rate not coded) were used to calculate simple correlation coefficients for all combinations of the four variables on a within cow basis. The significances

TABLE 8

Results from Simple and Multiple Correlation Analysis - Rectal Temperature (Y), Air Temperature (X_1), Respiration Rate (X_2) and Pulse Rate (X_3)

Partial Regression Coefficients

Cow		b_1^1	b_1	b_2^1	b_2	b_3^1	b_3	R^2	$\bar{R}^2$	$\bar{R}$
1		0.5169**	0.0591**	0.0531	0.0033	0.4122**	0.0296**	0.5594	0.5227	0.7230**
	SE	0.1192	0.0136	0.1414	0.0087	0.1175	0.0085			
74		0.5986**	0.0469**	-0.0101	-0.0003	0.2597*	0.0194	0.6057	0.5729	0.7569**
	SE	0.1170	0.0092	0.1421	0.0040	0.1281	0.0096			
3		0.6789**	0.0648**	0.0578	0.0028	0.0696	0.0063	0.5543	0.5172	0.7192**
	SE	0.1245	0.0119	0.1466	0.0072	0.1237	0.0112			
21		0.8507**	0.0720**	-0.1650	-0.0066	0.2352**	0.0219**	0.7388	0.7170	0.8468**
	SE	0.0911	0.0079	0.1277	0.0051	0.0860	0.0080			
29		0.3358**	0.0271**	-0.0314	-0.0011	0.6617**	0.0432**	0.6552	0.6265	0.7915**
	SE	0.1054	0.0085	0.1378	0.0050	0.1039	0.0068			
4		0.5826**	0.0689**	0.1642	0.0046	0.1452	0.0136	0.6687	0.6411	0.8007**
	SE	0.1166	0.0138	0.1345	0.0038	0.1183	0.0111			

Constants from the Simple Regression Equations

Cow	b_{YX_1}	a	$b_{X_2X_1}$	a
74	0.0589	96.9	1.5944	- 61.2
1	0.0701	96.4	0.9741	- 25.2
3	0.0704	96.5	1.2131	- 44.5
21	0.0719	96.1	1.2357	- 40.6
29	0.0423	98.3	1.2124	- 45.0
4	0.0944	95.0	3.1846	-147.1

Cow	r_{YX_1}	r_{YX_2}	r_{YX_3}	$r_{X_1X_2}$	$r_{X_1X_3}$	$r_{X_2X_3}$
	Partial Correlation Coefficients					
1	0.5513**	0.0608	0.4794**	0.3913*	-0.3406*	0.3671*
74	0.5819**	-0.0119	0.2847	0.2640	0.1414	0.4056*
3	0.6225**	0.0637	0.0915	0.3914*	0.0056	0.3378*
21	0.7945**	-0.2495	0.3793*	0.4828**	-0.1812	0.3158
29	0.4326**	-0.0388	0.6801**	0.4388**	-0.2907	0.3918*
4	0.5380**	0.1757	0.1817	0.3867*	0.1511	0.2815
	Zero-Order Correlation Coefficients					
1	0.6127**	0.5154**	0.5223**	0.5220**	0.1649	0.4667**
74	0.7515**	0.4974**	0.6194**	0.5771**	0.6115**	0.6241**
3	0.7389**	0.5113**	0.3320*	0.6198**	0.3464*	0.4692**
21	0.8294**	0.4021*	0.4938**	0.5668**	0.3928*	0.4096**
29	0.5252**	0.5265**	0.7486**	0.5435**	0.3121	0.5673**
4	0.7977**	0.6943**	0.6192**	0.7502**	0.6330**	0.6406**
Av.		0.5309**		0.6034**		0.5354**

* ($p < 0.05$) Significant

** ($p < 0.01$) Highly Significant

of the sizes of these zero-order coefficients were determined by entering the appropriate table of Snedecor (1955) with 38 degrees of freedom. The results of these calculations are presented in table 8. In order to test the hypothesis that the six (individual cows) coefficients from any one combination of variables were derived from the same population and, if possible, to combine them into an estimate of the population coefficient, the coefficients were transformed to Fisher's Z quantities. Computations were made according to the methods of Snedecor (1955) to obtain values of chi-square for 5 degrees of freedom. If the probability of obtaining a larger value of chi-square was high, it was concluded that the six sample correlations were drawn from a common population correlation and an average Z, and hence an average r, calculated.

Simple regression equations were derived for two of the six combinations of variables (the regression of rectal temperature on air temperature and that of respiration rate on air temperature). The constants of the twelve equations (6 cows) are given in table 8 ("a" constants from uncoded data) and the linear regression lines are presented in figures 12 and 13. The significances of the regression coefficients were tested by partitioning the SSy into two parts, one due to regression (b . SPxy) and one due to residual variance (SSy - b . SPxy). The resulting "F"s for 1 and 38 degrees of freedom were highly significant ($P < .01$) in all cases.

Rectal temperature (Y) was selected as the dependent variable and air temperature (X_1), respiration rate (X_2), and pulse rate

FIGURE 12

THE REGRESSION OF RECTAL TEMPERATURE ON AIR TEMPERATURE - INDIVIDUAL COWS

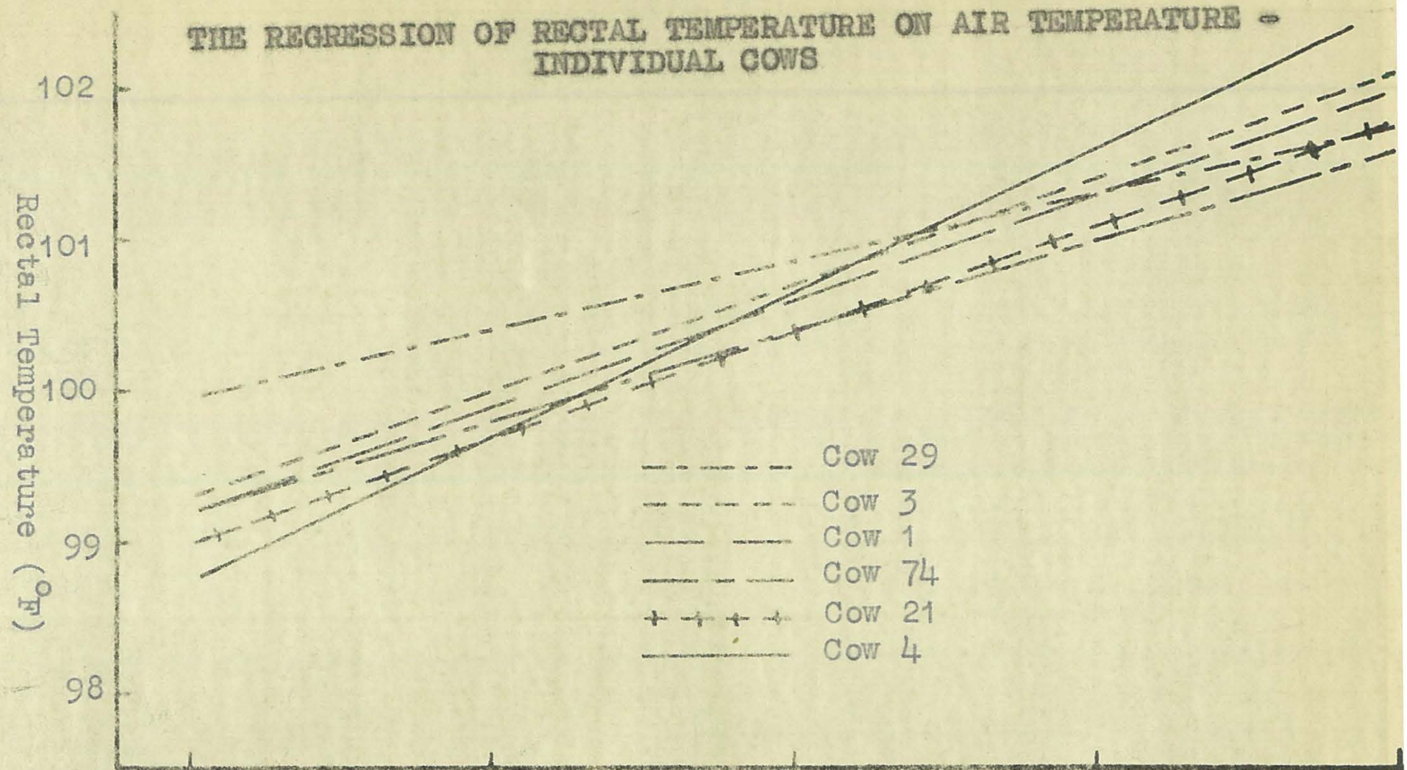
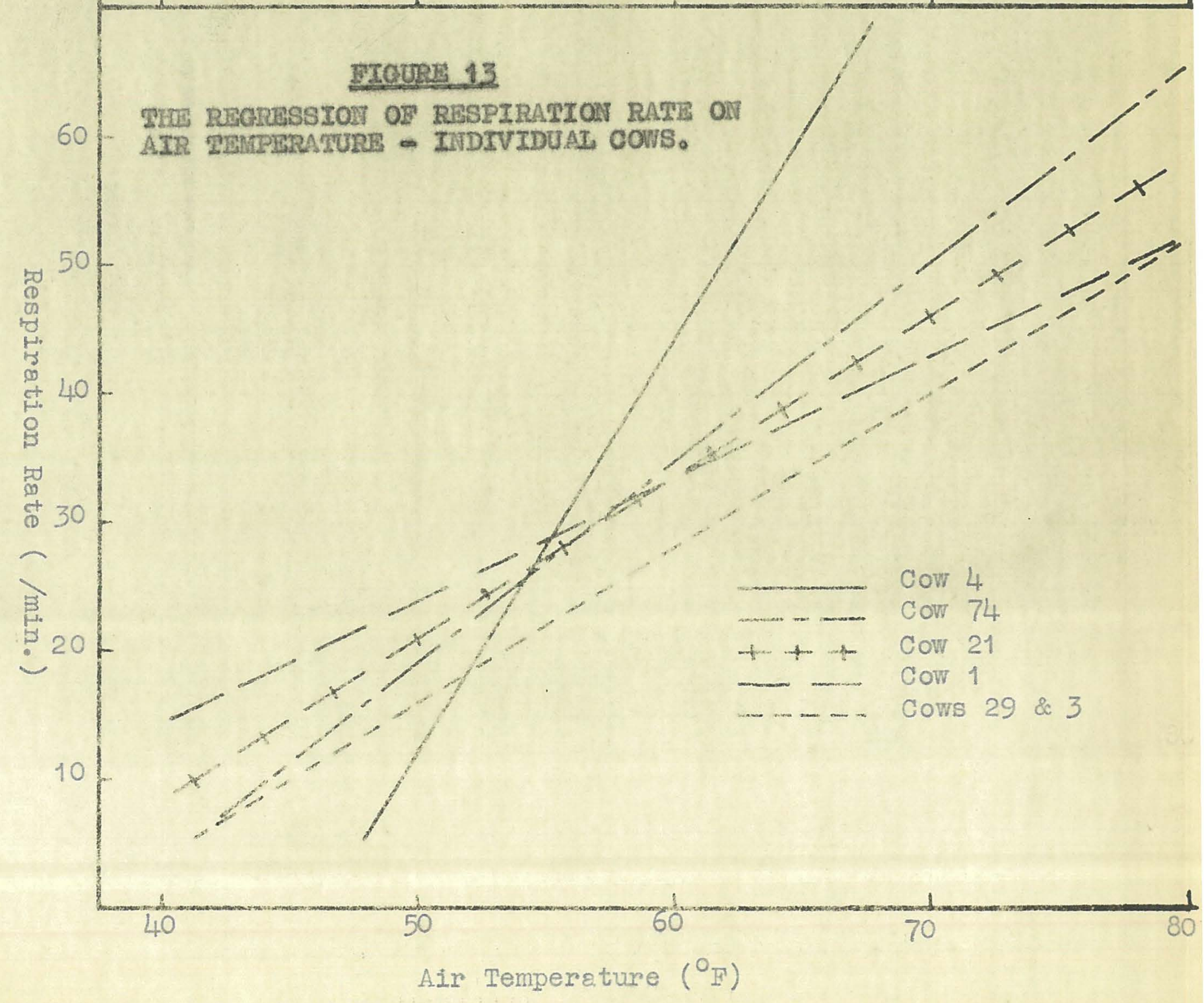


FIGURE 13

THE REGRESSION OF RESPIRATION RATE ON AIR TEMPERATURE - INDIVIDUAL COWS.



(X_3) were used as independent variables in the multiple regression equation:

$$Y_e = a + b_1 X_1 + b_2 X_2 + b_3 X_3$$

since it was assumed that the maintenance of a normal body temperature is a priority function in homeotherms.

The abbreviated Doolittle method for the solution of normal equations was used to derive a matrix of Gauss multipliers from the zero-order correlation coefficients obtained by the method of least squares. Second-order partial correlation and standard partial regression coefficients were calculated from this matrix according to the method given by Goulden (1952) and these are presented in table 8, along with the partial regression coefficients derived from the standard coefficients.

Coefficients of multiple determination (R^2) (Ezekiel, 1941) were calculated from the formula given by Snedecor (1955). These were adjusted by the formula of Ezekiel (1941) for size of sample to give unbiased estimates of the correlation ($\bar{R}$) most probably existing in the whole population of which these 40 sets of observations were but a sample. Coefficients of multiple correlation were obtained (R) and the significances of the adjusted coefficients ($\bar{R}$) tested by entering the appropriate table of Snedecor (1955) with 36 degrees of freedom. The significances of the partial correlation coefficients were tested by entering the same table at the column for two variables (m = 2) and again with 36 degrees of freedom. Values for all these statistics are given in table 8.

Ezekiel (1941) has given the following formula for the standard error of a partial regression coefficient $b_{Y1.23}$:

$$s\, b_{Y1.23} = \sqrt{\frac{\bar{S}^2_{Y.123}}{n s_1^2 \, (1 - R^2_{1.23})}}$$

also $$\bar{S}^2_{Y.123} = s_Y^2 \, (1 - \bar{R}^2_{Y.123}) \left(\frac{n}{n-1}\right)$$

and since $$\bar{R}^2_{Y.123} = 1 - (1 - R^2_{Y.123}) \left(\frac{n-1}{n-m}\right)$$

hence $$s\, b_{Y1.23} = \sqrt{\frac{s_Y^2 \, (1 - R^2_{Y.123})}{s_1^2 \, (1 - R^2_{1.23})\,(n-m)}} \qquad \ldots\ldots (1)$$

and $$s\, b^1_{Y1.23} = \sqrt{\frac{1 - R^2_{Y.123}}{(1 - R^2_{1.23})\,(n-m)}} \qquad \ldots\ldots (2)$$

where n = number of sets of observations.

m = total number of variates.

$R^2_{Y.123}$ = unadjusted coefficient of multiple determination.

and $R^2_{1.23} = (b^1_{12.3} \cdot r_{12}) + (b^1_{13.2} \cdot r_{13})$

Formulas (1) and (2) were used to calculate standard errors for the partial regression coefficients and the standard partial regression coefficients respectively. The significances of these statistics were tested by the distribution of "t".

The X_1 variate (air temperature) was deleted from the matrix of Cow 74 by the method given by Goulden (1952). The resulting statistics are presented in table 9.

Discussion

(Rectal Temperature, Pulse Rate, Respiration Rate, Air Temperature)

(a) Zero-Order Correlation

All of these coefficients were of significant size ($P < 0.05$ or $P < 0.01$) except for those between air temperature and pulse rate which were significant in four of the cows only. The three physiological variables are presumably inter-related biologically and each related to air temperature through the balance of body heat gains and losses. There seems to be a general agreement that pulse rate is not highly correlated with air temperature (see Review of Literature, Chapter II), probably because a complex of factors affect pulse rate with air temperature (more than is the case with rectal temperature and respiration rate) only a minor component of the complex. The differences between cows in the relative sizes of the different correlations may be expressions of physiological individuality, meaning that any biological model is only a generalisation with different emphasis being placed on each pathway in different cows.

In only three of the sets of correlations could the coefficients be legitimately combined into a common population coefficient. The probabilities of obtaining a higher value for chi-square were:

TABLE 9

Effect of Deletion of Variable X_1 (Air Temperature) from the Multiple Correlation Analysis - Cow 74

Partial Regression Coefficients

	b_2^1	b_2	b_3^1	b_3	R^2	$\bar{R}^2$	$\bar{R}$
	0.1815	0.0051	0.5060**	0.0378**	0.4037	0.3714	0.6094**
SE	0.1625	0.0046	0.1625	0.0122			

Partial Correlation Coefficients

r_{yx_2}	r_{yx_3}	$r_{x_2x_3}$
0.1807	0.4557**	0.4640**

** ($P < 0.01$) Highly Significant

Rectal Temperature	X Air Temperature	P	= 9%
Pulse rate	X Air Temperature	P	= 8%
Respiration rate	X Air temperature	P	= 60%
Respiration rate	X Rectal temperature	P	= 60%
Respiration rate	X Pulse rate	P	= 60%
Rectal Temperature	X Pulse rate	P	= 15%

The average correlation coefficients for the three sets (P = 60%) are given in table 10 along with the range of coefficients obtained for the correlation between rectal temperature and air temperature and the corresponding coefficients obtained by Patchell (1954a), Seath and Miller (1946b), Gaalaas (1945) and by Asker et al (1952) from field studies with European-type cattle.

(b) Linear Regression

The linear regressions of rectal temperature on air temperature and respiration rate on air temperature (all highly significant) again showed large divergences between individual cows. The outstanding feature was the steepness of the regression lines for Cow 4 and this is discussed in more detail in section C of this chapter. These regressions mean that for cows of this population, assuming a linear relationship over this air temperature range (56.0 - 79.8°F) (which may not be justified), a 1°F change in air temperature results in a change in rectal temperature of from 0.04°F to 0.09°F and in respiration rate of from 1.0 to 3.2 respirations per minute. Patchell (1954a) found the average regression of respiration rate on air temperature to be 1.21, all

<u>TABLE 10</u>

Average Zero-Order Correlation Coefficients Obtained From Various Studies.

Author	Present Study	Patchell	Seath & Miller		Gaalaas	Asker *et al*
Number of animals	6	12	52	68	17 - 34	11
Air Temperature Range °F	56.0 - 79.8	36.0-67.2	65-95	75-91	33 - 95	Mean 94.5°F
<u>Correlations</u>						
Rectal T. X Air T.	0.525 - 0.829	0.326	0.74	0.71	0.57	0.235
Respiration X Air T.	0.603	0.613	0.777	0.591	0.77	0.395
Rectal T. X Respiration	0.531	0.359				0.310
Respiration X Pulse	0.535	0.439				0.323

of the individual cow regressions belonging to a common population. A lower variation between animals in the responses of respiration rate to changes in air temperature would be expected in Patchell's study since there were no air temperatures above 70°F and only above this temperature does the rate increase greatly in response to increases in air temperature (Kibler and Brody, 1949). Above 70°F, the response would be expected to be different in cows of differing heat tolerance. Asker et al (1952), with Shorthorn cattle at a higher air temperature (mean 94.5°F), obtained lower regression coefficients (their correlation coefficients were lower also - table 10) as follows:

Regression of rectal temperature on air temperature	0.018
Regression of respiration rate on air temperature	0.856

One possible reason for these lower coefficients is that relative humidity was low (mean 47%) during this study and hence evaporative cooling would be more effective than if humidity had been high as is usual in New Zealand (see appendices 1 and 2).

Gaalaas (1945) obtained curvilinear relationships between body temperature and air temperature and between respiration rate and air temperature in the Jersey cow over the air temperature range of 33 - 95°F. However, his graphs were nearly linear over the range of 50 - 80°F and any errors inherent in the assumption of linearity over this range would probably not be large. Patchell (1954a) found no evidence of curvilinearity in the relationship between respiration rate and air temperature. Hence for the purposes of the present study, linearity was assumed for all the relationships.

(c) Multiple Correlation and Regression

For the purposes of this analysis the assumption was made that biologically, cattle attempt to maintain a constant deep body temperature and that rectal temperature is a function of the combined and separate effects of the other physiological variables and of the climatic variables according to the equation:

$$Y = f(X_1, X_2, X_3 \ldots Xn)$$

In order to obtain a measure of the actual influence on Y of a change in any one of the X variables, a multiple regression equation was set up as given previously (see Methods and Results). The set of simultaneous equations evolved by the method of least squares was solved to obtain values for the partial regression coefficients b_1, b_2, and b_3.

There are two basic assumptions in this type of analysis:

1. That the relationships are linear.
2. That the effects of the independent variables on the dependent are separate, distinct and additive.

That these assumptions are not necessarily valid can be seen from a consideration of the biological model (figure 11). The model itself is oversimplified and the actual situation is confused but is probably a rather delivate balance between inter-related variables. Hence, the value of this type of analysis in this situation can be questioned. Partial regression may be more useful than partial correlation analysis in this case although the true dependent and independent variables may not be clearly defined. Perhaps the main use to which the analysis can be put is in the prediction of rectal temperature responses from a consideration of the independent variables. The adjusted multiple correlation coefficients ($\bar{R}$) which are estimates of the correlation between Y and Y_e (Y_e being the Y as estimated from the X variables), ranged from 0.719 to 0.847 for the six cows. These coefficients measure the combined effects of the independent variables on the dependent and were all highly significant.

The adjusted coefficients of multiple determination ($\bar{R}^2$) measure the proportion of the variation in the dependent variable which is "explained" by variations in the independent variables. These ranged from 52% to 72%, meaning that a fairly good prediction of rectal temperature responses can be obtained by a consideration of changes in air temperature, pulse and respiration rate. The following question then arises. How good a prediction would be obtained by a consideration of pulse and respiration rate alone? Cow 74 was chosen as being an "average" cow and variable X_1 (air temperature) deleted from the analysis to yield a new multiple regression equation and a new coefficient of multiple determination of 57.14%. The previous value of this statistic for Cow 74 was 57.29%, the reduction emphasising the importance of considerations of air temperature in predicting rectal temperature responses.

In order to compare the relative potencies of considerations of each of the independent variables in predicting rectal temperature it is necessary to consider the standard partial regression coefficients within each cow rather than the partial regression coefficients which contain estimates of the variance which differs from variable to variable (Snedecor, 1955). It would probably also be desirable to compare between cows on the standard partial regression coefficients. In general (under the assumption made at the beginning of this sub-section that rectal temperature is determined by the other variables although biologically, rectal temperature may determine pulse and respiration rate in certain circumstances) air temperature was the most important determinant of rectal temperature with pulse rate of lesser and more variable importance. None of the respiration rate regression coefficients were significantly greater than their standard errors and the influence of this variable, when the other two were held constant, was negligible. Apparently the correlations between respiration rate and each of air temperature and pulse rate were so strong that a high correlation between respiration rate and rectal temperature resulted, but when these two independents were held constant to determine the actual influence of respiration rate on rectal temperature, the smallness of the influence became apparent. Even if the coefficients were not of significant size however, they were still the best estimates available of the situation in the population.

The partial correlation coefficients are interesting in that only in the case of the correlation between rectal temperature and air temperature, with pulse and respiration rate constant, were the coefficients significant for all cows. The correlation between air temperature and respiration rate approached this situation and apparently these two physiological variables were each directly and independently affected by air temperature changes. This was in general accordance with biological considerations.

On deletion of the variable X_1 in cow 74, the partial regression coefficients involving pulse rate and respiration rate both increased in size (the latter considerably), apparently taking up some of the relationship between air temperature and rectal temperature. An interesting feature was the increase in the standard errors of both coefficients after deletion of X_1, which is unusual. The partial correlation between Y and X_2, with X_3 constant, became considerably higher and positive while that between Y and X_3, with X_2 constant, also became higher. The partial correlation between X_2 and X_3, with Y constant, remained in the same order as before deletion of X_1, implying a more direct and stable relationship between pulse rate and respiration rate.

Results and Discussion

(Skin Temperature and Air Temperature)

The skin temperature data were coded ($X - 80^{o}F$) for ease of manipulation and zero-order correlations between skin temperature and air temperature derived. These coefficients, given in table 11, were based on 19 pairs of items and ranged from 0.235 to 0.561. Only the highest correlation, that for Cow 1, was significant ($p < 0.05$) (Snedecor, 1955). Air temperature ranged from $63.5^{o}F$ to $78.0^{o}F$.

The correlations might have been higher if account had been taken of the lag phases between mean air temperature and the

TABLE 11

Zero-order Correlations and Linear Regression Coefficients of Skin Temperature on Air Temperature

Cow	Correlation (r)	Regression (b)
21	0.4089	0.2767
4	0.4002	0.2314
29	0.3962	0.1998
1	0.5607*	0.4273*
74	0.2349	0.1735
3	0.3267	0.1082
Average	0.3927	0.2361**

* ($p < 0.05$) Significant

** ($p < 0.01$) Highly Significant

individual cow skin temperatures, discernible in figure 10. However, the immediate relationships between the two variables are probably more important in considerations of heat gains and losses. The coefficients were transformed to Z quantities and the hypothesis that the several coefficients were derived from the same population was tested and the probability of obtaining a larger value of chi-square found to be 93%. Therefore, the hypothesis was not rejected and an average population coefficient was derived but it was not significant. It was unfortunate that there was not more data on which to base this correlation as there is reason to believe that a real correlation does exist. Most of the six correlations were bordering on significance in the present study and Patchell (1954a) obtained a highly significant average correlation coefficient of 0.640.

Linear regression coefficients of skin temperature on air temperature were calculated and are also presented in table 11. Tests of significance were carried out by analysis of variance, deriving a mean square due to regression (b.SPXY) and a residual mean square. The only significant regression was that for cow 1 ("F" = 7.79* for 1 and 17 degrees of freedom). An average within cow regression coefficient (0.2361) was calculated by the method of covariance given by Snedecor (1955). This analysis is given in table 12. Since the mean skin temperatures did not differ significantly between cows after adjustment to a common air temperature basis, then variations in air temperature explain to a significant degree the differences between cows in their mean skin temperatures. Again the sum of squares of Y

* $(p < 0.05)$

TABLE 12

Analysis of Covariance and Test of Significance of Adjusted Cow Means, Regression of Skin Temperature on Air Temperature.

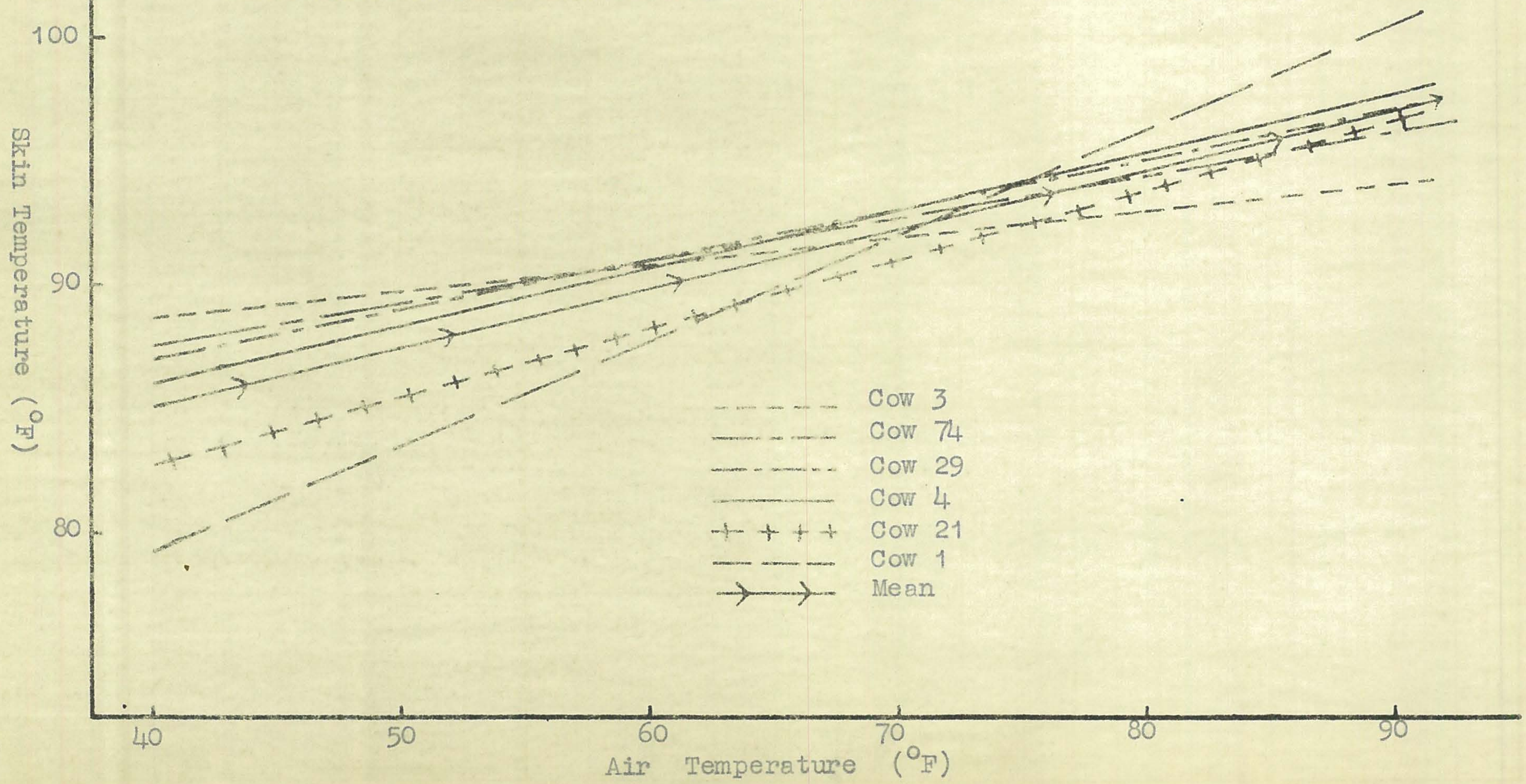
Source	df	Sums of Squares and Products			Errors of Estimate			
		SX^2	SXY	SY^2	SS	df	MS	F
Total	113	1751.88	413.69	720.95	623.26	112		
Between Cows	5			54.61				
Within Cows	108	1751.88	413.69	666.34	568.65	107	5.31	
					54.61	5	10.92	2.06

Average Within Cow Regression, b = 0.2361 was partitioned to test the significance of the reduction in variation due to the average within cow regression. The "F" for 1 and 107 degrees of freedom was highly significant ("F" = 18.39). Apparently through combination of the individual cow estimates of regression, a much more precise estimate has been obtained which was significant.

The individual cow regressions and the average within cow regression are presented in figure 14. A 1°F increase in air temperature produces a rise in skin temperature in the order of 0.11 - 0.43°F. Patchell (1954a) found that a 1°F increase in air temperature produced an increase in skin temperature of 0.31°F. Therefore, as air temperature rises, skin temperature rises but the gradient between the two decreases making it less and less possible for the animal to lose heat by non-evaporative cooling and ultimately resulting in virtual identity between the two temperatures at 100-105°F (Brody, 1956). In the present study, identity was reached at 99°F if the average regression is considered. This accounts for the findings of Kibler and Brody (1950) that at 0°F, non-evaporative cooling in European-type cattle amounted to 90% of the total heat dissipation while at 95°F, this type of cooling only amounted to 12% of the total.

FIGURE 14

THE REGRESSION OF SKIN TEMPERATURE ON AIR TEMPERATURE - INDIVIDUAL COWS AND AVERAGE WITHIN COW REGRESSION.



C. DISCUSSION ON VARIATIONS BETWEEN ANIMALS

A study of the results from the analyses of variance of the diurnal trial data reveals that there were highly significant differences between the means of individual cows for all four variables although the cows did not always rank in the same order. The components of variance show that (except for skin temperature) the diurnal patterns and variations between cows were the greatest contributors to the total "explained" variation. The individual cow means and standard deviations differed markedly from each other.

The total variation in any one physiological variable was generally greatest at 2 p.m. when, on average, air temperature was at a maximum. Bonsma (1940) demonstrated a diurnal pattern in the respiration rate of the calf with little variation between calves in the cooler morning but much variation in the hotter afternoon. The differences between cows in their physiological reactions may be greatest at the higher air temperatures when the animals, presumably of differing heat tolerance, are subjected to some thermal stress.

The respiration rate graphs show that cow 4 had a rate elevated above those of the other five cows throughout the whole 24 hours (four day average). Not only was there this consistent elevation but this cow also had a rate which responded most to changes in air temperature ($b = 3.185$). This regression line was considerably steeper than any of those for the other cows. Cow 74 had an elevated rate during the hotter part of the day and also had a steeper regression line (b = 1.594) than any of those for the other cows except cow 4.

The rectal temperature graphs show that between the hours of 10 a.m. and 6 p.m., cows 3 and 4 had higher temperatures than the other four cows. At 2 p.m. these two cows had rectal temperatures which were respectively 0.70°F and 1.05°F above the mean for the other cows whose rectal temperatures were all within 0.25°F of each other. Also, perhaps stangely, cow 4 again had the steepest regression line with air temperature (b = 0.094). Cow 3 did not stand out in this respect.

The following reasoning can be applied to these facts with some reservation. Cow 4's rectal temperature was readily affected by changes in air temperature, probably because of an inability to efficiently dispose of surplus heat. She therefore increased her respiration rate in an attempt to reduce rectal temperature but obviously failed in this respect. Cow 74 controlled her rectal temperature by an efficient use of respiratory evaporation. Cow 3 had an elevated rectal temperature but this did not increase much with air temperature increases, probably because of an efficient use of heat loss mechanisms other than respiratory. Biologically, the above reasoning emphasises the balancing involved in the maintenance of thermo-neutrality and the different weight placed on different aspects of the balancing mechanism by the different cows. Results from the partial regression analysis do not contradict this conclusion.

Did these cows differ from one another in heat tolerance?

The majority of workers who have studied heat tolerance have used rectal temperature response as the index of tolerance although Lee (1955) considered this to be too narrow a view. Since rectal temperature follows the deep body temperature which is maintained homeostatic as far as is possible, fluctuations in rectal temperature should indicate the presence or absence of thermal stress. Beakley and Findlay (1955a) found considerable variation among the rectal temperature behaviours of three similar, randomly chosen Ayrshire calves in a climatic chamber with one calf obviously capable of withstanding thermal strain much better than the other two. This calf had the highest "normal" rectal temperature at 59-68°F air temperature. Kendall (1948) suggested that large diurnal fluctuations in rectal temperature (more than 0.7°F) with fluctuations in air temperature indicated an inability to thrive, Zebus showing less variation than European-type cattle. Beakley and Findlay (1955a) have stated that:

> ".....the measurement of the normal (15 - 20°C)(59 - 68°F) rectal temperature of animals and the extent of their diurnal fluctuations in rectal temperature may be valuable indications of the ability of animals to withstand thermal stress."

On this basis, cows 3 and 4 were likely to be less heat tolerant than the others because they had rectal temperatures above average during the hotter part of the day. Regarding "normal" rectal temperature by the above definition (i.e. the average of all rectal temperatures taken at air temperatures between 59°F and 68°F in the diurnal trial of the present study), the range was only from 100.7°F to 101.0°F with cows 4, 3 and 29 all having an average of 101.0°F. Cow 29 however, had a uniform and low rectal temperature range and also a very flat response of rectal temperature to air temperature changes (b = 0.042). The results for cows 3 and 4 contradict the conclusions of Beakley and Findlay (1955a) regarding their calves. All six cows had diurnal fluctuations (taken over approximately the same period of the day) greater than that which Kendall (1948) suggested indicated inability to thrive. These fluctuations ranged from 1.0°F for cow 74 to 1.8°F for cows 4 and 1. Cow 3 had the next highest range with 1.6°F. Hutchison and Mabon (1954) found diurnal fluctuations in Zebu cattle of more than four times the 0.7°F of Kendall. This greater variation was due to low morning temperatures since the afternoon rectal temperatures corresponded closely with those of Kendall. The present study showed a similar wide variation with low morning rectal temperatures and since, like the Zebus of Hutchison and Mabon, these Jersey cattle thrive well in the local climate on all available evidence it seems that the conclusions of Kendall were too strict. Probably his unthrifty animals were this way for reasons other than because of the fluctuations in rectal temperature.

Perhaps the only conclusion that can be made is that no one aspect of rectal temperature response is a good measure of heat tolerance alone. It is possible to generalise and suggest that cow 4 was less heat tolerant than the others and might not thrive in a tropical environment but, on the other hand, this cow was the highest butterfat producer of the group at the time of measurement and this could have been a significant factor in the apparent lack of tolerance. Cow 3 was a two-year-old, the youngest cow in the group, and young animals generally have higher rectal temperatures than older stock under the same conditions (see Review of Literature, Chapter II). Cow 74 was a large cow with, therefore, a low surface area to volume ratio so that she may have had to use respiratory cooling at a lower air temperature than the smaller cows.

Cow 21 had a consistently lower pulse rate than the other cows. This cow had no obvious distinguishing features and either she was physiologically able to live and produce with a lower level of cardiac activity than the others or else she was less easily upset by the experimental procedure.

CHAPTER IV

THE INFLUENCE OF VARIOUS ANIMAL CHARACTERISTICS

A. DIURNAL TRIAL DATA

Source of Data and Methods

In view of the obvious differences between individual cows in their physiological variation shown in the analyses of the diurnal data (Chapter III), it was decided to investigate some other differences (besides differences in rectal temperature, pulse rate, respiration rate and skin temperature) between the cows in the hope of detecting some characteristic which would aid in explaining some of the variation between cows in the four physiological variables studied in the previous chapter. The cows were divided into groups on the basis of these characteristics and the between-cow sums of squares from the diurnal analyses of variance each divided into two portions, one between groups (with 1 or 2 degrees of freedom depending upon the number of groups involved) and one within groups. The significance of the variation between groups was then tested in each case by the distribution of "F" (Snedecor, 1955).

The characteristics chosen, after reference to the literature and after consideration of the availability of data, were coat colour, production level, body weight, age and stage of lactation.

(a) Colour

This was a purely subjective grading. Three groups were established as follows:

Dark Cows 21 and 4

Middle Cows 3 and 29

Light Cows 74 and 1.

(b) Production Level

The determinant for this classification was the sum of the two 30 day butterfat production totals for the two test periods ending on 21/2/58. Two groups were established as follows:

High Producing Cows 4, 29 and 74.

Low Producing Cows 1, 3 and 21.

(c) Body Weight

The average of four routine weekly weighings between 4/2/58 and 4/3/58 was used to establish three groups as follows:

Heavy Cows 29 and 74.

Medium Cows 4 and 21

Light Cows 1 and 3.

(d) Age

Normally, all the cows (except the two-year-old Cow 3) would be classified as mature. Two groups were established as follows:

Old Cows 74, 1 and 29

Young Cows 21, 3 and 4

(e) Stage of Lactation

The number of days in milk at 21/2/58 was used to establish three groups as follows:

Early Cows 21 and 1

Middle Cows 74 and 29

Late Cows 3 and 4.

The data on which all these classifications were made appears in table 2. It is perhaps a significant fact that no two cows appear together in all classifications.

Results and Discussion

The results of the analyses of variance and the group means are presented in table 13.

(a) Coat Colour

Differences between group means for all four physiological variables were not significantly large. This may have been because of the small range of coat colours present in this sample of pedigree Jersey cows or because of an overriding masking effect by other factors. Contrary to the findings of Patchell (1954a), there were significant differences between the mean skin temperatures (Diurnal Trial, Chapter III, Section A) of the cows in the present study but these could not be attributed to differences in coat colour on the basis of the above evidence.

(b) Production Level

Differences in production between the groups were small but in view of the reactions of the top producer, cow 4, mentioned in Chapter III, Section C, it was thought that such differences might explain a significant portion of the variation between cows in the

TABLE 13

Effect on Differences Between Animals in Their Physiological Reactions of Differences in Various Animal Characteristics.

Group Means

Group	Pulse	Respiration	Rectal T.	Skin T.
Coat Colour				
Dark	74.5	54.8	101.16	91.74
Middle	77.3	36.2	101.20	92.45
Light	79.9	43.2	100.97	92.00
Production Level				
High	77.3	50.0	101.13	92.66
Low	77.2	39.5	101.09	91.47
Body Weight				
Heavy	75.9	41.0	101.01	92.65
Medium	74.5	54.8	101.16	91.74
Light	81.3	38.4	101.16	91.80
Age				
Old	78.3	40.7	101.02	92.40
Young	76.1	48.7	101.20	91.72
Stage of Lactation				
Early	76.1	41.0	101.00	91.36
Middle	75.9	41.0	101.01	92.65
Late	79.7	52.2	101.32	92.18

Analyses of Variance

Source	d.f.	Pulse		Respiration		Rectal T.		Skin T.	
		MS	F	MS	F	MS	F	MS	F
Coat Colour									
Between Groups	2	1030.5	0.48	12736	1.46	2.5	0.94	7.6	0.26
Within Groups	3	2157.0		8715		2.67		29.1	
Total	5								
Production Level									
Between Groups	1	0.5	0.0002	11823	1.19	0.8	0.26	62.8	6.31 a.
Within Groups	4	2133.0		9948		3.05		9.95	
Body Weight									
Between Groups	2	1835.0	1.13	11183	1.15	1.35	0.39	15.35	0.64
Within Groups	3	1620.7		9749		3.43		23.97	
Age									
Between Groups	1	520.0	0.26	6848	0.61	3.9	1.71	19.8	0.96
Within Groups	4	2003.0		11191		2.28		20.7	
Stage of Lactation									
Between Groups	2	646.8	0.27	6097.5	0.46	5.1	5.48 a.	25.4	1.47
Within Groups	3	2412.8		13140		0.93		17.3	

a. Significant ($p < 0.10$)

four variables concerned. This was not so on this analysis however. Differences between groups in skin temperature were significant at the 10% level with the higher producers having the higher skin temperatures but it would be unwise to draw any conclusions from this result.

(c) Body Weight

The total range of body weight was less than 200 lb. so that again, differences between the groups were small. Since it has not been shown previously that body weight differences within a species contribute any variation to differences between animals in their physiological reactions, large differences between groups were not expected, especially with such a small and homogeneous sample, and were not seen.

(d) Age

Since all except one of the six cows were in the mature cow age category, the average level of a physiological variable among the cows was expected to be fairly uniform under these air temperature conditions. No significant differences between group means were found in this sample of cows and variables.

(e) Stage of Lactation

In the review of literature (Chapter II), the conclusion was made that stage of lactation probably has less influence on variation in the four physiological reactions than production level. No significant differences between groups were obtained in this analysis except possibly with rectal temperature. The later stage cows had a higher mean rectal temperature than the earlier stage cows ($p < 0.10$) which is contrary to any suggestions from earlier work reviewed in Chapter II. Probably with such small differences between groups in stage of lactation and such a small sample of cows, this could have been a chance event.

Conclusion

Although the differences between cows in their physiological variation as studied in the diurnal trial could not be attributed to any one characteristic on the basis of the above results, these characters could still have had an influence either singly or in combination. The influences of all these characters in each cow, probably aid her in the maintenance of homeostasis. A larger sample of cattle differing widely in a single character or small group of characters would have to be studied in order to gain an insight into the likely influence of any one character or combination of characters. Such influences would also probably become more evident under severe heat stress than under the conditions pertaining to this study.

B. DRY COW-LACTATING COW COMPARISON

Materials and Methods

From the Massey Agricultural College pedigree Jersey herd, six dry and six lactating cows were chosen at random, except that cows close to calving were avoided to minimise any possible influences of pregnancy on the comparison. Unfortunately in this respect, one of the dry cows was empty. Cow 88 proved on initial use to be too excitable for ease of handling and was replaced. This step was thought to be justified because data obtained on such an animal would be of little value. These cows are described in table 14.

The cows were grazed together in a single paddock of a similar nature to the paddocks of the Production-per-acre-Project farm and adjoining the Dairy Research Institute weighing yards where all measurements were taken. The cows were paired at random (but with age taken into account) and each group of four cows (two pairs were always recorded together) had their reactions recorded three times between 16/4/58 and 21/4/58. Either a dry or a lactating cow was recorded first (initially determined at random) and the others followed in either of the two sequences Dry-Lactating - Lactating - Dry or Lactating - Dry - Dry - Lactating throughout the experiment so that if a dry cow was recorded first in repeat 1, her lactating partner would be first in repeat 2 and so on. Four cows were brought into the yards at one time and although the measurements were taken in the weighing chute which

TABLE 14

Characteristics of the Cattle Used in the Dry Cow-Lactating Cow Comparison

Number	Name	Age	Weight	Production	Days in Milk	Calving Date	Colour
Lactating							
34	Lissie	2	721 lbs.	57 lbs.	244	21/1058*	Brown
93	Lilac	2	764	57	261	15/8/58	Dark brown
79	Glisten	6	1074	79	223	6/11/58	Fawn
42	Gentle	6	954	57	235	18/8/58	Fawn-grey
60	Jade	4	844	40	261	13/8/58	Light fawn
54	Gertie	6	809	109	278	3/8/58	Brown
Dry							
85	Lilian	2	826			19/8/58*	Dark brown
98	Lexia	2	881			22/5/58	" "
76	Embrace	8	960			Empty	" "
7	Fad	7	999			22/7/58	Light brown
19	Jacket	4	820			2/8/58	Dark brown
78	Glenda	6	1074			14/5/58	" "

Weight at 21/4/58

Production lbs. butterfat for 60 days ending 22/4/58

Days in Milk at 22/4/58

* Estimated from mating records because animals sold or culled before calving.

was shaded, each cow was only in the shade while her individual reactions were being recorded.

Measurements of pulse rate, respiration rate, rectal temperature and air temperature (for each cow) were made by the methods described for the diurnal trial (Chapter III, section A). Two repeated readings were taken for each variable but if these differed greatly one from the other, a third reading was taken as a check. The results were analysed on the means of these two repeated readings. Again the analyses were done on a split-plot basis with three splits (repeats) within each class of cow and pair of cows, and the tests of significance were handled as follows. The residual error term (second-order interaction) was used to test the first-order interactions, the interaction between pairs and classes to test the significances of differences between pairs and between classes. If one of the interactions involving repeats was significant it was used to test the difference between repeat means but if neither was significant, the largest mean square of the interactions involving repeats was used.

Results

Pair, class and repeat means, and the results of the analyses of variance are presented in table 15, and the mean raw data are given in appendix 9. The mean air temperature over all reading times was 61.0 ± 0.42°F with a range of 56.0 - 66.6°F. These air temperature data are given in appendix 10 and "Grasslands" meteorological data and general comments on the days concerned will be found in appendix 1.

TABLE 15

Comparison between Dry Cows and Lactating Cows

Means

		Rectal Temperature	Pulse Rate	Respiration Rate
Classes:	Lactating	101.69	81.6	29.8
	Dry	101.46	75.3	26.6
Pairs:	1	101.98	77.7	27.7
	2	101.70	80.5	31.2
	3	101.17	73.3	24.2
	4	101.54	75.0	26.2
	5	101.40	76.0	29.5
	6	101.66	88.2	30.3
Repeats:	1	101.69	82.7	28.6
	2	101.61	76.9	27.6
	3	101.43	75.8	28.3

Analyses of Variance

		Rectal Temperature		Pulse Rate		Respiration Rate	
Source	df	MS	F	MS	F	MS	F
Between Pairs	5	0.466	0.98	171.98	3.11	42.86	0.47
Between Classes	1	0.440	0.93	348.44	6.30[a]	93.40	1.02
Pairs x Classes	5	0.474	5.71**	55.31	5.38*	91.58	9.19**
Between Repeats	2	0.220	1.68	164.53	1.32	3.25	0.14
Pairs x Repeats	10	0.131	1.58	16.80	1.63	23.32	2.34
Classes x Repeats	2	0.060	0.72	125.04	12.15**	9.05	0.91
P x C x R	10	0.083	-	10.29	-	9.96	
Total	35						

a ($p < 0.10$)

* ($p < 0.05$) Significant

** ($p < 0.01$) Highly Significant

Discussion

(a) Rectal Temperature

There was no outstanding source of variation in these data and neither class of cows had consistently higher rectal temperatures than the other over all pairs of cows. The lactating cows had higher temperatures on the means of the three repeats but these differences were small. There were no significant differences between pairs of cows or between repeats. Air temperatures were uniform and lower during this trial than during the diurnal trial so that any effects of air temperature on the variables would probably be small.

(b) Pulse Rate

There was more variation in these data. The lactating cows had higher mean pulse rates than the dry cows on all repeats and for all pairs except for pairs 1 and 5. This difference was only approaching significance ($p < 0.10$) however. In odd cases (e.g. cow 54, pair 6, repeat 1) the lactating cow was more excited than her dry counterpart and also dry cows 76 and 7 (pairs 3 and 4) had lower rates than all other cows. In spite of all this, the interactions involving classes were both significant. It might have been expected that producing cows, having a greater heat load to dissipate and also probably having a higher basal metabolic rate, would have had a greater cardiac activity than dry cows, especially in conjunction with a greater feed intake (Thomas, 1949).

An interesting feature was the diminution of pulse rate with each consecutive repeat. Although not of significant magnitude, this diminution was probably real and can be attributed to the training of the stock with repeated handling. Unfortunately, pre-training was restricted due to lack of time before approaching cold weather. This "training" trend was also evident to a very minor degree in the rectal temperature data but not in the respiration rate data.

(c) Respiration Rate

Since the air temperature during this trial was always below 67°F (which is not far above the critical temperature for respiration rate in the Jersey breed, 60°F, given by Worstell and Brody, 1953), respiration rates were generally lower and more uniform than in the diurnal trial. The two dry cows, cows 76 and 7 (pairs 3 and 4), had consistently lower rates than all the other cows and this accounts for the fact that the dry cows had a lower mean rate on each repeat than the lactating cows. There were no distinguishing features about these two cows which had low pulse and respiration rates except that cow 76 was empty. There were no significant differences between the dry and lactating classes and there is no obvious explanation for the variation between individual cows.

C. HEIFER-MATURE COW COMPARISON

Materials and Methods

The general layout of this trial was identical with that of the previous dry cow-lactating cow comparative experiment (Section B of this Chapter). The twelve animals used were six yearling Jersey heifers of the Production-per-Acre-Project herd which were all pregnant, and the six dry cows of the previous study, except that the empty cow (cow 76) was replaced by another dry pregnant cow (cow 86) from the same herd. Cow 76 could have come into oestrus and Wrenn et al (1958) have shown that the rectal temperature of a cow can be upset during oestrus. These animals are described in table 16.

The cows and heifers were paired together at random and again recordings were made with the animals in groups of four and with the same randomisation as in the previous trial. Three repeats were taken between 13/4/58 and 20/4/58. The animals were run in the same paddock and the same measurements were taken in the same yards as before.

The means of the two repeated readings were analysed according to the split plot, time series design which was used for both these comparative trials.

Results

Pair, age group and repeat means, and the results of the analyses of variance are given in table 17. The mean raw data are given in appendix 11, and air temperature data for the trial

TABLE 16

Characteristics of the Cattle Used in the Mature Cow-Heifer Comparison

Number	Name	Age	Weight	Calving Date	Colour
Heifers					
114	Moira	1	743 lbs.	26/7/58	Red-brown
112	Mina	1	715	22/7/58	Brown
63	Mistletow	1	827	11/7/58	Light brown
10	Maggie	1	729	30/7/58	Grey
108	Makoko	1	768	25/8/58	Brown
118	Mouse	1	648	5/10/58	Dark brown
Mature Cows					
86	Harp	5	1102*	27/7/58	Light fawn

and Cows 85, 98, 7, 19 and 78 of Table 14.

* Weighed on 28/4/58

Weight Mean of two weighings on 22/4/58 and 29/4/58

TABLE 17

Comparison Between Heifers and Mature Cows

Means

		Rectal Temperature	Respiration Rate	Pulse Rate
Age Groups:				
	Heifers	101.88	36.5	91.2
	Cows	101.53	27.7	81.5
Pairs:	1	101.69	33.5	81.7
	2	101.70	32.2	85.5
	3	101.83	38.7	85.5
	4	101.82	35.0	96.5
	5	101.53	24.7	82.7
	6	101.66	28.7	86.3
Repeats:	1	102.23	37.8	92.7
	2	101.81	30.2	89.3
	3	101.07	28.4	77.2

Analyses of Variance

		Rectal Temperature		Respiration Rate		Pulse Rate	
Source	df	MS	F	MS	F	MS	F
Between Pairs	5	0.086	1.16	144.64	6.22*	167.96	0.80
Between Ages	1	1.130	15.27*	693.49	29.84**	850.70	4.07
Pairs x Ages	5	0.074	0.96	23.24	0.98	206.90	4.77*
Between Repeats	2	4.155	53.96**	295.37	8.93**	795.85	8.50**
Pairs x Repeats	10	0.038	0.49	33.06	1.40	93.63	2.14
Ages x Repeats	2	0.000		20.36	0.86	2.70	0.06
P x A x R	10	0.077		23.66		43.79	
Total	35						

* ($p < 0.05$) Significant

** ($p < 0.01$) Highly Significant

are given in appendix 12. The three days concerned were the coldest of the whole study, the mean air temperature being 57.4 ± 0.23°F, but temperatures were uniform with a range of only 54.5 - 59.5°F. General meteorological data and comments on the three days are presented in appendix 1.

Discussion

(a) Rectal Temperature

Wirth (1956) has stated that young animals have a higher body temperature than older animals (presumably meaning within a species or breed). This may be a sweeping statement but it is probably true in general (see Review of Literature, Chapter II). The yearling cow is growing and is also generally more excitable than the non-productive (except for pregnancy) dry cow. Among the animals of the present trial the heifers were more excitable than the mature cows (e.g. heifer 10, pair 4, repeat 2) and had consistently higher mean rectal temperatures than the cows on all repeats and for all pairs, the difference being statistically significant. There were no significant differences between pair means, rectal temperature being apparently reasonably constant within a class of cow at these air temperatures.

A similarity to the previous comparative trial can be seen in the significant decreases in rectal temperature with consecutive repeats. Although days (repeats) 2 and 3 were a little colder, and day 3 cloudier, than day 1, these differences were not likely to have contributed much variation to the differences between repeats and once again a "training" effect is postulated as an explanation. Wirth (1956) has stated that excitement can elevate rectal temperature by up to 1°F.

An interesting feature of the results of the analyses was the zero value obtained for the interaction between repeats and age groups. This emphasised the uniformity of the differences between repeats and of those between age groups.

(b) Respiration Rate

Since air temperature was low, respiration rates were generally low but significantly higher in the heifers than in the cows for all pairs and on all repeats. The reasons for this are not clear but the younger animal could require a greater supply of oxygen for metabolic processes than the dry cow or part of the difference could have been due to excitement. There was a consistent and significant difference between pairs of animals emphasising the individuality of basic respiration rate levels. Once again, respiration rate declined over the three repeats by a significant amount.

(c) Pulse Rate

Although the pulse rates of the heifers were generally higher than those of the cows, there was a significant interaction between pairs and age groups and in pair 6, cow 78 (a big 4 year old) had a higher mean rate than heifer 118 (a small heifer that was later culled from the herd). Probably because of the magnitude of this interaction, differences between pairs and between ages did not reach statistical significance. The pulse rates were all high, particularly among the heifers, which could have been due to excitement. Wirth (1956) has stated that excitement can cause an immediate increase in the pulse rate of the dairy cow of up to 10%.

Again the effect of training on pulse rate can be clearly seen in the significant differences between repeat means. The mean rates for the three successive repeats were 92.7, 89.3 and 77.2 beats per minute respectively and this sequence was consistent within the two age groups and within all the pairs except that in pairs 2, 3 and 4, the mean rate for repeat 1 was lower than that for repeat 2.

CHAPTER V

THE INFLUENCE OF BIOLOGICAL FACTORS

A. VALUE AND EFFECTS OF FLY SPRAY

Some difficulty was experienced in carrying out the experiments of the present study because of the unsettling influence that flies had on the cattle. During daylight hours, and especially on sunny days, the activities of biting flies caused restlessness among the cows, stamping and tail-flicking. This made the measurement of pulse and respiration rate and the general handling of the animals more difficult than it would have been without the flies. Therefore, the use of a fly spray was resorted to on three occasions and it was decided to investigate the effects of the spray on the fly numbers and on the rectal temperature, pulse and respiration rates of the cows before considering using it further.

Materials and Methods

The spray involved had been developed for contact use with animals and had the following formulation:

Active Ingredients:

Methoxychlor 90% technical 5.5% w/v or 0.55 lbs. per Imperial gallon.

(2,2 bis (p-methoxyphenyl) 1,1,1-trichloroethane 4.35% w/v or 0.435 lbs. per Imperial gallon.

Other isomers and reaction products 1.15% w/v or 0.115 lbs. per gallon).

Butoxypolypropylene glycols 50% w/v or 5.0 lbs. per Imperial gallon.

Inert ingredients comprising petroleum hydrocarbons and emulsifier 44.5% w/v or 4.45 lbs. per Imperial gallon.

An emulsion was made with water and the spray applied by means of a knapsack sprayer. Fly counts were made by counting the flies settled at a given instant on one half of the animal and doubling this figure. Bennie (1956) used the same method but observed that it was not possible to obtain exact counts due to the coming and going of flies. However, this method probably gave a sufficiently exact estimate for the purposes of this study.

The spray was used in a reversal or switchback trial with three treatment periods (4/3/58, 6/3/58 and 7/3/58) according to the method of Brandt (1938) in which two groups of cows were each subjected to two treatments, X and Y, simultaneously but in the order X-Y-X in group A and Y-X-Y in group B. In the present experiment, the treatments were spray and no-spray and there were four cows in each group. The animals were pedigree Jersey cows from the Production-per-Acre-Project herd, described in table 18. These cows were assigned to the two groups at random and there should have been no bias associated with the selection of the animals for the groups since it was not known in advance what their responses to the spray would be. The treated group was sprayed before readings commenced and then the cows of the two groups were dealt with alternately in each period. A different random order was used for each of the three

TABLE 18

Characteristics of the Cattle Used in the Fly Spray Trial.

Number	Name	Age	Weight	Production	Days in Milk	Calving Date	Colour
72	Elect	8	985 lbs.	77 lbs.	184	7/10/58	Dark brown
33	Dulcie	9	990	97	193	25/7/58	Light fawn

and the 6 cows of Table 2

Weight Mean of 2 weighings (4/3/58 and 11/3/58)

Production lbs. butterfat for 60 days ending 21/2/58.

Days in Milk at 21/2/58

periods except that the cows were handled in pairs (one sprayed and one not sprayed). The measurements were taken in the portable netting yard as in the diurnal trial and air temperature, pulse rate, respiration rate and rectal temperature recorded in the same manner (Chapter III, Section A).

The means of two repeated readings of pulse rate, respiration rate and rectal temperature, and the fly counts themselves were utilised in the analysis. The form of the analysis of variance has been given by Snedecor (1955). If the three treatment periods are represented by a, b and c, then the difference between the comparisons a - 2b + c for the two groups of cows gives a measure of the change in the variable attributable to the treatment. These differences for each analysis were tested by the distribution of "F" using as error variances the pooled sums of squares from the two groups of comparisons in each case.

Results and Discussion

The treatment means and the results of the analyses of variance are presented in table 19, and the mean raw data are given in appendix 13. Throughout the trial, the air temperature ranged from 73.0 to 81.5°F. "Grasslands" meteorological data and general comments are given in appendix 1.

The spray treatment had no significant effect on pulse rate either because the flies were not causing enough disturbance to the cows to affect pulse rate or because the reduction in fly numbers due to the spray was not sufficient to reduce any disturbance that there might have been. One reason for the relative

TABLE 19

The Effect of Fly Spray on Fly Numbers and on the Physiological Variables in Cattle.

Treatment Means

Treatment	Pulse Rate	Respiration Rate	Rectal Temperature	Fly Count
Sprayed	78.8	56.4	101.50	11.5
Not Sprayed	79.8	70.8	101.68	45.0

Analyses of Variance

		Pulse Rate		Respiration Rate		Rectal Temperature		Fly Count	
Source	df	MS	F	MS	F	MS	F	MS	F
Treatment	1	4.5	0.04	3784.5	12.63*	0.31	0.65	30,013	11.09*
Error	6	115.5		299.6		0.48		2707	

* ($p < 0.05$) Significant

ineffectiveness of the treatment in reduction of fly numbers might be because the blood-sucking flies were difficult to detach and could remain on the cow for some time after spraying, even if dead. However, there was a definite lessening of the general fly load and nuisance for up to two hours from the time of spraying. The significant effect on respiration rate was probably due to a cooling effect of the spray since reductions in respiration rate have been noted following sprinkling of cattle with water (see Review of Literature, Chapter II). This cooling was apparently not sufficient to affect rectal temperature to any great extent.

The Fly Species Involved

The flies which cause the trouble to the cows follow the animals into the shed at milking time. From a random sample of 14 flies caught amongst the cows in the milking yard on a warm, humid day, 13 were identified as *Stomoxys calcitrans*, the blood-sucking stable fly, and 1 as *Musca domestica*, the common house fly which could have been in the shed before the animals were brought in. The other fly, besides *S. calcitrans*, present in numbers in the field was identified as *Sarcophaga Spp.* (presumably *S. milleri*), the striped flesh fly which does not bite and probably causes as much discomfort to the observer as to the cattle.

General Fly Count Data

During the course of the diurnal trial (Chapter III, Section A), fly counts were made on the six cows on twenty occasions. On three of these occasions all of the cows were sprayed with the fly spray discussed above and on one occasion, the ground only was sprayed in an attempt to repel flies from the area. Although it was not possible to statistically analyse these data (given in table 20), the following observations were made:

(1) There were differences between cows in their tolerance towards flies. For instance, cows 29 and 21 often carried the heaviest fly load simply because they made less efforts to dislodge and repel flies than the other cows. Consequently, these cows were easier to handle when flies were numerous.

(2) It was not possible to test the effectiveness of the fly spray since all cows were sprayed at any one time but the counts did not seem to be reduced very much with treatment.

(3) On days when flies were numerous, fly nuisance was reduced at 6 p.m. when dusk was falling compared with 8 a.m., 10 a.m., noon or 2 p.m.

(4) It is possible that there was a reduction in fly load at 2 p.m. on 19/2/58 when the atmosphere was wet.

(5) A study of the repeated counts would suggest that the repeatability of the counting method was reasonably high considering the rapid coming and going of flies.

There was a suspicion that water alone could reduce fly counts when used as a spray. Preliminary investigations into this question gave results that indicated that this was true but the data on which this was based were meagre.

TABLE 20

Fly Counts made During the Diurnal Trial

Date	Cow Time	4	1	21	74	3	29	Remarks
13/2/58	noon	25	58	64	55	17	77	Repeated Counts
		20	73	136	83	14	90	
	2 p.m.	25	52	60	56	24	88	
		30	54	50	56	28	88	
	6 p.m.	10	22	16	34	24	22	
		12	18	8	24	6	16	
19/2/58	10 a.m.	60	34	46	68	32	140	
		60	34	112	68	32	140	
	noon	30	8	42	62	80	52	Cows Sprayed[1]
	2 p.m.	12	18	4	10	28	18	Rain
21/2/58	8 a.m.	20	24	50	28	20	42	
	10 a.m.	32	42	28	60	24	134	
	noon	38	28	94	26	20	40	Ground Sprayed[1]
	2 p.m.	6	16	50	28	26	26	Cows Sprayed[2]
	6 p.m.	3	2	5	4	5	4	
28/2/58	10 a.m.	20	26	40	54	48	64	
	noon	22	8	24	36	28	26	Cows Sprayed[2]
	2 p.m.	18	16	42	42	68	30	
5/3/58	8 a.m.	14	22	28	14	12	22	
	10 a.m.	38	42	46	44	22	42	
	noon	24	64	108	24	44	60	
	2 p.m.	16	62	36	38	12	120	
	6 p.m.	4	6	2	4	2	6	
12/3/58	2 p.m.	34	80	192	42	36	118	
Totals		573	809	1,283	958	652	1,465	

1. Sprayed 15 minutes before counts started

2. Sprayed 1 hour before counts started.

B. THE SHADING TRIAL

Materials and Methods

Because of the possibility of an effect of shade on the physiological variables in the diurnal trial and other experiments, and also as a general evaluation of shade in reducing any heat load on cattle, a reversal type shading trial was conducted during the summer of 1958-59. Eight cows were chosen at random (with the restriction that the highest producers were not considered because of the possibility of upsets to production by the experimental procedure) from the same herd as the cows used for the diurnal trial (Chapter III, Section A). These eight cows are described in table 21. They were separated from the herd and break-grazed on a paddock of the Production-per-Acre-Project farm, handy to the milking yards where the investigations were made. Turnips (Brassica rapa L.) were fed to the group in the paddock after the a.m. milking.

Four days were chosen between 9/1/59 and 15/1/59 and although there was not continuous bright sunshine on all days, all were fine and warm and there was clear-cut shade. The cows were paired on age. On the day of reading, two pairs of cows were brought into the yards and one of each pair penned in the shaded open front of an iron-roofed calf shed. The other member of each pair was left in the sun in an adjoining yard. The cows remained penned for one hour before recording was begun. Since, on average, each set of readings (4 cows) took 45 minutes to obtain, the second two pairs of cows were brought in 45 minutes

TABLE 21

Characteristics of the Cattle Used in the Shading Trial

Number	Name	Age	Weight	Production	Days in Milk	Calving Date	Colour
25	Janet	5	878 lbs.	109 lbs.	169	12/9/59	All 8 cows were shades of Jersey fawn-brown with no more variation than can be seen in table 2.
17	Lustre	3	785	78	149	31/7/59	
22	Gracie	7	1076	71	156	19/8/59	
18	Fin	8	979	77	165	28/7/59	
3	Love	3	846	78	185	7/8/59	
75	Happy	6	914	77	170	10/7/59	
74	Gerbera	7	960	77	156	21/8/59	
33	Dulcie	10	1015	78	173	11/7/59	

Weight   Mean of 2 weighings (7/1/59 and 21/1/59)

Production lbs. butterfat for 60 days ending 17/1/59

Days in milk at 17/1/59

Calving date estimated from mating records.

after the first two pairs or 15 minutes before recording began. These latter pairs were therefore in the yards for one hour before they were dealt with after the first pairs were finished with. On days 1 and 4, both groups of four cows were recorded in the order shade-sun-sun-shade, and this order was inverted on days 2 and 3. Treatments were reversed within a pair of cows each succeeding day so that if a cow was in the shade on day 1, she was in the sun on day 2 and so on. Finally, each cow within a group of four was recorded first on one of the four days.

Before recording, the cow was haltered and tied to the yard rails. Measurements of pulse rate, respiration rate, rectal temperature and skin temperature were taken as for the diurnal trial except that two repeated readings only were obtained and, for skin temperature, repeated readings were not taken but the thermocouple was kept in place and the reading checked over a few seconds to ensure a steady reading. This latter virtually meant obtaining perfect repeatability, without taking separate readings by removing the couple from the skin and replacing it as had been done previously. The couple was applied to the skin in a smaller holder than that used previously. This consisted of a large cork (2" across and 1" deep) through which were led (parallel to each other and as far apart as the 2 inch diameter of the cork would allow), two glass tubes about 3 inches long. These tubes were each tipped at one end by a small piece of rubber tubing. The thermocouple wire was led through one tube, across from one piece of rubber to the other, and back through the other tube so that the couple junction lay in the gap between the pieces of rubber which ensured a certain amount of spring. The ends of the wire were anchored to the cork before being led away to the potentiometer. Since a new thermocouple was used, a new calibration curve was obtained as follows:

$$Y\ (^{o}F) = 34.16 + 46.15\ X\ \text{(millivolts)}.$$

and used to convert all potentiometer readings to the temperature scale.

Air temperature was recorded with each cow by means of a mercury thermometer hung in the shade and wet and dry bulb temperature readings were also taken using a sling psychrometer (Middleton, 1942).

One complete set of preliminary readings was taken before the experiment was commenced. The experimental results were analysed by analysis of variance on a time-series, split-plot basis as in the diurnal trial. The first-order interactions were tested by the residual error term and the significances of differences between pair of cows means and treatment means were tested by the interaction between pairs and treatments. The significance of differences between the day means was tested by the largest of the interaction mean squares involving days. The means of the two repeated readings (pulse rate, respiration rate, rectal temperature) were used in the analyses.

Results

Pair, treatment and day means and the results of the analyses of variance are given in table 22. The mean raw data are given in appendix 14.

The mean air temperature during the trial was 79.1 ± 0.65°F with a range of 71.0 - 85.5°F. Mean relative humidity was 58.4 ± 0.97% with a range of 48 - 73%. These air temperature and humidity data are given in appendix 15 and the "Grasslands" meteorological data and general observations are given in appendix 1.

Discussion

(a) Pulse Rate

Pulse rates were relatively uniform during this trial and were high, even in the cows (cows 3, 74 and 33) which had been used the previous summer. The readings were taken in the middle hours of the day when values for all four variables would be expected to be the highest in the diurnal pattern (see figures 4 to 10 inclusive). There was a gradation in pulse rate from day 1 to day 4, being highest on day 1, and although this gradation did not show up as a significant difference between days, it could have been an effect of training since the preliminary training period was limited. The days were uniformly hot which could have reduced any variation between days that was not due to a training effect.

Pairing of cows on age only might or might not have reduced the variation between pairs since a cow with a high pulse could

TABLE 22

The Effect of Shade on the Physiological Variables

Means

		Pulse	Respiration	Rectal Temperature	Skin Temperature
Treatments:	Shade	84.9	37.4	101.78	93.56
	Sun	84.4	42.4	101.95	97.69
Pairs:	1	85.1	34.4	101.93	95.63
	2	85.5	39.0	101.69	96.55
	3	85.3	46.1	101.89	94.25
	4	82.8	40.3	101.95	96.09
Days:	1	87.9	40.4	102.01	96.39
	2	86.8	38.4	101.73	96.49
	3	85.1	45.0	101.90	94.64
	4	78.9	36.0	101.82	95.00

Analyses of Variance

		Pulse Rate		Respiration		Rectal Temp.		Skin Temp.	
Source	df	MS	F	MS	F	MS	F	MS	F
Between Treatments	1	1.53	0.03	200.01	4.54	0.340	8.37[a]	136.54	101.14[aa]
Between Pairs	3	13.11	0.29	187.21	4.25	0.133	3.28	7.89	5.84
Pairs x Treatments	3	44.54	0.69	44.08	0.46	0.041	0.56	1.35	0.42
Between Days	3	129.01	1.99	116.71	1.17	0.133	1.75	7.16	0.76
Days X Treatments	3	12.97	0.20	30.75	0.32	0.045	0.62	7.26	2.28
Days x Pairs	9	46.93	0.73	99.35	1.03	0.076	1.05	9.38	2.94
D x P x T	9	64.71		96.61		0.072		3.19	
Total	31								

a $(p < 0.10)$

aa $(p < 0.01)$ Highly Significant

have been paired with a cow with a low pulse rate or with another cow with a high rate. In the present study there were no significant differences between pairs of cows. Any possible cooling effects or reduction of heat load due to shading may not have had time to affect pulse rate but there was no significant treatment effect in this analysis.

(b) Respiration Rate

Respiration rates were also relatively uniform and none of the differences in the analysis were of significant size. In spite of the hot temperature conditions, no really high rates were manifested even in the sun, and it is likely that this group of cows was more uniform in heat tolerance than the group used in the diurnal trial which included cow 4, a cow whose respiration rate was generally higher than the other cows.

The no-shade treatment respiration rates were consistently higher than the shade treatment rates on day means and on pair of cow means, but not sufficiently so for the difference to reach significance, possibly because of the small sample of cows involved.

(c) Rectal Temperature

The rectal temperatures of the shaded cows were consistently lower than those of cows in the sun within all pairs and on all days except day 3 (the day of highest shade temperatures). In this case the difference more nearly reached significance ($p < 0.10$) and it is likely that there was a real effect of shade treatment on rectal temperature. Since the main effect of shading was probably to reduce the heat load due to solar radiation and since the heating effect of the radiation would act mainly through the skin and its body-heat balancing mechanisms, it might be expected that rectal temperature would have responded to shade treatment before pulse or respiration rates which would respond to the rise or fall in blood temperature. This assumes that the influence of the blood temperature on the central nervous "heat centre", and thence on cardio-respiratory activities, is more important than direct nervous paths from the skin to the "heat centre", which is possibly true.

It is possible to postulate that shade did have a cooling effect on the animals but it is doubtful whether this effect was great enough to be really beneficial under these New Zealand summer conditions.

(d) Skin Temperature

As mentioned above, the main effect of shading was probably to reduce the effects of solar radiation and it was therefore thought that the greatest effect of the treatment would be on skin temperature. This hypothesis was supported statistically by the obtaining of a highly significant difference between treatment means. This result suggests that care should be taken in the interpretation of skin temperature field data when alternating periods of sun and shade (cloud) are present. In this analysis, both first-order interactions involving days were fairly large (although not significant) suggesting differences between days in the effects of shading and since the days differed in the amounts of cloud present, this was not unexpected.

Quinlan and Riemerschmid (1941 - cited Findlay, 1950) found that the mean flank skin temperature (shaved) of a Sussex bull was 98.6°F in the sun and 96.7°F in the shade. The corresponding means in the present study were 97.7°F and 93.6°F respectively.

The thermocouple was always shaded by the hand when readings were being taken, but only to avoid a direct heating of the couple by the sun. The smaller applicator proved easier to use and was apparently just as efficient as the bow type holder of Patchell (1954b), used by the present investigator in the diurnal trial (Chapter III, Section A).

CHAPTER VI

THE MEASUREMENT OF SKIN TEMPERATURE

Introduction

By "skin temperature" is usually meant the temperature of the outer epidermal surface where the animal body and the environment come into contact one with the other. By "surface temperature" is often meant the temperature of the outer hair surface in hairy animals such as the cow, and this distinction can cause some confusion. Lee (1953) differentiates between the "skin surface temperature" and the "coat surface temperature" and there may be a considerable temperature gradient between the two (Thompson et al, 1951). The latter is easier to measure and Lee has actually stated that the measurement of skin surface temperature is not recommended as a general field procedure. However, it seems that skin temperature is physiologically as important as coat surface temperature (if not more so) and should be measured if suitable techniques are available.

The temperature of the skin depends upon the thermal conductivity of the underlying tissues and on the volume of the cutaneous blood flow (Lee, 1949). Peripheral vasoconstriction as a response to cold is under sympathetic nervous control while vasodilation as a response to heat is probably a generalised vascular relaxation brought about by both sympathetic and parasympathetic impulses (White et al, 1952). The thermal conductivities of the tissues are controlled to some extent by the addition or removal of water and these and other factors (e.g. cardiac activity, fat deposition) affect the thermal gradient between the "deep body" and the skin surface. Lee (1953) has pointed out that skin temperature is less constant than deep body temperature and is often sacrificed in order to maintain equilibrium in the latter. Heat loss from the body by physical avenues (radiation and convection) depends on the maintenance of a thermal gradient between the skin surface and the ambient air which disappears at air temperatures of 100°F to 105°F (Brody, 1956).

The following factors affect the skin temperature:

1. The climatic variables (air temperature, solar radiation, wind velocity, humidity).
2. The surface evaporation of moisture (sweating, diffusion, rainfall and sprinkling).
3. The hair covering.
4. The body metabolism and the deep body temperature.

A. METHODS OF MEASUREMENT

Instruments Used

Four different types of instruments have been used in the measurement of skin temperature:

1. Mercury thermometers.
2. Thermocouples.
3. Resistance thermometers.
4. Radiometers.

Mercury thermometers can normally only be used to measure hair surface temperatures. Macfarlane (1957) recommended a small, low heat capacity thermometer which gives contact over many hairs when rotated about its long axis and heats fairly uniformly. Findlay (1950) advocated only resistance thermometers or thermocouples, both of which types must be applied to the skin and therefore give readings which may be subject to the following errors:

1. Abnormal physiological reactions may be caused by contact, pressure or irritation.
2. Heat exchange might be physically disturbed.
3. Temperature equilibrium between instrument and skin may be difficult to obtain, depending upon the area of contact.

Lee (1953) pointed out that thermocouples and thermistors (resistance thermometer "heat sensitive" elements) must be fine enough to lie in close contact with the skin, with minimum disturbance to the overlying hairs. Resistance thermometers (incorporating thermistor elements) are usually more robust than thermocouples. Patchell (1954b) stated that the most accurate method for measuring skin temperature is by means of a radiometer, but he apparently did not differentiate between the skin temperature and outer-coat surface temperature since the radiometer only measures the temperature of the surface "seen" by the instrument and not the skin temperature as defined in the previous section. However, this type of instrument would be ideal for measuring coat surface temperatures if the various surface emissivities could be determined. Burton (1948) has drawn up a table giving a comparative evaluation of the electrical methods for skin temperature measurement.

Patchell (1954b) found that his bow-type thermocouple holder (as used in the diurnal trial of the present study) gave the most consistent results of the four types tried. Good repeatable results were obtained on the right hip region which was handy of access. Clipping and shaving both significantly reduced skin temperature and were not recommended as general practices.

The instrument used in the diurnal trial of the present study has been described (Chapter III, Section A). The disadvantages in the use of this apparatus were:

1. Two men were required to work the apparatus (applicator and potentiometer).
2. The whole apparatus was not readily portable.
3. The ice of the reference junction had to be replaced daily.
4. The thermocouples were easily broken and although they were fairly easily mended, the calibration curve had to be checked.
5. It was difficult to achieve and maintain good contact between the couple and the skin surface.

Some of these points no doubt contributed to the low repeatability (50%) found with this instrument.

The Construction of a Resistance Thermometer

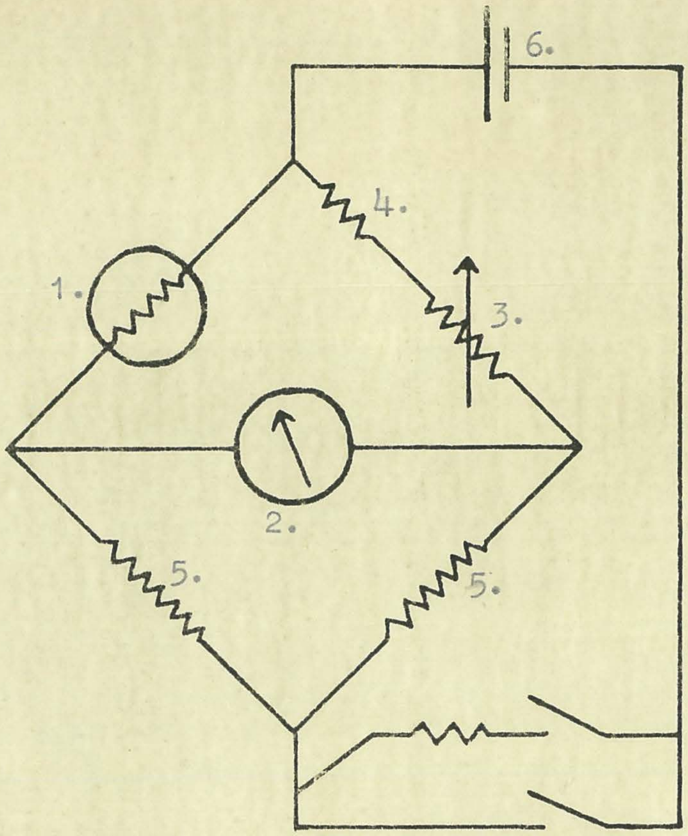
Because of the difficulties experienced in the use of thermocouples it was decided to investigate the possibilities of the use of thermistor elements in skin temperature measurement. McLean (1954) has defined thermistors as semi-conductors whose resistance varies with absolute temperature. A resistance thermometer would therefore consist of an applicator containing a thermistor element and some means of measuring the changes in resistance. Fleming (1958) pointed out that the elements are small, have low heat capacity, are potentially stable and are sensitive, requiring small changes in temperature to produce large changes in resistance. Findlay (1950) has discussed the use of resistance thermometers and thermistors.

With the assistance of the Dominion Physical Laboratory (D.S.I.R.) a circuit was designed (figure 15) similar to that of an instrument developed by W.R. Bockley of the Hannah Dairy Research Institute (Findlay, 1950), but using a more convenient method for determining the out-of-balance current in the bridge circuit. The author then constructed the instrument pictured in figure 16. The tip of the applicator (constructed by D.S.I.R.) was spring loaded to ensure an even pressure of the thermistor on the skin surface.

The principle of the circuit was a Wheatstone bridge with the resistance of the thermistor indicated by the out-of-balance current in the opposite arm of the bridge. The current supply was a 1½ volt dry cell and this was chosen, along with the values of the

FIGURE 15

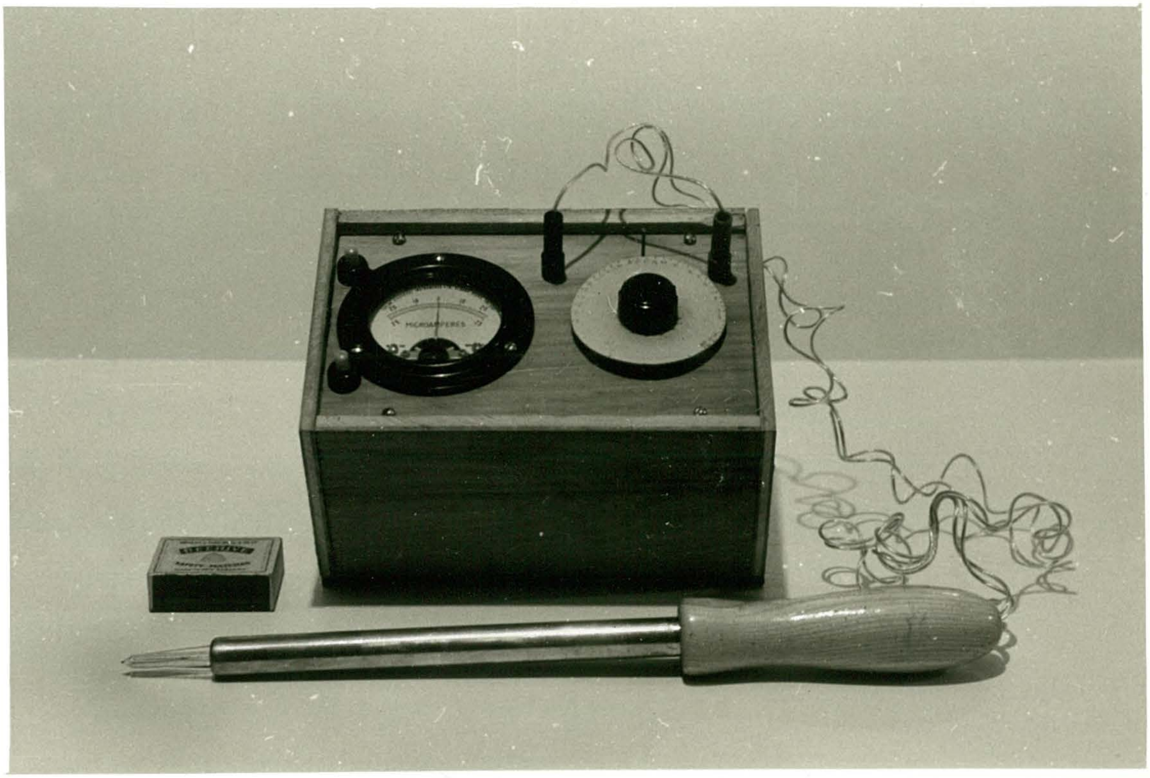
CIRCUIT DIAGRAM OF THE AUTHOR'S RESISTANCE THERMOMETER



1. Thermistor
2. Micro-ammeter
3. 0 - 1000 Ω Variable Resistance
4. 800 Ω Wire Wound Resistors
5. 1500 Ω " " "
6. 1½ volt dry cell.

FIGURE 16

THE AUTHOR'S RESISTANCE THERMOMETER



fixed arm resistances (wire-wound), with regard to the resistance range of the thermistor at the temperatures used and with regard to the need for keeping the circuit current under 0.8 mA to avoid undue self heating (internal heat) of the thermistor. The bridge was balanced to a nil reading on the micro-ammeter (centre-zero, 0-25 micro A) by means of the variable resistance so that the temperature could be read off at leisure from the scale attached to the variable resistance, even after the applicator had been removed from the skin. No compensating leads were required (one of the main problems of resistance thermometry) since the thermistor had a high temperature coefficient of resistivity.

The instrument was calibrated for the particular thermistor in a water bath, up and down the temperature range for which it was to be used. The type of scale used overcame the problem of non-linearity in the relationship between temperature and resistance. It would have been desirable to age the thermistor before use according to the method of Fleming (1958), and also to check the calibration from time to time, but Fleming's paper was not seen until after the thermometer had been made and used.

Although the instrument required two operators it was portable and robust and good contact between instrument and skin (and hence thermal equilibrium) was easily achieved. The main disadvantages (apart from any errors due to the relatively crude construction of the pilot model) were the difficulty of replacing a broken thermistor element and the need to recalibrate the instrument after any such replacement because of the wide manufacturing tolerance limits of thermistors (McLean, 1954).

B. THE USE OF THE RESISTANCE THERMOMETER

Methods

The resistance thermometer described in the previous section was used to take seven sets of readings on two cows on the 25/11/58 and 26/11/58. Skin temperature readings were taken on four body positions (shoulder, mid-side, hip and upper thigh) on each cow, and two repeated readings (immediately following one another) were obtained on each position, each cow and at each of the seven times. The measurements were made in an open fronted milking shed, in the shade, and all readings within a set were taken in the same order. The two mature cows were grazing with the Dairy Research Institute herd. In one (cow 83), a brown and white cow, all four positions were on white areas while in the other (cow 82), a dark brown cow with some white patches, all four positions were on dark areas. Wet and dry bulb air temperature readings were taken, using a sling psychrometer, at each reading time.

The data were analysed by analysis of variance on the split-plot basis in a similar way to the data of the diurnal trial (Chapter III, Section A) except that the significance of the variation between positions within cows was considered and tested over the second-order interaction term. The difference between cow means was tested over the interaction between cows and positions and that between times means over the interaction between cows and times.

Results

Means for positions, positions within cows, cows and times are given in table 23 together with the results of the analysis of variance. The raw data are presented in appendix 16.

Mean dry bulb air temperature during the trial was 69.8°F with a range of 65.5 - 71.5°F. Similarly, the mean relative humidity was 67% with a range of 61 - 85%. These data are given in appendix 17.

Discussion

Although the brown and white cow (cow 83) had the higher skin temperature on most occasions, the difference was too small or the sample too small for the difference to reach significance. Any differences between the means of the times of reading were also small and the times did not rank in the same order within each cow.

(a) Variation Between Positions

Various writers have reported variations in skin temperature over the body surface in cattle. Beakley and Findlay (1955b), using thermocouples on Ayrshire bull calves in a psychrometric room, found that the skin temperature varied over eight positions on the trunk but that no one position was significantly hotter than any other when all results were pooled. Thompson *et al.* (1953) measured the skin temperatures of European-type cattle, also using thermocouples in a climatic chamber, at 23 body positions. There were large differences between positions in these data, especially in the lower air temperature range up to

TABLE 25

Analysis of Skin Temperature Data Obtained with the Resistance Thermometer

Means (°F)

Positions Cows	Shoulder	Mid Side	Hip	Upper Thigh	Mean of All positions
85	94.8	95.5	92.9	95.0	94.6
82	94.0	93.7	92.9	94.5	93.8
Mean of both cows	94.4	94.6	92.9	94.8	94.2

Times	1	2	3	4	5	6	7
Mean	93.6	93.4	94.5	95.4	95.0	94.7	94.5

Analysis of Variance

Source	df	MS	"F"
Between Cows	1	17.70	4.50
Between Positions Within Cows	6	12.08	10.15**
Between Positions	3	20.23	5.15
Cows x Positions	3	3.93	3.30*
Between Times	6	6.87	1.98
Cows x Times	6	3.47	2.92
Positions x Times	18	1.26	1.06
Positions x Cows x Times	18	1.19	
Within Readings	56	0.18	
Total	111		

* $(p < 0.05)$ Significant
** $(p < 0.01)$ Highly Significant

40°F, but in this case, the positions ranged from mid-trunk to the ears and hoof cleft. Robinson and Klemm (1953) investigated seven different positions on Shorthorn cows at high air temperatures (86.0 - 108.5°F) and found high groin and belly temperatures which they attributed to low conduction and convection heat losses from these areas. The other positions, including the legs, were all at similar temperatures. Patchell (1954b) reported that the skin temperature of the extremities of the Jersey heifer was lower than that of the trunk but there was little variation between trunk positions under moderate air temperature conditions. Finally, Lee (1953) has suggested a gradation in skin temperature down the legs with the higher temperatures nearer the trunk, and that in the sun, temperatures could vary considerably between positions, even on the trunk.

Although there were no significant differences between the overall mean skin temperatures for the different body positions in the present study, within each cow such differences were highly significant. The four positions ranked differently in the two cows, the only consistent factor being the temperature of the hip position which was the lowest temperature in both cases. The reasons for this latter finding are not clear since it is difficult to conceive that the hip was more exposed for convective or radiative cooling than the shoulder or truly cooler than the thigh. On the basis of the previous work reviewed above, it was not expected that the average skin temperature would differ consistently from position to position on the trunk, especially since the measurements were made in the shade. However, because of the difference between positions within cows and the inconsistent ranking of the positions found in the present study, it seems wise to use more or less fixed and clearly defined positions in all comparative skin temperature work.

(b) <u>Repeatability</u>

A repeatability estimate was obtained for the resistance thermometer in the same manner as was obtained in the diurnal trial for the thermocouple (Chapter III, Section A). This estimate was calculated from the components of variance as follows:

$$\text{Repeatability} = \frac{P \times C \times T^2}{P \times C \times T^2 + \text{Within Rdgs}^2}$$

$$= \frac{\frac{(1.19 - 0.18)}{2}}{\frac{(1.19 - 0.18)}{2} + 0.18}$$

$$= \frac{0.51}{0.51 + 0.18}$$

$$= 0.74$$

This estimate of 74% is considerably higher than the estimate of 58% obtained for the thermocouple. This suggests that the resistance thermometer was the better instrument but in assessing this, two factors have to be taken into account. Firstly, the resistance thermometer readings were taken in the shade under more stable conditions than prevailed during the diurnal trial and secondly, the readings were obtained over a shorter period with a single assistant operator which probably meant that greater care was taken with the readings. However, even if this improvement in repeatability is not all truly attributable to the instrument, the resistance thermometer was much easier to use than the thermocouple and potentiometer, particularly as regards the application of the temperature sensitive element to the skin.

A possible source of variation considered important by Patchell (1954b) was differences in the pressure of application of the thermocouple to the skin. Using the resistance thermometer in the present study it was found that extreme pressure differences caused fluctuations in skin temperature of up to 0.5°F either way from normal but within the range of pressures used in normal careful measurement, there were no fluctuations in skin temperature due to this source of variation.

In a previous section (Chapter III, Section A) it was stated that no repeatability estimates of the type derived in the present study (i.e. repeated readings immediately following one another) could be found in the literature. Patchell (1954b) derived intra-class correlations between skin temperature readings taken on Jersey heifers at nine different body positions but it is not clear which figures relate to which positions. Also, the positions were taken in sequence and the sequence repeated rather than the reading for each position being repeated immediately. Finally, the positions were shaved so that, even if it were possible to tell with any degree of certainty which figures related to the positions used in the present study, the estimates obtained are not strictly comparable with the present one.

C. INSTRUMENT COMPARISON

Method

Four different types of temperature measuring instruments were compared in a closed vessel immersed in a controlled temperature water bath, the temperature of which was taken slowly from 85°F to 105°F at a rate of rise of approximately 0.5°F/minute. Readings of all four instruments were taken in approximately 2°F steps. The order of reading was:

1. Mercury thermometer (°F)
2. Commercial "Thermophil" resistance thermometer, the probe of which was unsuitable for skin temperature work.
3. The author's resistance thermometer.
4. Copper-constantin thermocouple as used in the present study.
5. Repeat of mercury thermometer.

The glass lid of the vessel was replaced by a lid of "Pinex" board through which the instruments were fixed so that their heat sensitive parts were grouped together in the centre of the vessel. Because the change in temperature was a steady rise and all four instruments could not be read simultaneously, it was not thought that the trial would give an accurate comparison but merely give an indication of any gross inaccuracies in any of the methods.

Results and Discussion

The results of the comparison are presented in table 24. The basic assumption was made that the mercury thermometer gave an accurate measure of temperature with which the measures given

TABLE 24

Comparison of Measuring Instruments (Skin Temperature) in a Vessel Immersed in a Controlled Temperature Water Bath

	Instruments					Differences			
	A	B	C	D	E	E-A	D-A	C-A	B-A
1.	86.8	85.9	86.0	88.0	87.5	0.7	1.2	- 0.8	- 0.9
2.	87.8	86.9	87.2	89.8	88.7	0.9	2.0	- 0.6	- 0.9
3.	89.6	87.9	89.3	91.7	90.6	1.0	2.1	- 0.3	- 1.7
4.	91.9	89.9	90.8	93.0	92.3	0.4	1.1	- 1.1	- 2.0
5.	93.2	92.0	91.9	95.0	94.0	0.8	1.8	- 1.3	- 1.2
6.	95.0	93.1	93.9	97.3	95.8	0.8	2.3	- 1.1	- 1.9
7.	97.2	95.0	95.5	99.7	98.0	0.8	2.5	- 1.7	- 2.2
8.	99.4	96.8	97.7	102.0	100.2	0.8	2.6	- 1.7	- 2.6
9.	100.4	98.1	98.5	103.0	101.0	0.6	2.6	- 1.9	- 2.3
10.	102.2	98.9	100.0	104.2	102.8	0.6	2.0	- 2.2	- 2.3
11.	104.0	100.9	101.5	105.7	104.8	0.8	1.7	- 2.5	- 3.1
	17.2[1]	15.0[1]	15.5[1]	17.7[1]	17.3[1]	0.75[2]	1.99[2]	- 1.38[2]	- 1.92[2]

1. Temperature Rise
2. Mean Difference

A. Mercury thermometer
B. "Thermophil"
C. Resistance thermometer
D. Thermocouple.
E. Repeat of Mercury thermometer.

by the other instruments could be compared. The difference between the reading of the mercury thermometer at the beginning and that at the end of each series of readings was assumed to give an accurate measure of the change in temperature over this time (E - A). These assumptions may or may not have been completely valid. On average there was a 0.7 - 0.8°F rise in temperature over the period of each series. The thermocouple gave readings higher than the mercury thermometer by a relatively constant amount (D - A; + ve because of the order of reading) but the total rise in temperature (17.7°F) over the whole trial as given by this instrument was in close agreement with that given by the mercury thermometer (17.2 or 17.3°F). This suggests that the thermocouple measured change in temperature equally as well as the mercury thermometer, even if the readings were not identical in absolute terms. No check was made as to whether or not the instruments came to the same reading if left at a relatively constant temperature for a time (as is the case in skin temperature measurement). However, within the limitations of this trial with a steadily increasing temperature, the findings seemed to support the use of the thermocouple as an instrument for measuring change in temperature and it was this instrument which was used for most of the present study.

The two resistance thermometers lagged behind the mercury thermometer by an amount which increased as temperatures rose (B - A and C - A). In other words, it seems that they were slower to respond to changes in temperature and never caught up with the mercury thermometer at that rate of temperature rise. The "Thermophil" readings were higher than those of the author's model because of the order of reading but both gave approximately the same rise in temperature over the trial period (15.0 and 15.5^{o}F) which suggests that the two were of similar use in measuring changes in temperature. One possible reason for the discrepancy between these two and the other two instruments is that the resistance thermometers had wires that were insulated except for the sensitive element and these could have conducted heat away from the element. The couple had wires that were exposed to the vessel temperature for some distance on each side of the junction.

Another possible source of discrepancy between the different instruments lies in the fact that the author's resistance thermometer and the thermocouple were calibrated against the mercury thermometer in a water bath. Could the calibration curves have changed when the instruments were used in a different medium such as air? The answer to this question is not known but for the purposes of the present study, it was felt that the couple and the resistance thermometer gave an adequate measure (compared with the mercury and commercial resistance thermometers) of change in temperature even if absolute measures of temperature would not be strictly comparable between instruments.

D. THE EFFECTS OF ALTERNATE LIGHT AND SHADE

In many cases during the diurnal trial and the shading trial (sun treatment), skin temperature readings were taken when there was scattered moving cloud and therefore alternate periods of bright sun and shade. Patchell (1954b) noted that if clouds passed across the sun there followed a fall in skin temperature probably due to the sudden cessation of solar radiation. In view of this and of the effect of shade on skin temperature seen in the shading trial over a long term, it was thought desirable to investigate the effects of alternate shade and sun in the short term in order to judge the possible effects of this potential source of variation on the skin temperature data as obtained and on variation between repeated readings (on repeatability). To this end, the thermocouple and potentiometer were used to take two series of readings on a single cow on the same position and under varying (recorded) sky conditions. The first series in table 25 were taken at 1 p.m. over a 10 minute period. In this case there was a steady decline in temperature over the 10 minutes with little variation obviously attributable to sky conditions. The second series in table 25 was a series of continued repeated steady readings. In this case there were marked variations of up to 1.8°F between adjacent readings. Many of the rises in temperature appear to be associated with a change in sky conditions from cloudy to bright but it is difficult to separate the effects of such factors and real changes in skin temperature from fluctuations between repeat readings due to sources associated with

TABLE 25

Repeated Readings of Skin Temperature Taken over Approximately 10 Minutes on a Single Cow.

Sky Conditions	Reading
Bright	98.3°F
Soft cloud	97.8
Cloud	97.0
Bright	97.0
Light cloud	97.0
Bright	97.0
Cloud	96.5
Cloud	96.5
Light cloud	96.5
Cloud	95.5
Cloud	94.5
Light cloud	95.0
Light cloud	93.0

Continuously Repeated Steady Readings of Skin Temperature.

Cloud	96.0°F	Cloud	97.0
Bright	97.8	Cloud	97.0
Semi cloudy	97.8	Cloud	96.5
Semi cloudy	97.0	Semi cloudy	96.0
Semi cloudy	97.3	Bright	97.0
Semi cloudy	96.5	Bright	97.3
Semi cloudy	96.5	Bright	96.5
Semi cloudy	96.0	Semi cloudy	97.0

Range: 96.0 - 97.8°F

with the apparatus and observer. Probably, however, at least a portion (if not a large portion) of the variation between repeated readings in skin temperature could be due to real changes in skin temperature some of which could be associated with rapid changes in the cloud cover of the sky.

Intermittent breeze was noted during the second series of readings mentioned above. Since an increase in wind velocity from 0.5 to 5.0 m.p.h. reduces the heat load on cows when air temperatures are between 75° and 95°F (Brody, 1956), the intermittent breeze could have contributed some variation to the series of readings apart from variations due to real changes in skin temperature, sky cover and the apparatus.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Field studies of variation in the rectal temperature, pulse rate, respiration rate and skin temperature of some New Zealand pedigree Jersey cows and heifers were made during the summers of 1957-58 and 1958-59. The aim was to investigate the use of these four variables as indicators of the physiological status of an animal and to relate variations in these to variations in air temperature with the following four questions in mind.

1. What are the best ways of measuring in the field, the variables concerned?

2. What variations are there in these variables (particularly diurnal and between animals) and what relationships exist among them?

3. What constitutes "normality" as regards the physiological variables and does the New Zealand summer climate cause any gross departures from normality (i.e. are the animals subjected to any direct climatic stress)?

4. What influences do various animal characteristics and managerial factors have on these physiological variables.

This chapter contains a summary of the main results of these studies and the conclusions drawn therefrom, discussed as possible answers to the above questions.

1. The methods used for the measurement of rectal temperature, pulse and respiration rate are probably the most convenient and simple methods available and were adequate, although the repeatability

for the pulse rate measurement was not very high (75%).

Pulse and rectal temperature measurements (and possibly respiration rate also) are affected by excitement of the animals.

Rectal temperature measurements should be taken at a constant depth in the rectum, when the animal is consistently either lying or standing, and not when the animal is defaecating. Measurements of the rectal temperature (changes in which parallel changes in deep body temperature) and variations thereof, are probably still the best criteria of heat tolerance.

The thermocouple method (bow-type holder) for taking skin temperature gave a repeatability of only 50%. The method used in the shading trial (different holder and non-removal of the couple from the skin during repeated readings) was easier and probably more accurate. The resistance thermometer which was made proved easy to use, portable and robust, and gave a repeatability of 74%. Although conditions were more uniform during this repeatability trial than during the one in which the thermocouple was used, some of the difference in repeatability was probably due to differences in the method of applying the heat sensitive element to the skin. Differences in pressure of application under normal conditions had no effect on the recorded skin temperature.

Repeatability estimates of the type derived for each measurement system in the present study have apparently never been derived before.

From the results of the instrument comparison it is suggested that the thermocouple and resistance thermometer gave adequate measures of change in temperature, even if absolute temperatures were not strictly comparable between instruments. More work is required to be done on methods for the calibration of these instruments.

A more reliable continuous method for air temperature and humidity recording was required. The sling psychrometer proved useful and convenient for the measurement of these climatic variables.

2. There is a need for further investigation into diurnal rhythms in the physiological variables, independent of air temperature changes.

There was a distinct diurnal pattern and significant difference between individual cows for all four variables in the present study. The diurnal pattern tended to take the form of a peak around midday and a low point in the early morning. A distinct 10 p.m. rise, particularly in pulse and respiration rate, was probably due to metabolic activities independent of air temperature. There were no significant differences between cows in their mean skin temperatures when these were reduced to a common air temperature basis. Identity between skin temperature and air temperature was reached, on average, at 99°F.

Skin temperature rises with air temperature but at the skin temperature-air temperature combination at which the outbreak of sweating occurs in the cow, the skin temperature may fall because of evaporative cooling. There was significant variation between trunk positions in skin temperature within each cow but not if the results for all cows were pooled.

Definite positive relationships were found among the variables and the four physiological variables were positively related to air temperature to a varying degree. There were important differences between cows in the emphases placed on the different aspects of the balancing mechanism involved in the maintenance of homeostasis.

A good prediction of rectal temperature responses can be obtained by considerations of pulse rate, respiration rate and air temperature and a lesser, but reasonable, prediction from considerations of pulse and respiration rate alone. Pulse rate appears to be more important in this respect, under these conditions, than respiration rate.

3. Homeostasis, heat tolerance and "normality" have been defined. The ranges for each of the physiological variables were probably not outside the normal range although there was some thermal polypnea (respiration rates up to 118/minute). The rectal temperature range of 99 - 103°F probably borders on the limits of normality at both ends of the range. Some thermal stress might be present when rectal temperatures reach the 102 - 103°F level. Low rectal temperatures down to 99°F need not necessarily be considered as abnormal.

All the cows were high producers and grazing in the field and these factors could have influenced any assessment of heat tolerance. The Jersey has generally a higher heat tolerance than the Friesian and some work needs to be done on the latter breed, but it is suggested that any possible thermal stress on the New Zealand Jersey cow during summer is not of great economic importance.

It might be possible, on the basis of rectal temperature responses to local summer climatic conditions, to select within New Zealand those cows likely to thrive in the tropics, but this is a suggestion only.

4. It was not possible to explain a significant portion of the differences between cows in any of the four physiological variables on the basis of any one of the animal characteristics studied. All of these latter probably had an influence singly or in combination and these influences might have shown up with wide differences between animals or under severe heat stress.

Probably, lactating cows have a greater cardiac activity than dry cows and heifers have a higher rectal temperature and greater respiratory activity than mature cows. More work is required to be done on the relationships among body weight, production level, efficiency of production and heat tolerance.

There was a definite diminution in rectal temperature, pulse rate and respiration rate over time in some of the studies, which could possibly be attributed to a training effect.

The fly spray reduced the fly load on the cattle but had a significant effect only on this and on respiration rate. This latter was presumably a cooling effect of the liquid.

There was a possible effect of shade in reducing respiration rate, a more definite effect on rectal temperature and a highly significant effect on skin temperature. The shading presumably reduced the heat load incident to solar radiation and thus reduced skin and body temperatures. It is doubtful whether the cooling effect was enough to be economic under local summer conditions.

Alternate sun and shade could have had a real effect on skin temperature, lowering the repeatability of this measurement.

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APPENDIX 1

Meteorological Data for all Experimental Periods

Grasslands Observations [1]

Date	Experiment	Max. Temp. [2] °F	Screen Min. Temp. °F	Rel. Hum. %	Wind Direction	Wind Force*	Cloud Eighths	Rainfall [3] inches	Bright Sunshine hrs.	Time of Reading	Remarks (Field Observations)
11/2/58	Diurnal	78.0	52.6	84	W	1	5	-	7.7	10a.m. - midnight	10a.m. in shade. Sunny afternoon. 6pm dusk
12/2/58	"	78.2	56.0	64	NW	2	3	-	12.8	Midnight - 6a.m.	
13/2/58	"	84.2	52.7	58	N	4	3	-	12.9	8a.m. - midnight	8p.m. dusk and calm. 10 p.m. damp.
14/2/58	"	83.1	56.7	58	W	2	4	-	12.1	Midnight - 4a.m.	
19/2/58	"	71.5	60.2	88	Calm		8	0.03	2.8	10a.m. - midnight	Fly spray used at noon. 2p.m. wet. 6p.m. dusk & wet.
20/2/58	"	79.0	54.0	83	E	1	3	-	11.2	Midnight - 4a.m.	
21/2/58	"	77.8	54.3	99	Calm		8	-	9.7	8a.m. - midnight	8a.m. misty. 10a.m. breeze. Noon sunny, fly spray used. 2p.m. dark. 6pm. sheltered, 8p.m. dusk, 10p.m. calm.
22/2/58	"	73.2	61.0	68	NE	3	8	0.38	0.0	Midnight - 4 a.m.	
28/2/58	"	75.1	50.2	84	N	1	0	-	11.3	8 a.m. - 6 p.m.	Fly spray used 11a.m. 6p.m. overcast and dusk.
4/3/58	Fly spray	78.8	58.9	83	SW	1	5	-	11.2	10 a.m.	Air temperature 73°F - 75°F.
5/3/58	Diurnal	79.0	56.3	91	Calm		8	-	8.7	8a.m. - 6 p.m.	10a.m. cloud clearing. 2p.m. sunny, breeze. 6p.m. dusk.
6/3/58	Fly spray	80.4	59.9	82	Calm		5	-	9.7	2 p.m.	Air temperature 78.0°F - 81.5°F.
7/3/58	" "	81.0	56.5	79	E	2	2	-	11.4	Noon	" " 81.3°F.
12/3/58	General	76.7	50.2	70	S	2	6	0.42	8.9	2 p.m.	" " 80°F. Some cloud but sunny. Cool breeze.
16/4/58	Dry/Lact.	63.2	40.6	77	N	3	8	0.17	1.7	11a.m. 3 p.m.	11a.m. cloudy, cool breeze. 3p.m. overcast, windy.
18/4/58	"	61.0	52.3	85	NW	5	7	0.06	1.0	Noon	Overcast, cool wind, damp.
19/4/58	"	61.7	30.5	81	[illegible]	1	2	-	9.2	11a.m. 2 p.m.	11 a.m. alternate sunny and cloud, calm. 2p.m. sunny, cool breeze.
21/4/58	"	62.1	52.6	74	W	4	7	0.27	7.8	10a.m. 11.30am.	10a.m. sunny, some cloud, wind. 11.30 a.m. cloud and wind.
25/4/58	HPr/nature	60.0	46.7	66	W	2	6	-	8.5	2p.m. - 4 p.m.	Sunny, some cloud, cold wind.
27/4/58	"	59.0	36.0	83	N	1	3	-	9.5	3.30p.m. - 5p.m.	Sunny, breeze.
28/4/58	"	59.3	45.5	78	NW	4	8	-	2.8	10.30a.m. - 12.30 p.m.	Overcast, cool wind.
9/1/59	Clinding	80.2	50.0	60	Calm		1	-	13.2	12.30p.m. - 2.30 p.m.	Bright sun.
10/1/59	"	76.8	54.5	75	W	1	6	-	4.0	Noon - 2 p.m.	Overcast but bright. 1.15p.m. sun shining.
11/1/59	"	80.2	57.0	67	W	2	3	1.53	5.0	12.30p.m. - 2.30pm	Alternate cloud and sun.
15/1/59	"	71.9	61.0	99	SE	5	6	-	7.9	Noon - 2 p.m.	" " " ", strong breeze.

1. Routine 9 a.m. (N.Z. Standard Time) observations - Grasslands Division, D.S.I.R., Palmerston North - altitude 110' (175° 37' E, 40° 23' S).
2. Maximum temperature read at 9a.m. on any day entered to previous day.
3. Rainfall observations at 9a.m. entered to previous day (24 hour period).
* Beaufort Scale.

APPENDIX 2

Diurnal Trial Data

Mean Air Temperature Data (Four Main Days) °F

Time / Day	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
1	69.5	73.0	78.0	70.0	66.0	65.0	64.5	63.0	62.5
2	76.75	78.25	79.8	70.75	65.3	61.0	56.0	58.65	59.5
3	68.4	70.5	70.0	65.5	63.35	61.0	60.35	59.5	56.0
4	72.1	74.65	74.1	67.25	66.25	65.4	65.35	67.25	68.0

Relative Humidity Data (Main Days) %

Time / Day	10 a.m.	Noon	2 p.m.	6 p.m.	8p.m.	10p.m.	Midnight	2 a.m.	4 a.m.
1	77	73	76	54	90	83	83	88	90
2	-	-	52	70	85	90	93	95	92

Mean Air Temperature Data (Skin Temperature Days) °F

Time / Day	8 a.m.	10 a.m.	Noon	2 p.m.	6 p.m.
1	67.3	72.1	74.7	74.1	67.3
2	63.5	67.7	71.9	75.5	65.7
3	69.0	72.5	76.3	77.0	71.5

Data Obtained at 8 a.m.

Cow	Pulse	Respiration	Rectal T.	Pulse	Respiration	Rectal T.	Pulse	Respiration	Rectal T.
4	88	32	101.10	80	70	101.5	88	50	100.4
	84	34	101.25	80	68	101.6	84	46	100.5
74	78	30	101.15	80	42	101.3	72	48	100.9
	70	38	101.15	74	40	101.3	76	54	100.9
3	84	38	101.75	96	44	101.75	72	30	100.8
	82	34	101.70	86	46	101.70	74	30	100.7
21	76	48	101.55	68	42	101.8	60	46	100.75
	78	50	101.50	68	44	101.9	60	48	100.80
29	72	36	101.0	90	50	102.10	64	38	100.60
	72	40	100.9	92	44	102.05	64	34	100.45
1	76	40	101.55	82	40	102.20	76	44	100.75
	80	44	101.45	80	42	102.15	74	38	100.80

APPENDIX 3

Diurnal Trial Raw Data - Rectal Temperature

Day 1

Time / Cow	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	101.55	101.4	101.8	101.6	101.1	100.7	100.95	100.7	100.6
	101.55	101.45	101.75	101.4	101.0	100.55	100.75	100.65	100.5
74	101.1	101.3	101.5	101.7	101.0	101.1	100.75	100.4	100.7
	101.25	101.4	101.45	101.6	101.0	101.1	100.65	100.55	100.6
3	101.4	101.5	101.65	101.8	101.4	101.65	100.9	101.3	100.5
	101.4	101.6	101.8	101.75	101.4	101.6	100.95	101.25	100.45
1	101.2	101.05	101.45	102.1	100.8	100.9	100.55	100.1	100.0
	100.95	101.25	101.55	101.9	100.75	100.8	100.40	100.15	100.05
4	101.3	101.8	102.1	102.4	101.3	101.35	101.05	100.8	100.5
	101.5	101.8	102.3	102.35	101.3	101.25	100.95	100.8	100.4
29	101.35	101.55	101.6	101.55	100.85	101.2	101.0	100.5	100.55
	101.3	101.6	101.7	101.4	101.1	101.2	100.9	100.6	100.7

Day 2

Time / Cow	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	102.05	101.9	101.7	101.65	100.95	100.5	100.8	100.4	100.0
	102.15	101.9	101.5	101.7	100.8	100.55	100.9	100.5	99.9
74	101.45	101.5	101.3	101.4	101.2	101.0	100.55	100.4	100.4
	101.45	101.5	101.2	101.3	101.25	100.9	100.55	100.4	100.3
3	101.8	101.45	101.8	102.05	101.2	101.1	100.75	100.65	100.4
	101.8	101.55	101.75	102.05	101.25	101.3	100.7	100.55	100.25
1	101.6	101.55	101.85	101.7	100.65	101.15	101.25	100.1	99.2
	101.7	101.6	101.8	101.5	100.7	101.2	101.25	100.05	99.1
4	102.4	103.3	103.3	102.75	100.95	100.65	101.1	100.65	100.35
	102.3	103.15	103.2	102.7	101.15	100.45	100.95	100.5	100.15
29	101.4	101.65	101.9	101.7	101.5	100.7	101.3	100.55	100.05
	101.4	101.7	101.75	101.65	101.65	100.9	101.05	100.4	100.0

Day 3

Time / Cow	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	101.25	101.05	101.3	101.3	100.7	100.7	100.4	100.3	100.0
	101.15	101.05	101.3	101.05	100.9	100.6	100.4	100.3	100.05
74	102.1	101.2	100.95	101.1	100.25	100.25	100.05	100.2	100.0
	101.95	101.3	100.95	101.15	100.3	100.05	100.1	100.2	100.25
3	101.4	101.7	101.75	101.6	101.2	100.95	100.5	100.8	100.65
	101.35	101.7	101.8	101.55	101.3	100.9	100.4	100.4	100.45
1	101.3	101.4	101.3	101.15	101.95	101.35	100.2	100.45	100.1
	101.3	101.15	101.15	101.2	101.95	101.2	100.4	100.4	99.95
4	101.7	101.85	101.8	101.3	101.3	101.2	100.85	100.35	100.7
	101.7	101.85	101.7	101.5	101.3	101.2	100.95	100.35	100.6
29	101.5	101.85	101.7	101.2	101.1	101.7	101.0	100.9	100.6
	101.45	101.75	101.7	101.1	101.2	102.1	100.8	100.8	100.5

Day 4

Time / Cow	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	101.1	101.2	101.1	101.05	100.7	100.7	100.7	100.5	100.2
	101.1	101.2	101.1	101.15	100.7	100.95	100.7	100.45	100.3
74	100.9	101.5	101.05	101.1	100.7	100.7	100.4	100.3	100.45
	101.1	101.5	101.15	101.2	100.7	100.6	100.4	100.45	100.45
3	101.8	102.3	102.9	101.55	101.2	100.9	100.6	100.6	100.5
	101.85	102.2	102.6	101.55	101.1	100.7	100.6	100.4	100.5
1	101.65	101.9	101.45	101.95	100.7	101.4	101.4	100.7	100.6
	101.6	102.1	101.45	102.05	100.5	101.7	101.3	100.7	100.45
4	101.5	101.15	101.6	101.9	101.0	101.3	101.0	100.65	100.9
	101.2	101.2	101.8	101.6	101.3	101.1	100.95	100.9	100.65
29	101.05	101.3	100.1	101.0	100.9	101.45	101.0	100.9	100.9
	100.9	101.3	100.1	100.95	100.8	101.2	101.1	100.9	100.75

APPENDIX A

Diurnal Trial Raw Data - Pulse Rate

Time	Day 1									Day 2								
Cow	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	76	78	64	70	62	72	70	66	60	76	74	72	68	70	74	68	66	52
	72	74	64	70	64	68	72	64	60	70	78	74	70	68	70	68	68	58
74	82	78	86	78	82	80	78	72	62	78	84	78	76	78	76	72	68	56
	76	80	90	78	78	78	82	70	64	78	84	82	72	78	78	70	64	60
3	74	76	78	78	74	76	78	80	62	74	90	92	76	82	88	78	72	68
	78	80	76	78	78	80	74	78	62	80	88	88	80	82	88	78	68	68
1	74	80	76	76	78	76	84	74	62	84	98	88	82	78	94	78	72	58
	74	82	82	78	74	76	84	74	62	84	98	92	80	74	98	78	72	58
4	80	80	82	84	74	88	84	72	74	94	92	92	84	82	80	72	64	58
	82	84	84	82	78	84	86	72	70	90	90	88	82	82	80	72	62	58
29	74	82	72	72	72	78	72	74	66	84	80	76	70	84	66	70	68	58
	72	78	76	72	74	80	68	76	64	80	80	80	68	82	66	70	66	58

Time	Day 3									Day 4								
Cow	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	70	76	66	80	76	74	72	62	62	74	62	62	68	68	74	72	70	70
	72	76	66	78	70	68	68	60	60	72	66	68	72	66	70	74	70	68
74	84	84	78	86	80	72	80	72	66	84	86	74	76	84	76	76	70	72
	88	82	76	86	80	72	76	74	66	80	86	76	74	80	74	74	74	68
3	82	86	82	88	86	86	82	76	74	86	82	70	80	80	86	80	76	76
	86	82	82	94	84	86	76	76	78	78	80	70	82	78	86	80	82	78
1	92	86	96	96	96	106	86	90	76	82	80	78	84	96	94	86	82	78
	92	86	96	94	96	104	86	88	74	82	82	70	84	92	94	88	88	76
4	80	83	92	82	82	82	80	72	64	84	80	70	78	78	82	84	82	76
	86	83	96	88	80	86	78	74	70	84	80	72	80	78	88	84	82	76
29	94	86	78	76	82	90	74	80	68	74	74	64	74	80	80	80	82	68
	94	80	80	76	80	84	76	76	72	74	78	64	74	78	80	78	78	66

APPENDIX 5

Diurnal Trial Raw Data - Respiration Rate

Time / Cow	Day 1									Day 2								
	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	40	48	62	32	32	28	34	26	32	50	60	58	32	34	32	32	32	40
	38	44	68	34	34	30	30	28	34	44	56	60	36	38	32	32	34	42
74	24	62	64	34	34	36	38	34	28	52	52	68	44	34	32	30	28	26
	24	60	56	40	32	34	40	34	32	46	58	64	38	36	36	32	24	30
3	34	28	52	32	26	28	34	28	28	40	48	52	36	32	38	38	32	32
	30	36	60	36	28	32	34	34	30	36	50	46	38	34	34	36	26	28
1	32	30	46	24	30	32	36	34	24	44	60	56	44	30	34	36	28	26
	30	36	50	30	30	28	34	32	26	40	58	56	42	30	30	36	32	26
4	76	98	114	78	66	74	56	28	34	84	100	110	62	40	36	36	30	28
	70	92	118	72	74	74	58	34	40	82	104	112	58	42	36	34	30	26
29	30	38	44	28	32	34	24	22	24	38	46	40	28	28	22	18	20	28
	30	38	44	26	34	32	22	26	24	34	44	46	22	24	22	18	18	26

Time / Cow	Day 3									Day 4								
	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.	10 a.m.	Noon	2 p.m.	6 p.m.	8 p.m.	10 p.m.	Midnight	2 a.m.	4 a.m.
21	42	68	38	34	50	56	34	20	22	42	70	32	28	38	56	68	50	40
	38	70	40	36	50	56	34	26	24	44	68	28	30	44	52	68	48	36
74	90	88	42	42	40	52	50	30	28	50	98	56	44	52	46	38	46	36
	88	88	48	44	46	54	52	28	30	52	94	60	44	50	44	44	52	38
3	54	76	36	38	30	34	24	22	24	52	58	34	28	30	26	36	24	36
	60	72	34	34	32	36	24	24	24	46	60	36	34	32	28	38	30	38
1	50	54	40	34	40	56	40	36	30	48	84	44	32	38	48	56	46	34
	52	54	40	34	40	54	38	36	30	48	84	40	30	42	46	52	44	36
4	74	110	98	38	80	84	72	48	30	80	86	82	56	54	78	76	74	74
	84	110	92	40	84	80	76	36	30	78	88	80	56	48	82	82	72	74
29	52	82	42	38	34	48	30	28	22	62	64	24	32	28	50	44	38	36
	60	78	38	34	38	44	30	26	26	58	70	26	30	28	46	42	40	36

APPENDIX 6

Diurnal Trial Raw Data - Skin Temperature

Day 1

Time / Cow	8 a.m.	10 a.m.	12	2 p.m.	6 p.m.
21	91.55	95.60	98.20	89.37	91.60
	92.70	93.00	97.00	88.95	91.60
74	92.80	94.30	95.15	87.52	94.45
	92.45	93.67	94.52	88.40	94.20
3	90.30	92.65	93.45	90.40	92.70
	89.87	93.80	94.30	90.05	92.67
1	93.00	91.95	97.05	90.55	95.60
	92.57	93.00	96.60	90.40	95.75
4	93.27	96.65	94.90	92.90	93.90
	93.87	95.30	97.05	92.00	94.50
29	93.87	93.70	98.45	90.35	92.85
	93.60	94.95	98.07	90.50	93.90

Day 2

Time / Cow	8 a.m.	10 a.m.	12	2 p.m.	6 p.m.
21	92.30	86.05	90.90	88.55	88.30
	88.40	86.40	91.00	88.35	90.30
74	92.10	92.70	95.95	91.10	89.25
	94.27	92.55	95.70	91.05	86.85
3	91.33	88.30	92.70	92.85	90.60
	92.40	88.90	94.90	93.15	91.50
1	87.20	87.60	95.80	93.05	89.05
	87.00	87.55	95.55	92.80	90.50
4	91.10	90.25	95.45	94.80	87.95
	92.30	90.60	95.30	94.85	90.20
29	91.60	92.70	96.40	96.00	93.40
	92.25	93.3[illegible]	94.65	95.40	88.95

Day 3

Time / Cow	8 a.m.	10 a.m.	12	2 p.m.	6 p.m.
21	89.60	89.45	92.55	90.50	90.73
	90.10	89.03	91.98	91.35	90.95
74	92.50	89.30	94.40	90.50	88.60
	92.60	91.35	91.30	91.00	92.05
3	91.80	91.40	92.67	91.40	89.60
	91.40	92.80	91.80	91.75	91.15
1	90.65	89.85	92.33	94.75	90.37
	89.67	91.83	92.20	93.97	89.25
4	92.90	88.30	93.45	94.80	89.65
	91.30	89.45	92.15	89.63	91.50
29	92.00	94.65	90.90	93.20	91.10
	91.97	92.20	92.15	92.35	90.95

APPENDIX 7

Raw Data for Correlation Analysis

Air	Cow 74			Cow 3			Cow 21			Cow 4			Cow 29			Cow 1		
Temperature	Pulse	Respiration	Rectal T.	Pulse	Respiration	Rectal T.	Pulse	Respiration	Rectal T.	Pulse	Respiration	Rectal T.	Pulse	Respiration	Rectal T.	Pulse	Respiration	Rectal T.
69.5	79	24	101.2	76	32	101.4	74	39	101.6	81	73	101.4	73	30	101.3	74	31	101.0
73.0	79	61	101.4	78	52	101.6	76	56	101.4	82	95	101.8	80	38	101.6	81	33	101.2
78.0	88	60	101.5	77	56	101.7	84	65	101.8	83	116	102.2	74	44	101.7	79	48	101.5
70.0	78	57	101.7	78	34	101.8	70	33	101.9	83	75	102.4	72	27	101.5	77	27	102.0
66.0	80	33	101.0	76	27	101.4	63	33	101.1	76	70	101.3	73	33	101.0	76	30	100.8
65.0	79	35	101.1	78	30	101.6	70	29	100.6	86	74	101.3	79	33	101.2	76	30	100.9
64.5	80	39	100.7	76	34	100.9	71	32	100.9	65	57	101.0	70	23	101.0	84	35	100.5
63.0	71	34	100.5	79	31	101.3	65	27	100.7	72	31	100.8	75	24	100.6	74	33	100.1
62.5	63	30	100.7	62	29	100.5	60	33	100.6	72	37	100.5	65	24	100.6	62	25	100.0
76.8	78	49	101.5	77	38	101.8	73	47	102.1	92	83	102.4	82	36	101.4	84	42	101.7
70.3	84	55	101.5	89	49	101.5	76	58	101.9	91	102	103.2	80	45	101.7	98	59	101.6
75.8	80	66	101.3	90	49	101.6	73	59	101.6	90	111	103.3	78	43	101.6	90	56	101.8
70.8	74	41	101.4	78	37	102.1	69	54	101.7	83	60	102.7	69	25	101.7	81	43	101.6
65.5	78	35	101.2	82	33	101.2	69	30	101.9	82	41	101.1	65	26	101.6	76	30	100.7
61.0	77	34	101.0	88	36	101.2	72	32	100.5	80	36	100.6	66	22	100.8	96	32	101.2
56.0	71	31	100.6	78	37	100.7	68	32	100.9	72	35	101.0	70	16	101.2	78	36	101.3
58.7	66	26	100.8	70	29	100.6	67	33	100.5	63	30	100.6	67	19	100.5	72	30	100.1
59.5	58	28	100.4	68	30	100.3	55	41	100.0	58	27	100.3	58	27	100.0	58	26	99.2
68.4	66	89	102.0	84	57	101.4	71	40	101.2	85	76	101.7	94	56	101.5	92	51	101.3
70.5	85	88	101.3	84	74	101.7	76	69	101.1	88	110	101.9	83	60	101.6	86	54	101.3
70.0	77	46	101.0	82	35	101.8	66	39	101.3	94	95	101.8	79	40	101.7	96	40	101.2
65.5	86	43	101.1	91	36	101.6	79	35	101.2	85	39	101.4	76	36	101.2	95	34	101.2
63.4	80	45	100.3	85	31	101.3	73	50	100.8	81	82	101.3	81	36	101.2	96	40	102.0
61.0	72	55	100.2	86	35	100.9	71	56	100.7	84	82	101.2	87	46	101.9	105	55	101.3
60.4	78	51	100.1	79	24	100.5	70	54	100.4	79	74	100.9	75	30	100.9	86	39	100.3
59.5	73	29	100.2	76	23	100.6	61	29	100.3	73	42	100.4	78	27	100.9	89	36	100.4
58.0	66	29	100.1	76	24	100.6	61	23	100.0	67	30	100.7	70	24	100.6	75	30	100.0
72.1	82	51	101.0	82	49	101.8	73	45	101.1	84	79	101.4	74	60	101.0	82	46	101.6
71.7	86	96	101.5	81	59	102.3	84	69	101.2	80	87	101.2	76	67	101.3	81	64	102.0
74.1	75	50	101.1	70	35	102.0	65	50	101.1	71	81	101.7	64	25	100.1	74	42	100.5
67.3	75	44	101.2	81	31	101.0	70	29	101.1	79	56	101.8	74	31	101.0	84	31	102.0
66.3	82	51	100.7	79	31	101.2	67	41	100.7	78	51	101.2	79	20	100.9	94	40	100.6
65.4	75	45	100.7	86	27	100.8	72	54	100.8	65	60	101.2	80	48	101.3	94	47	101.6
69.4	75	41	100.4	80	37	100.6	73	66	100.7	84	79	101.0	79	43	101.1	67	54	101.4
67.3	72	49	100.4	79	27	100.5	70	49	100.5	62	73	100.8	80	39	100.9	65	45	100.7
68.0	70	37	100.5	77	57	100.5	69	38	100.3	76	74	100.8	67	36	100.8	77	35	100.5
76.0	83	67	101.2	92	71	101.9	85	72	101.7	92	118	102.2	85	61	101.8	90	48	102.2
69.5	74	34	101.2	83	36	101.7	77	49	101.5	83	33	101.2	72	36	101.0	76	42	101.5
75.5	77	41	101.3	91	45	101.7	68	45	101.9	80	69	101.6	91	47	102.1	81	41	102.2
6[illegible].5	74	51	100.9	73	30	100.8	60	47	100.8	66	48	100.5	64	36	100.5	75	41	100.8

APPENDIX 8

Raw Data for Skin Temperature - Air Temperature Correlation Analysis

	Skin Temperature						Air
Cow	21	4	29	1	74	3	Temperature
	91.5	92.9	91.8	90.2	91.3	91.6	69.5
	93.5	95.3	94.3	94.7	95.1	92.7	73.0
	97.0	96.2	96.2	97.7	100.8	92.3	78.0
	92.0	95.4	92.6	95.6	95.3	93.5	70.0
	92.1	93.6	93.7	92.8	92.6	90.1	67.3
	93.3	96.0	94.3	92.5	96.0	93.2	72.1
	97.6	96.0	98.3	96.8	94.8	93.9	74.7
	89.2	92.5	90.4	90.5	88.0	90.2	74.1
	91.6	94.2	93.4	95.7	94.3	92.7	67.3
	90.4	91.7	91.9	87.1	93.2	91.9	63.5
	86.2	90.4	93.0	87.6	92.6	88.6	67.7
	91.0	95.4	95.5	95.7	95.8	92.8	71.9
	88.4	94.8	95.7	92.9	91.1	93.0	75.5
	89.3	89.1	91.2	89.8	88.1	91.1	65.7
	89.9	92.1	92.0	90.2	92.6	91.6	69.0
	89.2	88.9	93.4	90.8	90.3	92.1	72.5
	92.3	92.8	91.5	92.3	92.9	92.2	76.3
	90.9	92.2	92.8	94.4	90.8	91.6	77.0
	90.8	90.6	91.0	89.8	90.3	90.4	71.5

APPENDIX 9

Raw Data from Dry Cow - Lactating Cow Comparison
Means of Two Repeated Readings

Repeat Pair	Lactating Cows 1	Lactating Cows 2	Lactating Cows 3	Dry Cows 1	Dry Cows 2	Dry Cows 3	Pairing Cow Number Lactating	Pairing Cow Number Dry
			Rectal Temperature					
1	102.45	101.85	101.6	102.2	101.7	102.1	34	85
2	102.0	101.6	101.9	101.4	101.35	101.95	93	98
3	101.7	101.6	101.35	100.95	101.2	100.2	79	76
4	102.2	101.9	101.5	101.35	101.2	101.1	12	7
5	100.55	101.4	101.1	101.85	101.9	101.6	60	19
6	102.35	101.9	101.4	101.3	101.7	101.3	54	78
			Pulse Rate					
1	84	74	73	81	75	79		
2	91	83	86	71	78	74		
3	84	76	75	68	67	70		
4	92	74	77	67	73	67		
5	82	72	74	76	78	74		
6	104	87	80	92	84	82		
			Respiration Rate					
1	33	24	25	27	29	28		
2	35	28	32	38	28	26		
3	30	28	27	23	17	20		
4	35	32	33	19	18	20		
5	24	25	27	24	39	38		
6	30	34	34	25	29	30		

APPENDIX 10

Air Temperature Data from Dry Cow-Lactating Cow Comparison.

Groups of Four Cows	Repeat 1			Repeat 2			Repeat 3		
	1	2	3	1	2	3	1	2	3
	64.0	66.0	62.0	57.0	60.0	64.5	61.5	60.0	61.0
	65.5	65.5	61.5	56.0	58.0	61.0	61.5	61.0	61.0
	65.0	61.5	61.0	56.0	59.0	59.5	58.0	61.0	61.0
	64.0	63.0	61.0	59.0	58.5	60.0	59.0	61.0	62.0

APPENDIX 11

Raw Data from Heifer-Mature Cow Comparison,
Means of Two Repeated Readings

Repeat Pair	Heifers 1	Heifers 2	Heifers 3	Mature Cows 1	Mature Cows 2	Mature Cows 3
			Rectal Temperature			
1	102.2	102.0	101.35	101.85	101.55	101.2
2	102.1	101.75	101.2	102.4	101.65	100.9
3	102.95	102.1	101.1	102.05	101.7	101.1
4	102.85	102.2	101.4	102.05	101.7	100.7
5	102.0	102.15	101.1	101.85	101.45	100.6
6	[illegible]	101.7	101.55	102.35	101.6	100.65
			Pulse Rate			
1	100	91	61	91	80	67
2	94	100	89	82	79	69
3	93	103	82	84	82	69
4	101	106	120	87	91	74
5	93	88	70	85	85	75
6	101	79	71	101	87	79
			Respiration Rate			
1	52	31	32	34	26	26
2	39	36	36	29	29	24
3	42	41	39	49	38	27
4	43	34	50	33	27	23
5	34	33	22	22	19	18
6	44	24	25	36	24	19

Pairing Cow Number

Heifer	Mature
63	85
114	98
108	19
10	86
112	7
110	78

APPENDIX 12

Air Temperature Data from Heifer-Mature Cow Comparison

Groups of	Repeat 1			Repeat 2			Repeat 3		
Four Cows	1	2	3	1	2	3	1	2	3
	59.0	58.5	59.0	59.0	58.0	56.0	57.0	58.0	56.5
	59.0	58.5	59.0	59.0	57.0	55.0	56.0	57.0	56.5
	59.0	58.5	59.0	58.0	57.0	55.0	56.3	55.0	56.5
	59.0	59.5	58.0	58.0	56.0	54.5	57.0	56.3	56.5

APPENDIX 13

Raw Mean Data -

The Influence of Fly Spray on Fly Counts and on Pulse Rate, Respiration Rate and Rectal Temperature.

Sprayed					Not Sprayed				
Cow	Pulse	Respiration	Rectal T.	Fly Count	Cow	Pulse	Respiration	Rectal T.	Fly Count
Day 1					Day 1				
3	78	26	101.45	12	1	74	54	101.0	22
72	77	30	101.35	12	33	84	39	101.7	28
74	78	57	101.15	14	21	68	42	101.25	98
29	77	31	100.85	26	4	86	84	101.1	30
Day 2					Day 2				
1	93	70	101.95	6	3	86	81	101.55	8
33	83	74	101.75	24	72	79	72	101.85	14
21	79	77	101.3	26	74	79	110	101.4	40
4	88	119	101.75	2	29	80	78	102.4	76
Day 3					Day 3				
3	77	44	101.5	4	1	86	60	101.85	52
72	68	42	102.0	4	33	87	44	102.1	26
74	79	55	101.2	6	21	67	67	101.5	64
29	78	52	101.8	2	4	82	119	102.4	44

APPENDIX 14

Raw Mean Data of Shading Trial

Pair / Day Cows	1 Shade	1 Sun	2 Shade	2 Sun	3 Shade	3 Sun	4 Shade	4 Sun
				Pulse Rate				
1. 33 & 16	91	97	83	84	86	84	76	80
2. 22 & 74	87	86	87	91	85	86	88	74
3. 25 & 75	89	99	98	74	83	87	83	69
4. 3 & 17	81	73	85	92	85	87	73	88
				Respiration Rate				
1.	33	34	36	35	39	39	27	34
2.	36	36	35	35	40	75	29	36
3.	52	37	42	49	48	48	41	52
4.	33	62	38	39	32	39	38	41
				Rectal Temperature				
1.	102.2	102.25	101.6	102.0	101.8	101.95	101.85	101.8
2.	101.8	102.05	101.45	101.5	102.05	101.95	101.3	101.4
3.	101.6	102.3	101.8	101.9	101.6	101.9	101.7	102.3
4.	102.45	101.75	101.4	102.45	102.25	101.7	101.85	102.35
				Skin Temperature				
1.	90.4	101.1	95.3	96.1	94.8	97.9	91.4	98.0
2.	95.0	100.5	94.6	98.3	96.0	94.8	93.0	96.2
3.	93.5	98.6	92.5	95.8	92.5	93.5	91.7	97.9
4.	94.0	98.0	97.0	104.3	91.3	92.3	94.0	97.8

APPENDIX 15

Air Temperature and Relative Humidity Data from the Shading Trial

Day / Group of 4 Cows	1		2		3		4	
	Temp.	R.H.	Temp.	R.H.	Temp.	R.H.	Temp.	R.H.
1.	78.5	54	78.5	58	83.5	59	71.0	65
	76.5	53	77.5	63	82.5	57	72.0	65
	80.0	52	77.5	58	82.0	60	73.0	65
	80.0	54	77.0	65	83.0	55	74.0	61
2.	85.5	50	79.0	61	80.0	59	77.0	64
	85.0	51	80.5	62	81.5	59	76.0	56
	83.5	51	80.0	58	81.0	62	75.0	55
	85.0	48	78.5	61	79.0	58	77.0	73

APPENDIX 16

Repeatability of Resistance Thermometer - Skin Temperature (^{o}F)

Time / Position	1	2	3	4	5	6	7
			Cow 83				
Shoulder	94.6	93.2	95.0	94.6	96.7	95.5	95.3
	94.7	93.6	94.6	94.6	95.2	95.6	94.8
Mid-side	95.4	94.1	95.5	94.2	96.3	97.0	95.7
	94.9	95.0	95.5	94.0	96.1	96.9	96.0
Hip	94.1	93.3	92.8	91.4	91.8	94.1	93.0
	94.6	92.9	91.9	90.8	92.4	94.4	93.4
Upper Thigh	95.0	94.6	94.2	94.7	96.7	95.0	95.1
	94.9	94.3	94.7	94.2	96.5	95.3	95.1
			Cow 82				
Shoulder	94.3	92.9	94.4	93.4	95.7	95.1	94.5
	94.7	92.6	94.8	92.6	95.5	93.1	94.9
Mid-side	91.0	91.6	95.5	92.5	95.2	94.5	94.2
	92.3	91.9	94.9	92.9	95.5	94.8	94.6
Hip	90.6	93.0	93.8	93.3	94.0	93.5	92.5
	90.7	92.7	93.8	92.8	93.9	93.0	92.8
Upper Thigh	93.3	94.6	95.4	94.9	94.8	94.7	94.3
	92.9	94.3	95.3	94.8	95.2	94.3	95.0

APPENDIX 17

Air Temperature and Relative Humidity - Resistance Thermometer Repeatability Trial

Time	Air Temperature	Relative Humidity
1 (2 p.m.)	71.5°F	65%
2 (10.30a.m.)	69.0	64
3 (11 a.m.)	65.5	85
4 (11.30a.m.)	70.0	65
5 (1.30 p.m.)	71.0	61
6 (2 p.m.)	71.5	61
7 (2.30 p.m.)	70.0	65
Mean	69.8	67