A STUDY ON THE INHERITANCE AND PHENOTYPIC AND GENETIC INTERRELATIONSHIPS AMONG SOME PHYSIOLOGICAL AND PRODUCTIVE VARIABLES IN JERSEY COWS.

A Thesis presented in partial fulfilment of the requirements for the degree of Master of Agricultural Science

by

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"The key is man's power of accumulative selection: nature gives successive variations; man adds them up in certain directions useful to him." - Darwin, p. 35, sixth edition of "The Origin of Species", 1920 (Quoted by Hazel, L.N., 1943).

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PART I

INTRODUCTION

A survey of literature shows clearly that in general, when dairy cattle of European origin are imported to tropical or subtropical localities as a basis for dairy cattle improvement, either by pure breeding or by cross-breeding with the native breeds, they usually degenerate in the course of a few generations (Wright, 1936; Villegas, 1939; French, 1941; Maule, 1953, and others).

However, genetic differences in adaptability to tropical and sub-tropical conditions have been observed to exist between breeds and between cows within a breed (Bonsma, 1940, 1948, 1949; Rhoad, 1938, 1940, 1942; Gaalaas, 1947; Seath and Miller, 1947a; Badreldin et al., 1951; Arrillaga et al., 1952; Robinson and Klemm, 1953; McDowell, 1955; Johnston et al., 1958, and others) among European dairy cattle.

Such empirical observations on the poor adaptability to tropical conditions and existence of genetic variability amongst European dairy cattle in their ability to adapt to such an adverse thermal environment, has led to extensive and thorough investigations into the physiological aspects of this problem in dairy cows.

To start with, most of these studies were done under field conditions in the tropics. Later, controlled-temperature laboratories (psychrometric rooms) were established in temperate countries to study this problem under a wide range of controlled climatic variables. Understanding of the physiological aspects of temperature regulation, mostly in dairy cattle, was the main aim of these experiments.

Cattle, like all homeotherms, attempt to maintain their body temperature (deep-body temperature) as measured by rectal temperature, within the range most suitable for biological activities by virtue of their homeostatic mechanisms.

Respiration rate, by regulating cooling processes, and heart rate (as measured by pulse rate), by regulating the rate of blood flow to the evaporative surfaces, help to maintain the body temperature within a certain range under fluctuating thermal environmental conditions.

Because of these reasons, environmental physiologists have used rectal temperature, respiration rate and pulse rate (referred to hereafter as physiological variables in this thesis) as indicators of the physiological status of the animals under heat stress.

Rectal temperature change (Rhoad, 1944) and its combination with respiration rate change (Benezra, 1954) are still used extensively throughout the world to measure the adaptabilities, in terms of heat tolerance, of dairy cattle, to tropical conditions. They have been a great aid to the selection of heat tolerant cattle to be used in tropical countries.

The physiological variables have been intensively studied in connection with temperature regulation by dairy cattle under tropical and subtropical field conditions and inside the psychrometric rooms. These results have been reviewed from time to time (Findley, 1950; Findley and Beakley, 1954; Payne, 1955; McDowell, 1958). Similar studies under temperate field conditions were done by Patchell (1951) and Quartermain (1959). However, genetic studies of these physiological variables are scarce, the only report being that of Seath (1947) from Maryland, United States of America, which dealt with the heritability of rectal temperature and respiration rate. A search of literature has failed to reveal evidence of genetic studies of the physiological variables carried out under temperate field conditions.

The main aim of the present investigation was, therefore, to study the genetic aspects of the physiological variables under temperate field conditions.

An attempt to estimate the inter-relationship between the physiological variables and the productive variables (lactation milk and fat yield, and milk and fat yield for the month of observation) has been made (see Chapter 9). No reports on such relationships have been located in the literature. To study this relationship was also the purpose of the present investigation. The whole study has been designed, therefore, to acquire the following information from the Jersey population of the Manawatu district of New Zealand:

(I) REPEATABILITY OF THE PHYSIOLOGICAL VARIABLES;

(II) VARIATION IN THE PHYSIOLOGICAL VARIABLES;

(III) HERITABILITY OF THE PHYSIOLOGICAL VARIABLES;

(IV) PHENOTYPIC AND GENETIC CORRELATIONS BETWEEN THE PHYSIOLOGICAL VARIABLES; and

(V) PHENOTYPIC AND GENETIC CORRELATIONS BETWEEN THE PHYSIOLOGICAL VARIABLES AND THE PRODUCTIVE VARIABLES.

The thesis has been divided into four parts, each of which has several chapters with several sections and subsections.

Each type of experiment is described under the following headings:

(i) INTRODUCTION;

(ii) MATERIALS AND METHODS;

(iii) RESULTS;

(iv) DISCUSSION; and

(v) SUMMARY.

Part I Gives the review of literature on the basis of which the experiments were designed.

Part II Describes the preliminary investigations in the Massey University herds.

Part III Describes the main experiments on the physiological variables.

Part IV Describes the inter-relationships between the physiological variables and the productive variables.

The last chapter (10) gives the final summary and conclusions of the entire work.

CHAPTER I

REVIEW OF LITERATURE

1.1 VARIATION ENCOUNTERED IN THE PHYSIOLOGICAL VARIABLES

Most of the results to be reviewed in this chapter are those reported in the literature from the experiments conducted either in climatic chambers or from field studies made under tropical conditions. This writer located in the literature only two results on the subject, reported from field experiments conducted under temperate environments. Most of the results from the tropics are published in terms of heat tolerance either by the IBERIA HEAT TOLERANCE TEST (H.T.C.)[1] or the BENEZRA COEFFICIENT TEST (B.C.)[2]. So readers are requested to keep in mind the relationships between heat tolerance, rectal temperature and respiration rate. Reports on the variability of pulse rates are very meagre in the literature.

Pioneering works by Bonsma (1940, 1948, 1949) and Rhoad (1938, 1940, 1942) clearly suggested that great genetic variability existed between breeds of cattle and between cattle within a breed, in the reactions of their physiological variables to heat stress, and that such variability in the response of cattle to heat stress was associated with their productivity under similar conditions (Rhoad, 1940; Bonsma, 1949).

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[1] IBERIA HEAT TOLERANCE COEFFICIENT (H.T.C.) = 100 - 10 (B.T. - 101.0) where B.T. is body temperature after exposure to direct sunlight for a certain period of time.

[2] BENEZRA COEFFICIENT (B.C.) = $\frac{B.T.}{38.33} \times \frac{R.R.}{23}$

Where B.T. is the observed body temperature in $^{\circ}$C;
R.R. is the observed respiration rate.

Results of cross-breeding experiments with cattle of different heat tolerance, conducted in different parts of the world, suggested that the mode of inheritance of such differences was multifactorial and that the progeny from such crosses were intermediate, generally, in their heat tolerance (Rhoad, 1944a; Bonsma, 1949; Phillips, 1948, and others).

Reports from field experiments (Badreldin et al., 1951; Arrillaga et al., 1952; Robinson and Klemm, 1953) and from the climatic chamber studies (Findley, 1950; Johnston et al., 1958; McDowell et al., 1955; Riek and Lee, 1948a; Schein et al., 1957; Seath and Miller, 1947a; Worstell and Brody, 1953) showed that Zebu cattle were superior in heat tolerance to European cattle, that Jersey and Brown Swiss breeds were superior to all other European breeds, that crossbreds were intermediate between the two (B.indicus and B.taurus) and that among the crossbreds, heat tolerance was directly proportional to the Zebu blood present in them.

However, McDowell et al.(1952, 1955) reported that some of the individual Jersey cows were less affected in their response to heat stress than some of the crossbred individuals with similar production levels under similar conditions.

With the Jersey breed, a wide range of variability in the response of the physiological variables (in terms of heat tolerance) to heat stress, was reported both from field studies (Gaalaas, 1947; Rhoad, 1944; Asker et al., 1952) and from a chamber study (Klemm and Robinson, 1955). The range of heat tolerance coefficient (H.T.C.) values was reported as from 61% to 92% for the chamber experiments, and from 66% to 94% for field studies.

Gaalaas (1947), Johnston and Branton (1953) and Shrode (1958) stressed the importance of such variation present in a population and McDowell et al. (1961), Johnston et al. (1958) and Branton et al. (1961) found a large variability of heat tolerance within the Jersey breed and advocated on the basis of their results that selection for heat tolerance in the southern part of the United States of America could be done within the Jersey breed rather than introducing Zebu blood.

Reports from temperate field studies showed that significant differences in the physiological variables existed between identical twin heifers (Patchell, 1951) and between lactating Jersey cows (Quartermain, 1959). Comparisons of their results (see Table I) suggested a positive association between the magnitude of air temperature and variability of the physiological variables.

TABLE I

Ranges, standard deviations and coefficients of variation of the physiological variables as reported by Patchell (1951) and Quartermain (1959)

Author		Rectal temperature	Respiration rate *	Pulse rate *	Range of air temperature (°F)	Number of Cows used
Quartermain	Range	99.1-103.3	18-118	52-96	56.0-79.8	6
	S.	0.64	20.43	9.00		
	C.V.	0.63%	45.68%	11.66%		
Patchell	Range	100.6-103.8	18-75	50-92	36.0-67.0	12
	S.	0.22	5.48	2.89		
	C.V.	0.22%	15.99%	4.12%		

Coefficients of variation were highest for respiration rate and lowest for rectal temperature in both studies.

* per minute

SUMMARY

Significant differences in the response of the physiological variables to heat stress were observed between breeds and between cattle within breeds. Among European breeds of dairy cattle, the Jersey was one of the most heat tolerant breeds in which wide variation in such responses existed when under heat stress.

Significant variations in the physiological variables between Jersey cows were observed under temperate field conditions.

1.2 INFLUENCE OF ENVIRONMENTAL FACTORS ON THE PHYSIOLOGICAL VARIABLES

A. ANIMAL FACTORS

(i) COAT CHARACTERISTICS

The general aspects of the influence of coat characteristics on the physiological variables have been reviewed (Findley, 1950; McDowell, 1958; Quartermain, 1959; Atmadilaga, 1959). This discussion will deal with the more recent findings on the influence of coat characteristics on the physiological variables including the facts from the results already reviewed, in so far as they are pertinent to the present work.

According to a number of reports it appeared that coat types were associated with heat tolerance. Bonsma (1949) and Lee (1953) emphasized the importance of coat colour in relation to heat tolerance in the tropics, and the latter suggested that coat characteristics should be one of the main criteria in selection of cattle in tropical countries. He went on to say that cattle with dark hides, light coat colour, and short, smooth, glossy hair were more resistant to temperature and intense solar radiation.

Bonsma (1949) and Badreldin and Ghany (1954) reported that dark hide helped to dissipate heat more rapidly in the shade. Seath and Miller (1947a) found no significant relationship between the percentage of white surface area and the physiological variables. Ittner _et al_. (1954) found that the white cows (9 cows with approximately 80% white surface area) had a higher respiration rate than the black cows (5 cows with approximately 80% of black surface area) in the shade, whereas in sunlight at a temperature of 102°F the reverse was the case, the black cows being more sensitive than the white cows (118 respirations per minute v. 105 respirations per minute). This work supported the observations made by several workers that black coat colour best dissipated heat in the shade and also absorbed more solar radiation. Yeates (1955, 1957) noted that woolly coated and thick, curly coated animals were at a grave disadvantage in their response to heat stress as compared with those of short, flat and glossy coats: thus supporting Bonsma's findings. Australian workers (1955) reported a correlation coefficient of coat score with rectal temperature of 0.4 to 0.6.

Turner et al. (1959) reported the repeatability of coat score as 0.60 and its heritability as 0.63. The coat scores were strongly correlated with body temperature and respiration rate in his study. Dowling (1959a, 1959b) studied the significance of medullation in coat type and reported that animals with a higher incidence of medullation in their hair were more heat tolerant than those animals with a lower incidence of medullated hair. He estimated the correlation coefficient between the incidence of medullation in the coats, and the animals' ability to regulate rectal temperature, to be as high as 0.95.

Berman and Volcani (1960) found large variations in coat characteristics between groups of the daughters of different sires. These variations could make it possible to select a uniform breed of certain coat characteristics. But they suggested that because of the negative relationship between light coloured coat and thyroid activity, and because of the latter's positive relationship with milk yield, selection for a light coat might have a negative affect on milk production.

Hayman and Nay (1960) found significant differences in the coat characteristics of B.taurus and B.indicus in different seasons and they discussed the possibility of breeding more heat tolerant cattle on the basis of this observation.

Finally, Schleger (1962) reported the heritability of coat colour to be as high as 0.53 and also indicated that animal's coat colour was itself influenced by factors such as age, sex, reproductive stage, growth phase of coat, season and exposure to solar radiation.

SUMMARY

Differences in coat colour were important in causing differential responses of animals to heat stress due to solar radiation. These differences due to coat colour no longer applied in the shade. Coat type was important in the dissipation of heat from animals to the atmosphere.

Coat type and colour were highly correlated with heat tolerance and their repeatability and heritability estimates were quite high. Therefore, coat colour and type of coat could be very important criteria in selecting heat tolerant cattle for use in the tropics.

(ii) AGE

Studies on the influence of age on the physiological variables have been reviewed in detail by Quartermain (1959) and Bianca (1961). Most of the results confirmed Bonsma's (1949) conclusion made after extensive investigation on South African cattle of various breeds and types: "The work done in this country, however, indicates beyond all doubt that an animal's H.T.C. (heat tolerance coefficient) increases considerably, especially after the second year."

In the present review only those facts that are important to the present study will be considered.

Evidence suggested that heat tolerance increased with an increase in age among heifers (Klemm and Robinson, 1955; Asker et al., 1953), cows (Gaalaas, 1947; Walker, 1957) and bulls (Casady et al., 1956). These results confirmed the statement made by Bonsma (1949).

Badreldin et al. (1951) grouped their experimental cows according to age and found that the physiological variables decreased as age increased. The range of air temperature during their study was 51.8° - 82.0°F.

In contrast to such results, Worstell and Brody (1953) working with Brown Swiss cows and heifers, found that the latter were more heat tolerant than the former. They reasoned that this might be due to higher surface areas and increased cardio-respiratory activities of heifers in response to hot conditions.

This was supported by the evidence produced by Seath and Miller (1948) in their experiment designed to study the effects of shade and sprinkling water. Arzumanjan (1950) reported higher pulse rates and respiration rates in young dairy stock than in older cows.

However, no further detail was given in his report. Working with Jersey and Red Sindhi crossbred heifers, McDowell *et al*. (1955) and Schein *et al*. (1957) concluded that younger animals had higher rectal temperatures than older ones. Respiration rate did not follow this pattern. Schein *et al*. (1957) reported both higher test-rectal temperature and respiration rate among the younger animals.

The work of Atmadilaga (1959) with Madura (Zebu) cattle and Red Danish crossbreds was quite interesting in so far as the effect of age on heat tolerance was concerned. He divided his stock into 1 year and younger, and above one year, age groups and found that the older group was significantly (at the 5% level) more heat tolerant than the younger group, measured in terms of both Rhoad's Coefficient and Benezra Coefficients, thus confirming the conclusion reached by Bonsma.

In most of the results reviewed here, the affect of weight was confounded with that of age.

SUMMARY

Heat tolerance increased with advancing age. Young animals seem to have higher levels of the physiological variables than older animals under normal conditions. Therefore, to obtain reliable results the effect of age should be accounted for in any genetic study of these physiological variables.

(iii) BODY WEIGHT

Brody (1948) observed that smaller animals had a larger surface area per unit of body weight. Therefore, they should be able to dissipate heat under heat stress, through the channels of heat loss (conduction, convection, radiation and evaporation), at faster rates than larger animals.

Conversely, it may be stated that smaller animals, by virtue of their larger surface area per unit bodyweight, could absorb more heat from the surrounding environments than larger animals.

According to the above mentioned statements, differences in body weight should account for a portion of differences in the physiological response of animals of different body weights. Unfortunately, this field has not been thoroughly investigated as yet.

The only works, by Arzumanjan (1950) and Minett (1955), as reviewed by Quartermain (1959), showed that there was no significant effect of body weight on the physiological variables. Arzumanjan, working with dairy cows and heifers, found no affect of body weight on respiration rate and pulse rate.

Minett, working on the buffalo bullocks, found that heavier animals had lower rectal temperatures than lighter ones, but the observed differences were not statistically significant. He worked in a shed with an air temperature range of 95^{o} - 109^{o}F.

As differences in age are highly correlated with differences in body weight (other factors being constant), the age and weight effects were confounded in these studies, as was also the case in those studies mentioned in the preceding section.

No subsequent reports have been published on the subject.

SUMMARY

Body weight does not seem to have any significant effect on the physiological variables.

(iv) STAGE OF PREGNANCY

The results of Thomas (1949), Wrenn et al. (1958), Gaalaas (1947) and Patchell (1954) on dairy cows, and that of Alim and Ahmed (1957) on buffaloes (B.babalus), on the influence of stage of pregnancy on the physiological variables were critically reviewed by Quartermain (1959). In this context it is intended to indicate only those facts that are related to the present study.

The experiment of Thomas (1949) pointed out that pulse rate increased rapidly as pregnancy advanced. The average rates were 65, 72 and 92 beats per minute at 70 - 90, 30 - 50 and 0 - 10 days pre-partum.

Wrenn et al. (1958) observed that body temperature was at a higher level during pregnancy until a few days before calving, when there was a precipitous decline of about 1.0°F to 1.6°F.

Lastly, Alim and Ahmed (1957) reported that pregnant, dry buffalo cows had a higher rectal temperature and respiration rate than open, dry cows. The range of air temperature was 77.0° - 100.4°F.

SUMMARY

It seemed that thelevel of all the three physiological variables was higher during the last few months of pregnancy with the largest effect on pulse rate.

(v) STAGE OF LACTATION AND PRODUCTION LEVELS

Studies on the influence of production level and stage of lactation on the physiological variables were adequately reviewed by Quartermain (1959). An attempt will be made here to express those facts that are closely related to the present study.

It was estimated that each pound of F.C.M. produced, increased the metabolic heat production by approximately 10 kilocalories per hour (Brody *et al.*, 1948; Johnston *et al.*, 1958).

Thus, the higher producing cows tended to have higher body temperatures under heat stress than the lower producers (Ittner *et al.*, 1954; Johnston *et al.*, 1954) and the former would generally be less heat tolerant than the latter (Lee, 1953).

The report of McDowell *et al.* (1955) from their psychrometric study on Jersey and Red Sindhi-Jersey (F1) crossbred females, indicated that the response of rectal temperature to air temperature was virtually independent of the stage of lactation. The same report indicated that there were no significant differences in initial rectal temperatures between cows of different production levels; but lactating cows had a higher initial rectal temperature than dry cows. Furthermore, differences in rectal temperatures among the cows of different production levels increased after exposure to hot atmosphere. There was a significant influence of production level on respiration rate only before exposure to heat; following severe exposure to a hot atmosphere (105°F and 60% humidity) the difference disappeared.

Johnston *et al.* (1958) found that Red Sindhi-Jersey crosses were more heat tolerant than Jerseys of similar production level. The difference was probably because of the genetic difference in the heat tolerance between the two breeds. Schein et al. (1957), from a similar study, reported no significant differences in the initial rectal temperatures and respiration rates among cows of different production levels, but on exposure to hot atmospheric conditions, the increase in initial rectal temperature was greater in higher producers (3.1°F in 45 lbs. F.C.M. per day class) than in lower producers (2.6°F in 15 lbs. F.C.M. per day class). However, the respiration rate did not follow the same trend.

The reports of Gaalaas (1947) and Ittner et al. (1954) were of some interest. The report of Gaalaas indicated that the rectal temperature was not influenced by the stage of lactation, even under heat stress. This finding was based on his determination of heat tolerance for 29 mature Jersey cows at various lactational stages, which were closely connected with production levels.

Ittner et al., on the other hand, divided their Friesian cows into high and low producing groups and found that these groups did not differ appreciably in either rectal temperature or respiration rate, when the range of air temperature was 50° - 86°F. However, when the air temperature ranged from 71° - 112°F high producers always had higher rectal temperatures than low producers. The respiration rate did not show distinct differences. Arzumanjan (1950) suggested, with little evidence, that pulse rate and respiration rate could be higher in high producing cows.

SUMMARY

The results reviewed above suggest that in the temperature range (58.5° - 76.0°F) experienced during the writer's experiment, stage of lactation and production level would not be expected to have any great influence on the physiological variables.

Conversely, under heat stress, high producing cows had higher values for the physiological variables than low producing cows. In other words, low producing cows were more heat tolerant than high producing cows.

B. CLIMATIC FACTORS

The results of both psychrometric chamber and field studies on the effect of climatic factors on the physiological variables were comprehensively reviewed by Lee and Phillips (1948), Findley (1950), Findley and Beakley (1954) and McDowell (1958). An attempt will be made here to extract the facts from the previous reviews and to review the subsequent results which are connected with the present study.

(i) AIR TEMPERATURE AND HUMIDITY

Numerous laboratory and field studies demonstrated the greater effect of air temperature compared with other climatic variables on the rectal temperature responses of cattle (Bonsma, 1940, 1949; Rhoad, 1944b; Seath and Miller, 1946; Gaalaas, 1947; Findley, 1950; Arrillaga et al., 1952; Robinson and Klemm, 1953; Hermosura, 1953, 1957; Quazi and Shrode, 1954; Beakley and Findley, 1955a; Hancock and Payne, 1955; Cartwright, 1955; Dowling, 1956; Alim and Ahmed, 1956; Walker, 1957; McDowell, 1958).

Generally it appeared that air temperature above 80°F influenced the body temperature of cattle, but the degree of the effect was somewhat dependent on breed (Lee et al., 1954; Schein et al., 1957; Branton et al., 1953; Quazi and Shrode, 1954), age, physiological state and level of nutrition (McDowell et al., 1955).

High correlation coefficients between air temperature and rectal temperature were reported by various workers (Branton et al., 1953; Barrada, 1957; Quazi and Shrode, 1954). Careful consideration of these results revealed such correlation estimates to be higher at higher air temperatures and in less heat tolerant breeds than at lower air temperatures and in more heat tolerant breeds.

Studies of Seath and Miller (1946), Regan and Richardson (1938), Arrillaga et al. (1952), Quazi and Shrode (1954) and McDowell (1958) suggested that under field conditions humidity had little or no effect at all on body temperature, in the case of dairy breeds. However, studies made in psychrometric rooms demonstrated a marked effect of humidity on body temperature (Riek and Lee, 1948a; Kibler and Brody, 1953; McDowell, 1958; Klemm and Robinson, 1955; Beakley and Findley, 1955b). Klemm and Robinson (1955) found that high humidity had an even greater adverse effect on body temperature than high air temperature in the case of dairy calves (1 to 12 months of age).

The effect of air temperature on respiratory response was studied by various workers (Bonsma, 1940; Lee and Riek, 1947; Gaalaas, 1947; Kibler and Brody, 1950; Arrillaga et al., 1952; Benezra, 1954; Quazi and Shrode, 1954; Lee et al., 1954; Beakley and Findley, 1955b; Klemm and Robinson, 1955; Schein et al., 1957). Their results suggested that an increase in respiratory frequency was the predominant response of cattle to increasing air temperature and that such increase in respiratory frequency was the primary mechanism for maintaining body temperature balance in the face of increasing air temperature. From these reports it also appeared that increased respiratory frequency was pronounced above 85°F.

There was an interaction between air temperature and humidity, the effects of high relative humidity being much more pronounced at higher temperatures. Reports of Barrada (1957) and Beakley and Findley

(1955b) showed that at higher air temperatures (104°F) and higher relative humidities (80%) the peak respiratory rate (about 170 per minute) was attained, after which it declined. Beakley and Findley (1955b) found that at 86°F and 95°F high relative humidity had the same effect on the respiration rate as had low humidity at 91.4°F and 114.8°F.

Of all the physiological variables, pulse rate appeared to be leat affected by climatic variables under normal conditions. Contradictory results were reported on the responses of pulse rate to changing atmospheric conditions both from field and psychrometric room studies.

The studies of Brody (1945) and Kibler and Brody (1949, 1950, 1951) showed a slight decrease in pulse rate with increasing air temperature from 40°F to 105°F.

Riek and Lee (1948b) found no positive effect of increasing air temperature or humidity on the pulse rate of Jersey calves. Kibler and Brody (1953) found a small response of pulse rate to variable humidity at air temperatures from 86.0°F to 100.4°F.

Worstell and Brody (1953) concluded from their results that pulse rate declined only on raising air temperature above 86°F. Beakley and Findley (1955b) reported that pulse rate increased with increasing air temperature above 68°F and with increasing humidity above 86°F in the case of Ayrshire calves in the climatic chamber. The same authors found a non-significant effect of humidity on pulse rate at 86°F, but a marked effect was observed when humidity was near saturation point (i.e. 100%) at an air temperature of above 95°F.

Klemm and Robinson (1955) found no response of pulse rate to heat stress, whereas Arrillaga et al. (1952) found an increase in pulse rate with increasing air temperature under field conditions.

(ii) SOLAR RADIATION

Results of Bonsma (1949), Riemerschmid (1945), Quazi and Shrode (1954), Shrode et al. (1960), Williams et al.(1960) and Harris et al. (1960) concerning the influence of solar radiation on the physiological variables, suggested that solar radiation might be more important than wind velocity, or humidity, in determining body temperature responses of dairy cattle. The degree of such response to solar radiation depended mostly on colour. Williams et al.(1960) found that solar radiation had a direct effect on body temperature when the air temperature was close to the range of thermoneutrality (below 90°F), but that at higher air temperatures (above 90°F) solar radiation caused little change in body temperature.

Information on the influence of solar radiation on respiration rate was limited. Shrode et al. (1960) and Williams et al. (1960) observed the importance of variations in solar radiation, in producing respiratory response. This factor was comparable to that of variations in air temperature, and was considerably more important than vapour pressure and wind velocity variations under field conditions. Supporting evidence was reported by Harris et al. (1960). Williams et al. (1960) found that the respiration rate was affected more by solar radiation than by any other climatic influence.

Reports of Williams et al. (1960) and Harris et al. (1960) on the influence of solar radiation on pulse rate, showed small but inconsistent positive effects. Williams et al. found a definite relationship between the climatic variables and pulse rate under the influence of solar radiation when the air temperature was less than 90°F, above which the relationship disappeared. They interpreted this as being due to the slight effect of solar radiation and its reduced effectiveness in air temperatures of above 90°F.

(iii) RAIN AND WIND

The only results on the effect of rain, as such, on rectal temperatures came from the work of Minett (1947) who reported a significant decrease of 1.6°F to 3.8°F in rectal temperatures of Zebu bulls, standing in the monsoon rain at an air temperature of 59°F and rain water temperature of 82° - 48°F.

Another type of study, which could be accepted as producing similar effects on the physiological variables as rain, was experiments on the effect of sprinkling water on the animal's body. The general aspects of such work were reviewed by Findley and Beakley (1954), Findley (1950) and Payne (1955). All these reports indicated a depressing effect of sprikling water on the physiological variables, except the study of Ragab et al. (1953), who found no significant decline in the physiological variables. These results, in general, would suggest a similar depressing effect from rain.

The influence of wind velocity on body temperature was studied by Kibler and Brody (1954). Their study indicated that increased wind velocity caused a decrease in rectal temperature at the range of air temperature of 75° - 95°F.

SUMMARY

Of all the climatic variables, air temperature and intense solar radiation exerted the most marked effect on rectal temperature, respiration rate and to a lesser extent on pulse rate. High humidity at high air temperature also had some affect on all three physiological variables. The effect of rain and wind on the physiological variables was to lower these values.

1.3 TECHNIQUES FOR RECORDING THE PHYSIOLOGICAL VARIABLES

Knowledge of the right technique for measurement of the variables to be studied, and of the factors affecting their recording, is very important in any research to obtain reliable results. Success in getting reliable results depends on proper knowledge of the various technical difficulties involved in recording the data. This is especially true in connection with the recording of data on the physiological variables studied in this experiment.

Findley (1950) and Lee (1953) discussed the various methods used to record the physiological and climatic variables. Since the method of recording used in the present study will be discussed in later chapters, and since the general aspects of the measurement of the physiological variables have already been reviewed by Patchell (1951) and Quartermain (1959) with no subsequent reports on this problem published since, an attempt will be made here to extract from the reviews mentioned, important facts which are closely connected with the present study.

Rectal temperature is generally regarded as a good index of deep body temperature under normal field conditions (Bligh, 1955) and it has been measured by most of the field workers using an ordinary clinical thermometer. In taking such a measurement, three main sources of error are involved.

(a) Inaccurate Calibration of Thermometers

This source of error was obviated by most workers in the field, by standardizing all the thermometers to be used against a standard thermometer in a water bath.

(b) Use of Different Depths of Insertion

Kriss (1921), Minett and Sen (1945) and Bligh (1955) reported a temperature gradient in the rectum; the deeper the insertion in the rectum, the higher the body temperature recorded. Kriss reported that the reading was 0.8°F lower when inserted to a depth of 4" as opposed to a depth of 6" - 7".

However, various workers used different depths for their recording of rectal temperature: Regan and Richardson (1938) used 5", Seath and Miller (1946) 3" and Bonsma (1940) 4".

Kibler and Brody (1951) concluded, on the basis of their observations, that satisfactory results could be achieved if the temperature was taken by a mercury thermometer at a depth of 4" from the anal sphincter.

(c) The Effect of Different Times of Insertion

Various times of insertion have been suggested by different workers: Kriss (1921) 4 minutes, Seath and Miller (1946) 3 minutes, Bonsma (1940) 4 minutes etc. However, 3 minutes of insertion was generally believed to be sufficient to obtain equilibrium with body temperature.

The effect of change of position on the data recorded was reported by various workers (Kriss, 1921; Patchell, 1954a; Beakley and Findley, 1955a).

Kriss found no effect of change of position of cows on rectal temperature, whereas Patchell found higher rectal temperatures when cows were lying, than when standing. Beakley and Findley suspected the sudden rise of 0.3° - 0.4°F in the rectal temperature of their calves to be due to either movement of the thermometer in the rectum, or the movement of organs causing a change in the thermal environment of the thermometer.

The effect of defaecation on the rectal temperature was reported by Kriss (1921) and Minett and Sen (1945). The former found no consistent effect but the latter found a difference of 0.1° - 0.8°F between the rectal temperature readings taken immediately before and after defaecation. However, it is generally believed that defaecation momentarily lowers the temperature of the anal, mucous membrane.

Various methods used for recording pulse rate and respiration rate, both in the climatic chamber and under field conditions, were described by Findley (1950), Patchell (1951) and Lee (1953). The most common method used to record respiration rate under field conditions is counting flank movements. Each complete inward and outward movement is counted as one complete respiration and the respiration rate is defined as the average number of complete respirations per unit time (Lee, 1953).

Of the many places in the animal's body that could be used to record pulse rate, the most convenient and most commonly used position is the coccygeal artery, which is manually palpated. Pulse rate, like respiration rate, is counted as the number of heart beats (i.e. pulse beats) per unit time.

SUMMARY

Reliable records on rectal temperature changes can be secured by standardizing clinical thermometers and taking the temperature at a constant depth, between 3" and 5", provided that there are no marked changes in the position and posture of the animal: likewise, for respiration rate, by counting the flank movements, and for pulse rate, by manual palpation of the coccygeal artery, with the least possible disturbance of the animal under observation.

1.4 REPEATABILITY OF THE PHYSIOLOGICAL VARIABLES

It is always highly desirable that a procedure intended for use as a test should give results with a high degree of repeatability. Interest in repeatability of observational data, in as far as it pertains to physiological variables in relation to heat tolerance in dairy cattle, is primarily two-fold. Data on repeatability furnish information as to which of the observations are most reliable and furnish a method for determining the number of observations necessary to arrive at a reasonably accurate estimate of the relative ability of animals to withstand heat. Estimation of repeatability also gives a rough idea of the magnitude of heritability for a character (Lush, 1945).

The method employed for estimating repeatability, in general, is that of determining the intra-animal correlation coefficient of observations repeated consecutively, or at different time intervals, on a number of animals. This method was described by Snedecor (1946) and was recommended by Lush (1945).

Very few reports have been published in the past on the repeatability of the physiological variables.

The estimates of repeatability of rectal temperature and respiration rate as reported by various workers in this field (Seath, 1947; Seath and Miller, 1947b; McDowell et al., 1953; Australian workers, 1955; Quartermain, 1959; Patchell, 1951) are of varying magnitude.

Seath (1947), using all the data of two years (1944 and 1945) on the rectal temperatures and respiration rates of Holstein and Jersey breeds, estimated the repeatability of rectal temperature as 0.08 and

0.07 for the two years respectively. However, when he used only the records for the 8 hottest days in each year, then the corresponding repeatabilities were 0.15 and 0.38 respectively. Likewise, the repeatability of respiration rate estimated from only the 8 hottest days in each year, was higher than when all observations were used (0.42 and 0.48 vs. 0.25 and 0.17 respectively). A comparison of the repeatability of single records of the same cow for the 8 hottest days as against the entire period, is shown in Table No. 2.

TABLE 2

Comparison of the repeatabilities of single records of the same cow for the 8 hottest days, versus the entire test period (reported by Seath, 1947).

	Using entire test periods		Using 8 hottest days	
	1944	1945	1944	1945
Air temperatures for test periods:				
Range................	65° - 93°F	75° - 91°F	86° - 93°F	87° - 91°F
Average..............	85°F	86°F	89°F	89°F
Repeatability of single records:				
Body temperature......	0.08	0.07	0.15	0.38
Respiration rate......	0.25	0.17	0.42	0.48

Under similar environmental conditions, Seath and Miller (1947b) reported the average repeatability of rectal temperature to be 0.29 in a barn study and that of the respiration rate to be 0.45 for the barn observations and 0.37 for the pasture observations during a 14 day study on 20 milking Holstein cows, when the mean air temperature was 88°F. The repeatability estimates for both rectal temperature and respiration rate were in agreement with the values reported by Seath for the 8 hottest days.

McDowell _et al_. (1953) found that the repeatability coefficient of rectal temperature response in Jersey heifers (8 - 22 months of age) remained fairly low, unless the responses were assembled into three seasonal groups when they reached a high and satisfactory level. In the case of lactating Jersey cows, the repeatability of rectal temperature was negative (-0.07) whereas in Red Sindhi x Jersey lactating cows, the corresponding value was 0.19. This was not significantly different from zero. In the case of the lactating group, adjustment for either stage of lactation or for level of production, resulted in no improvement in repeatability. The repeatability of respiration rate of heifers, in response to heat stress (6 hours at 105°F and 34 mm.Hg.V.P.) remained low even after seasonal grouping. Repeatability of respiration rate was not computed for lactating cows. In this experiment, all the cattle were subjected for six hours to a standard hot atmosphere (105°F and 34 mm.Hg.V.P.) at repeated intervals of two months or longer.

Australian workers (1955) reported repeatability values of 0.45 and 0.80 for rectal temperatures and respiration rates respectively in the case of Shorthorn and Hereford cattle.

Under temperate field conditions (in New Zealand) Patchell (1951) estimated the repeatability of the physiological variables in three different ways, from data collected during a period of three months from 12 identical twin heifers,

(a) the repeatability estimates were very low for rectal temperature (-0.04 to 0.11) and respiration rate (0.01 to 0.10) and highly significant for pulse rate (0.29 to 0.52) when the entire data were used in the calculation;

(b) all the repeatability estimates were highly significant (rectal temperature, 0.28 - 0.34; respiration rate, 0.28 - 0.40, and pulse rate, 0.25 - 0.75) when between days and between cows variance was eliminated;

(c) the repeatability estimates were highly significant for all cows in the case of pulse rate (0.27 - 0.76) and respiration rate (0.36 - 0.73) and mostly non-significant in the case of rectal temperature (0.08 - 0.51) when calculated for each heifer on a within-day basis.

Quartermain (1959) computed, for the first time, the repeatability of consecutive observations for all three physiological variables in Jersey cattle under New Zealand field conditions, thus obtaining the following estimates; pulse rate (0.75), respiration rate (0.91) and rectal temperature (0.92). Such estimates showed the reliability of the measurement systems used. The high values of these repeatability coefficients suggested that one measure taken at a time could be almost as satisfactory as taking two or more consecutive measurements on the experimental animals.

SUMMARY

Repeatability coefficients for rectal temperature and respiration rate observed over long intervals, are generally low until the data are assembled according to similar environmental conditions, as a result of which the values increase. In other words, when the environmental conditions at the time of recording data are variable, the repeatability values are generally very low. Only one report on such estimates indicated that under temperate conditions repeatability of pulse rate was fairly high.

However, the repeatability of consecutive readings for all three physiological variables is generally very high.

1.5 HERITABILITY OF THE PHYSIOLOGICAL VARIABLES

It will be appropriate here, to quote the statement made by Shrode (1958) regarding the problems involved in the estimation of heritabilities of physiological variables. He states: "Since the estimation of heritability has become such a prevalent pastime for animal husbandry research workers, it seems that we could have expected at least a 'rash' of estimates of heritability of many variables the physiologists measure in their 'heat tolerance' research. However, relatively few such estimates have been published. I am certain that this does not mean that many heritability estimates have not been calculated. I do not know, but I suspect that others have had the same experience as I have had in estimating heritability of such things as daily range in rectal temperature, respiration rate, etc. The lack of consistency of the results has been so striking that publication would contribute more confusion than clarification. The variables generally measured in 'heat tolerance' studies are correlated with so many other variables such as age, stage of gestation, stage of lactation and level of production that the amount of adjustments indicated is discouraging, if not prohibitive, if one is to obtain reliable estimates of heritability". Perhaps because of the reasons suspected by Shrode, only one report (Seath, 1947) has been published on the heritability estimates of rectal temperature and respiration rate, whereas that of pulse rate has not been found reported in the literature.

Studies made by Bonsma (1940, 1948, 1949) and Rhoad (1938, 1940, 1942) showed that genetic differences were, at least in part, responsible for the observed differences in animal response to climatic stress. Such genetic differences are undeniable in view of the striking breed differences observed (see Chapter 1.1). Gaalaas (1947) reported from his study of heat tolerance in Jersey cows that there were some differences in the response of daughter groups of various sires when measured at 2 and 3 years of age, but little, if any, when measured at 4 years of age or more.

The only attempt to estimate the heritability of rectal temperature and respiration rate was made by Seath (1947) who estimated the heritability of individual records, based on sire-progeny differences, as 0.15 and 0.31 for rectal temperature and 0.77 and 0.84 for respiration rate, for the years 1944 and 1945 respectively, when the data of the 8 hottest days of each year, with a mean air temperature of 89^{o}F in the both years, were used in the estimation.

The estimates of the heritability of body temperature (0.15 and 0.31), though subject to much sampling error because of the small number of animals involved, were quite reasonable and were smaller, as expected, than the repeatability estimates computed in the same study. Unexpectedly, however, heritability estimates (0.77 and 0.84) of respiration rate greatly exceeded its repeatability estimates (0.42 and 0.48) in the same study. This could be explained as being due to sampling error, because the Fiducial limits (22% to 177% in 1944 and 25.6% to 232% in 1945) for those heritability estimates were very wide as would be expected from the number of cows (52 and 68 in 1944 and 1945 respectively) and the number of sires (7 and 8 in 1944 and 1945 respectively) involved in the estimations.

SUMMARY

There were genetic differences in the response of the rectal temperature and respiration rate of cattle to heat stress. The value of heritability of rectal temperature appeared to be similar to that of milk yield, but that of respiration rate was much higher under the conditions involved in the study. Unfortunately, heritability of pulse rate was not reported in the literature.

1.6 PHENOTYPIC AND GENETIC CORRELATIONS BETWEEN THE PHYSIOLOGICAL VARIABLES

There have been many reports published in the past on the relationships between the climatic variables and the physiological variables (reviewed by Lee and Phillips, 1948; Findley, 1950; Findley and Beakley, 1954; McDowell, 1958; Quartermain, 1959). However, very few have been published on the phenotypic correlations, and none on the genetic correlations, between the physiological variables (Asker et al., 1952; Casady et al., 1956; Patchell, 1951; Quartermain, 1959; Atmadilaga, 1959). An attempt will be made here to review their results critically.

Asker et al. (1952) reported a significant correlation between rectal temperature and respiration rate (0.31) and between respiration rate and pulse rate (0.32) for Egyptian cattle which were exposed to sun at an air temperature of 94.5°F.

Under New Zealand conditions, Patchell (1951) and Quartermain (1959) reported significant correlations between rectal temperature and respiration rate, and between rectal temperature and pulse rate, computed on a within-animal basis.

In a climatic chamber, Casady et al. (1956) exposed 4 Holstein bulls sequentially, to continuous air temperatures of 60°F, 70°F, 80°F, 85°F, 90°F and 95°F from 4 to 29 days at an absolute humidity of 10.0 - 14.5 mm.Hg. and computed the phenotypic correlations between rectal temperature and the two other physiological variables, on within and between bulls bases, for each of the temperature treatments. Their results lacked significance in most cases, but showed consistent relationships, both between bulls and within bulls, only in the case of phenotypic correlations between respiration rate and rectal temperature, which were closely associated when the air temperature ranged from 80°F to 90°F. However, at a chamber temperature of 60°F the within-bull correlation coefficient between rectal temperature and respiration rate was negative and non-significant. But at the same temperature (60°F) the within-bull correlation coefficient between rectal temperature and pulse rate (1.00) was highly significant.

Atmadilaga (1959) estimated the phenotypic correlations for various breeds of cattle under different environmental conditions. In one experiment he exposed to intense sunlight, six breeds of cattle for an hour, with a mean air temperature of about 84°F, and estimated the phenotypic correlations between the physiological variables for all breeds separately. The results showed that in the Bali breed (Indonesian Zebu) the correlation coefficient between rectal temperature and respiration rate was highly significant (0.69), whereas in all other breeds this correlation was non-significant (range being ~~0.80~~ 0.08 to 0.46). The value of the correlation coefficient between rectal temperature and pulse rate ranged from - 0.12 to 0.32 for all breeds, all being statistically non-significant. However, in the case of two buffaloes, in the same experiment, the corresponding value was significant at 5%, with a negative sign (-0.67) Because of the small number of animals involved, the differences in the values obtained would be quite expected.

In other experiments he exposed the cattle of a particular breed to a tropical atmosphere from 10 a.m. to 3 p.m. and computed the correlation coefficients for different breeds for 10 a.m. and 3 p.m. observations separately. The summary of his results (see Table 18) demonstrated that the range of correlations between the physiological variables for different breeds and for the same breed were too unsystematic to make any generalizations. Nevertheless, two conclusions could be made from those results. Firstly, it was clear that there was not much similarity in values between breeds and even for the same breed observed at different times of the day. Secondly, the magnitude of the correlations was associated with that of atmospheric temperatures in the case of the correlation between rectal temperature and respiration rate: the higher the atmospheric temperature, the higher the value of the correlation for a particular breed. This conclusion could also apply in the case of the correlation between rectal temperature and pulse rate with the exception of the Bali breed where the reverse was the case.

In most of the results reviewed, the number of cattle involved was very small, so little reliance could be placed on the figures reported for the relationships. This could also be the main cause for the wide range of values for these relationships reported, plus the fact that the observations were made under variable climatic conditions, which seemed to considerably affect the estimates.

SUMMARY

The magnitude of the correlation coefficient between rectal temperature and respiration rate was positively influenced by air temperature, the degree of the effect differing from breed to breed. In the case of the correlation between rectal temperature and pulse rate, the association with air temperature seemed to be negative, i.e. the lower the air temperature the higher the correlation coefficient.

1.7 PHENOTYPIC AND GENETIC CORRELATIONS BETWEEN THE PHYSIOLOGICAL VARIABLES AND THE PRODUCTIVE VARIABLES

This writer has found no reports in the literature of studies on phenotypic and genetic relationships between the physiological variables and productive variables.

PART II

CHAPTER II

PRELIMINARY INVESTIGATIONS IN THE MASSEY UNIVERSITY HERDS

2.1 INTRODUCTION

The importance of correct knowledge of the problems involved in the conduct of any experiment, cannot be over-emphasized. This is especially so when experiments involve the handling of livestock. Success in conducting such experiments, to obtain unbiased results, depends on proper knowledge of the technical problems, and the behaviour and management of animals involved in such investigations.

As most of the data had to come from commercial herds, it was considered desirable to conduct a preliminary study in the Massey University herds on the behaviour of cows in response to the collection of data. The purpose was to understand the problems to be faced in commercial herds.

Having done so, a system of recording the data on pulse rate, respiration rate and rectal temperature, to be followed in the commercial herds, was established. The reliability of such a recording system was assessed later, before the actual observations were made for the main investigations.

2.2 PURPOSE, MATERIALS, METHODS AND CONCLUSIONS

The first week was spent making observations on some of the Massey cows in order to study:

(a) place of recording (under solar radiation or in the shade);

(b) time of recording (morning, afternoon or evening);

(c) recording procedure; including

  (i) method of handling the cows;

  (ii) treatment of the cows; and

  (iii) recording system.

(a) Place of Recording

It was indicated in the review of literature that genetic variability of rectal temperature and respiration rate increased when cattle were subjected to heat stress, either by exposing them to high ambient temperature, or tc direct solar radiation at near thermoneutral temperature (see review). Such genetic variability was at a minimum when the air temperature was low and recordings were done in the shade. The main cause of increased variability in rectal temperature and respiration rate under solar radiation was the variability present in coat colour (Lee, 1953).

As uniformity in coat colour could not be obtained in the present study, the effect of colour differences would be confounded with the inherent variability present in the physiological variables under study, if the observations were made under direct solar radiation. Nevertheless, hoping to take advantage of the increased variability caused by solar radiation, some cows were kept inside the wooden corral and different methods of handling them while taking observation on the physiological variables, were tried. None of the methods proved to be useful in acquiring reliable data because of the following reasons:

(i) <u>Flies</u>

Cows were very disturbed by the increased activity of flies under these herded conditions. This could not be controlled, even by spraying the cows and the surroundings, with fly repellent.

(ii) <u>Strange Surroundings</u>

Those cows, like all others, were not used to being kept in an enclosure, which had been used previously for unpleasant handling, and consequently they were always uneasy, which made recording impossible.

(iii) <u>Tying</u>

Those cows, like all others unused to tying, could not be secured easily around the neck, without greatly disturbing them.

(iv) <u>Small Number of Cows</u>

Most important of all the drawbacks was that only a few cows could be handled at a time, thus affecting the experimental design which entails the observation on as large a number of cows in a herd as possible.

Because of these difficulties encountered while making the observations outside, it was decided to carry on further preliminary investigations inside the milking shed. This decision was well worthwhile because it solved most of the practical problems encountered outside. Above all, the effect of colour on the physiological variables recorded under solar radiation was also obviated by recording the data in the shade (see review).

(b) Time of Recording

Different times of the day (9 a.m. to noon; 1 p.m. to 3 p.m.; and 5 p.m. to 6 p.m.) were tried, to decide at which of the three periods, cows were most willing to enter the milking shed and remain there, with least excitement. This period would therefore yield the most accurate data.

It was observed that cows were least willing to remain inside the milking shed after the afternoon milking was over and most willing to enter and remain in the milking shed in the morning (9 a.m. to noon) and afternoon (1 p.m. to 3 p.m.) The later period was avoided because of some practical difficulties.

From all practical points of view the morning period was found to be the most convenient time to make observations on the cows. It was also observed (Quartermain, 1959) that variability in diurnal change patterns of the physiological variables among lactating Jersey cows was at a minimum during this period of the day, under similar temperate field conditions.

(c) Recording Procedure

Inside the milking shed during the morning, it was endeavoured to establish a system of recording that would be followed in all the commercial herds. Accordingly, many alternative procedures were tried, but one to be described here was found to be the least disturbing to the experimental cows, thus offering the most reliable data on the physiological variables. In such a procedure cows were gently brought to the milking shed and, at will, they would choose their places and be secured in the same way as was done during milking. Those which were reluctant to take their places were driven gently towards the empty bails which they generally accepted without being greatly disturbed.

All the cows would remain in their positions until the last cow was recorded (because of some psychic problems involved). While the cows were resting, they were sprayed with fly-repellent around the hind-quarters, treating all the cows alike. The spraying, and later the recording, were started from one end of the bail and finished at the other, so that the cows which were sprayed first had enough time for any possible effects of spraying to subside before the recordings were started. After spraying, dry and wet bulb temperatures were recorded in the shed by a whirling hygrometer which was hung on a nearby wall. The recording of atmospheric conditions was repeated every half hour throughout the recording period, with a final check at the end of the recordings.

Similarly, out of all the alternative procedures tried for recording the physiological variables, the following one was found to be the most convenient and reliable. With this system, a clinical thermometer was inserted inside the rectum while respiration rate and pulse rate were recorded. Finally rectal temperature was recorded. A complete set of such recordings took on an average, 3.5 minutes.

This system of recording caused the least disturbance to the experimental cows, and hence was followed in all the commercial herds.

2.3 METHODS USED FOR RECORDING THE PHYSIOLOGICAL VARIABLES

(i) RECTAL TEMPERATURE

The rectal temperature was recorded with a 4" mercury-in-glass, clinical thermometer (certified correct to within 0.2°F) which was inserted in the rectum to a depth of 3" from the anal sphincter. A 0.8" long rubber cork on the end of the thermometer ensured this constant depth of insertion. According to instructions for the use of these thermometers, they required 30 seconds to record equilibrium temperature. Because of the reasons mentioned already, the thermometer was left in the rectum for approximately 3.5 minutes.

All the thermometers used in this experiment were standardized against a standard thermometer in a water bath, and the readings were recorded to the nearest of 0.05°F. Any readings just before or after defaecation were disregarded and another reading was taken after a while (see review).

(ii) RESPIRATION RATE

The most convenient method for recording respiration rate was counting the flank movements (an inspiration and expiration constituting one complete respiration) over 30 second intervals, timed with a stopwatch. It was observed in the course of the preliminary investigations that the longer the time taken to count the respiration rate, the greater was the disturbances caused by activities such as swallowing, eructation etc. When a recording was disturbed by such acts as already mentioned, it was discarded and another count made on respiration rate.

(iii) PULSE RATE

Pulse rate was recorded by manual palpation of the ventral coccygeal artery and timed in a similar manner to respiration rate. When this coccygeal artery was located deep in the muscle of some cows, and difficult to record, heart beats were recorded by manual palpation of the femoral artery, located on the inside of the hind leg above the hock. Fortunately, in only a very few cases was this necessary.

CHAPTER III

REPEATABILITY OF THE PHYSIOLOGICAL VARIABLES

3.1 INTRODUCTION

Having decided on the procedure for recording the data, which was most reliable from the practical point of view, the usefulness of this recording system was assessed by computing the repeatability of consecutive readings* on pulse rate, respiration rate and rectal temperature. Such repeatability estimates helped to form a basis for recording these data in commercial herds, and also suggested the approximate number of readings required to represent the physiological state of the cows at the time of observation. The repeatability coefficient was also computed for observations taken on the same cows at longer intervals. Such estimates would suggest to what extent observations taken at a particular time of the year could be used to predict future records at some other time of the year when the environmental conditions were quite different. This was similar to the method used to predict the future records of cows on the basis of the repeatability coefficient for productive characters by Lush (1945).

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* i.e. two sets of readings taken one after another on the same cow.

3.2 REPEATABILITY OF CONSECUTIVE READINGS

(i) MATERIALS AND METHODS

55 Jersey cows consisting of 25 dams and 30 daughters from five Massey University herds were used for taking two consecutive readings for each of the physiological variables. These cows were subjected to uniform treatment throughout the observation period and the procedure followed in all the herds was standardized as described in the previous chapter.

If two consecutive readings deviated four counts per minute in the cases of pulse rate and respiration rate and 0.3°F in the case of rectal temperature, or more, a third reading was taken and the two closest ones were used in actual computation. This was an arbitary method used to eliminate 'atypical' records.

(ii) STATISTICAL METHOD

The method of intra-class correlation as outlined by Snedecor (1946) and recommended by Lush (1945) was used to calculate the between cows and between readings within cows variance components. The formula used was:

$$R = \frac{\sigma^2 s}{\sigma^2 s + \sigma^2 e}$$

where R = repeatability coefficient;

$\sigma^2 s$ = variance between cows; and

$\sigma^2 e$ = variance between readings on the same cow.

Using this formula, repeatability of the physiological variables were estimated for dams' and daughters' groups separately for all the herds. An example of such a calculation is shown in Appendix I.

(iii) RESULTS

Table No. 3 shows the results of repeatability of the physiological variables for both dams' and daughters' groups estimated separately for all five herds.

TABLE 3

Repeatability of consecutive observations on the physiological variables, estimated for dam and daughter groups separately in five herds

Herd No.		1	2	3	4	5	
Time		10.15 a.m. to 12.25 p.m.	9.40 a.m. to 11.25 a.m.	1.15 p.m. to 2.54 p.m.	9.40 a.m. to 10.50 a.m.	1.30 p.m. to 3. p.m.	
Air tempera-ture(°F)	Range	71 - 75	66 - 70	71 - 72	69 - 72	75 - 76	
	Mean	73.4	68.2	71.2	70.3	75.8	
No. of animals	Dam	6	4	5	6	4	
	Dtr.	6	5	6	7	6	
Pulse rate	Dam	0.95	0.89	0.96	0.98	0.95	REPEATABILITY
	Dtr.	0.90	0.70	0.75	0.93	0.95	
Respir-ation rate	Dam	0.88	0.89	0.98	0.98	0.90	
	Dtr.	0.87	0.85	0.85	0.99	0.92	
Rectal tempera-ture	Dam	0.99	0.44	0.92	0.98	0.99	
	Dtr.	1.00	0.98	0.90	0.98	0.98	

The results show that these physiological variables are highly repeatable in both dams'and daughters' groups in all the herds when the readings were taken consecutively. The smallest value estimated for rectal temperature of dams' group of herd No. 2 was 0.44. Excluding this, all other figures were very high (rectal temperature, 0.90 - 1.00; respiration rate, 0.85 - 0.99, and pulse rate, 0.70 - 0.98) in both groups. There did not appear to be consistent differences between dams' and daughters' groups in the repeatability estimates of the physiological variables.

(iv) DISCUSSION

As the error due to cows, observer, techniques of measurement and any unknown factors are of additive nature, they should tend to reduce the repeatability estimates which, by definition, are a measure of the closeness of agreement between repeated observations on the same animal.

However, high values for repeatability coefficients of the physiological variables indicate that the above mentioned errors are not important when the readings are taken consecutively and that no great accuracy is gained by taking more than one of each type of reading to represent the physiological state of the cows at the time of observation. For example, consider the formula;

$$\sqrt{\frac{n}{1 + (n-1)\ R}}$$

where n = no. of records per animal; and

R = repeatability coefficient.

This is used to calculate the accuracy gained by using the average of n records per animal compared with using single records, at different values of repeatability (R). Only 3% more accuracy was gained by using the mean of two records as opposed to using a single record per animal, when the repeatability of these traits was approximately 0.90.

These estimates are very similar to the results reported by Quartermain (1959). Both Quartermain's and this study indicate that under summer conditions in New Zealand repeatability of consecutive readings is highest for rectal temperature, intermediate for respiration rate and lowest for pulse rate in comparative terms.

In trying to understand the underlying factors that caused the repeatability of rectal temperature of dams' group of herd No. 2 to be so low (0.44), the data were looked through again and the following facts revealed:

(a) that the mean air temperature for the period when records were taken in this herd was the lowest (68.2°F);

(b) that the total variance was very low in both groups but was 35 times greater in the daughters' group than that of the dams' group; and

(c) that between cows variance was 55 times that of the within cows variance in the case of the daughters' group as compared to only 0.8 times in the case of the dams' group.

Other facts suggested from this evidence were that at lower temperature, total variance and between cows variance were lower in both groups but were lower still in the case of the older cows as compared to the corresponding variance for younger cows under similar conditions. This low variance could be a matter of chance.

SUMMARY

Repeatability coefficients of consecutive recordings on the physiological variables were very high (rectal temperature, 0.44 - 1.00; respiration rate, 0.85 - 0.99; pulse rate, 0.70 - 0.98). Very little accuracy was gained when two recordings were taken instead of only one.

3.3 REPEATABILITY OF THE PHYSIOLOGICAL VARIABLES WHEN THE OBSERVATIONS WERE TAKEN AT LONGER INTERVALS

(i) MATERIALS AND METHODS

Observations on the physiological variables were made on 51 cows from 6 Massey University herds. The first readings were taken in March and the second in April. Atmospheric conditions were very different during those two periods (see Table 4).

The data were analysed into between cows and between readings within cows variance components and repeatability estimated from them:

(a) using the entire data; and

(b) for all herds separately;

according to the method already described.

(ii) RESULTS

The results of the repeatability estimates computed for all herds combined, and for individual herds separately, together with the climatic conditions prevailing during the first and second observational periods, are shown in Table 4.

TABLE 4

Repeatability of observations on the physiological variables taken at longer intervals in six herds, separate and combined.

Herd No.	No. of animals	Reading I		Reading II		REPEATABILITY ESTIMATE		
		Temp. (°F)	Humidity %	Temp. (°F)	Humidity %	Pulse rate	Respiration rate	Rectal temp.
1	8	71.2	60.2	65.5	69.5	-0.18	0.36	0.26
2	9	73.4	65.0	64.2	78.5	0.19	0.61	0.40
3	5	62.7	87.2	58.8	94.5	-0.32	0.01	0.61
4	7	62.7	87.2	58.5	90.5	0.42	0.40	-0.27
5	10	70.3	61.6	55.5	89.0	0.62	-0.15	-0.10
6	12	68.2	60.0	66.8	77.0	0.31	0.37	0.67
Entr. period	51	68.8	56.9	61.5	83.20	0.20	0.32	0.03

The last row of Table 4 shows that repeatability estimates of the physiological variables are, in general, low when entire data are used in the computation. This value is highest for respiration rate (0.32), intermediate for pulse rate (0.20) and lowest for rectal temperature (0.03). The analysis of variance for the entire data is shown in Appendix 2.

However, when the same data were analysed for individual herds and repeatability estimates computed, wide ranges of values were found: for pulse rate (-0.32 to 0.62); respiration rate (-0.15 to 0.61), and rectal temperature (-0.27 to 0.67).

(iii) DISCUSSION

(a) Rectal Temperature

Repeatability of rectal temperature when the entire data were used is smaller than those values reported by Seath (1947), Seath and Miller (1947b) and Australian workers (1955); but is greater than those reported by McDowell *et al*. (1953) and in line with those reported by Patchell (1951) from similar studies.

However, when estimates were computed for all the herds separately, the range of values (~~-0.10~~ -0.27 to 0.67) covered all the results reported by these workers.

Close scrutiny of the results (Table 4) revealed the following facts:

(1) the main cause of the low repeatability value for the entire data was the negative sign of values in herds 4 and 5; and

(2) the values of repeatability estimates became higher, as the differences between climatic conditions prevailing during observations lessened.

A similar observation was reported by Seath (1947).

(b) Respiration Rate

The value of the repeatability coefficient for respiration rate, using the entire data, at 0.32 is the highest for the variables studied. This figure is higher than those reported by Seath (1947) for the entire data and Patchell (1951); smaller than those reported by Seath (1947) when the data on the eight hottest days were used, Seath and Miller (1947b) for barn observations, and Australian workers (1955); and is in line with the report of Seath and Miller (1947b) from observations of cattle on pasture.

However, wide ranges of such estimates for individual herds (-0.15 to 0.61) as shown in Table 4 cover all the values reported so far, except one by Australian workers (1955) whose value was 0.80.

(c) Pulse Rate

The repeatability of pulse rate (0.20) based on the entire data is the second highest in the present study and is smaller than the range of similar estimates (0.29 to 0.52) reported by Patchell (1951) whose results, however, were in line with the range (-0.32 to 0.62) estimated in this study for individual herds.

SUMMARY

Repeatability estimates of the physiological variables, recorded at a longer interval, were low (pulse rate, 0.20; respiration rate, 0.32; rectal temperature, 0.03) when the entire data were used in the computations. However, a wide range of values was obtained for all the physiological variables when calculated for individual herds.

PART III

CHAPTER IV

COMMERCIAL HERD STUDY

4.1 INTRODUCTION

The procedure used in all herds to record data on the physiological variables was described in Chapter II. The materials and methods used for different types of investigations have been described in their respective sections. Climatic and geographical characteristics of this location have already been described by Quartermain (1959).

This chapter describes the characteristics of herds under observation in the present investigations, and the materials and methods that are common to all of those investigations.

4.2 CHARACTERISTICS OF HERDS, STOCK AND MANAGEMENT

(i) HERDS

18 herds were selected mainly on the basis of breed (Jersey), except herd No. 9 which was Jersey grade, and the number of dam - daughter pairs present in them. These herds were scattered over a radius of approximately 15 miles from Massey University. The owners of these herds identified dams and daughters and later sent in details on the productivity of these animals. All the herds were under the A.B. scheme which operates only two months in every year. Of these herds only 10 were under the monthly testing scheme.

(ii) STOCK

All the cows were normally lactating, milked twice daily, pregnant and of mixed age groups. Some dams had more than one daughter. All of them looked normal and healthy except No. 135 of herd No. 2 and one cow (Midget) of herd No. 8, the former being fistulated and the latter very small.

(iii) MANAGEMENT

All the cows were kept outside the year round and pasture grazed. Within the herd all cows were treated similarly in management and nutrition.

4.3 RECORDING

All the recording was done by the author in the morning (9 a.m. - noon) for the reasons given in the Chapter II except herd No. 8 where recording was done during afternoon milking and Dr. Flux helped record due to limited time.

(i) GENERAL PROCEDURE

The whole process of recording was kept as uniform as possible in all the herds and all the cows within a herd were treated alike. On arrival at the farm the dam and daughter pairs were separated from the rest of the herd, driven gently to the milking shed, chained and then identified by a system of chalk markings. The farmers helped throughout this process, during which cows were treated as gently as practically possible to minimise excitement. The rest of the recording process was followed exactly as described in Chapter II.

Random recording was guaranteed by the following factors:

(a) the author did not know the cows individually;

(b) no attempt was made to place dam and daughter together in the shed nor was any tendency of their staying together observed; and

(c) observations were started from one end of the shed and finished at the other.

(ii) NUMBER OF RECORDINGS OBTAINED

Only one record of each of the physiological variables was taken to represent the physiological state of the cows at the time of observation. As evidenced by the high values of repeatability of consecutive readings on the physiological variables, more than one recording would add only slightly more accuracy to the result (see Chapter III), whereas taking two readings per variable per cow would mean spending twice the time, hence causing the following disturbances:

(a) climatic conditions would be more likely to change over a longer observational period, thus introducing extra error which would be difficult to account for;

(b) diurnal stages of the physiological variables would have been more pronounced between the cows recorded first and last (Patchell, 1951; Quartermain, 1959), hence introducing unaccountable extra error;

(c) fly activities would have increased owing to accumulated dung and increasing ambient temperature, causing disturbance to the cows; and

(d) farmers would not have liked their cows to be kept under observation, when they should have been grazing.

Therefore, it was decided to take only single recordings, and that the number of dam - daughter pairs would be increased as far as possible. However, when the recorder had any doubt as to the reliability of a record, due to any disturbing factor, second or even third readings were taken and the one thought to be most reliable recorded.

4.4 GENERAL MATERIALS AND METHODS

(i) MATERIALS

Data on the physiological variables and age were recorded on 273 lactating cows (130 dams and 143 daughters) of mixed age (2 to 13 years), which came from 18 herds. Wet and dry bulb temperatures were recorded in all the sheds in the manner described in Chapter II. Ten herds consiting of 68 dam - daughter pairs (where necessary dam's record was repeated with each of its daughter's) were tested and the data supplied for the productive variables (lactation milk and fat yield and milk and fat yield for the month when data were collected), length of lactation (7 herds only), stage of lactation and stage of pregnancy at the time of observation. Two of these ten herds did not have data on the month's milk and fat yield.

These data on the productive and related variables were acquired by sending a printed form to the testing farmers who sent back the required data at the completion of the lactation. A summary of all the data is given in Appendix 3 and raw data have been deposited at the Dairy Husbandry Department of Massey University. These 10 farms provided the only material on productive variables used in this study.

(ii) METHODS

Due to the differences among the herds in the levels of feeding, management and climatic conditions at the time of observation, which were difficult to appraise, estimations of heritability, genetic and phenotypic correlations were made on a within-herd basis. Methods for these calculations have been described in their respective chapters.

However, before the data were subjected to an analysis of variance for the estimation of the heritability, genetic and phenotypic correlations, they were corrected for non-genetic causes of variation.

CHAPTER V

PRELIMINARY INVESTIGATIONS ON THE RAW DATA FOR THE PHYSIOLOGICAL VARIABLES

5.1 INTRODUCTION

Before the data is subjected to genetic study it is always desirable that the influence of non-genetic factors be minimised by special experimental design, statistical correction, or by the appropriate combination of these two methods.

In the present study the design of the experiment and the systems of breeding and management in the herds, were such that most of the non-genetic causes of variation were automatically accounted for when the computations were done on a within-herd basis. A survey of the raw data showed clearly that all the cows within a herd were at similar stages of pregnancy, there was not much fluctuation in the climatic conditions during short observational periods, they were treated alike prior to and during the observational period, effect of colour was nullified by making the observations in the shed, therefore, the only 'correctable' factors that could have any effect on the physiological variables were age and to a lesser extent the level of production and stage of lactation. However, the review of literature showed that under the temperature range during this study, level of production and stage of lactation would not have significant effects on the physiological variables. Hence, only one 'correctable' non-genetic factor, i.e. age was left, that might have had a significant influence on any or all of the physiological variables under study.

Therefore, it was decided that the influence of age on the physiological variables should be thoroughly investigated.

5.2 BETWEEN HERDS, WITHIN HERDS AND BETWEEN AGE GROUPS WITHIN HERDS VARIANCE

(i) MATERIALS AND METHODS

The materials for this investigation have already been described in Chapter IV. Seventeen of those herds comprising 264 cows were used in this study. In order to study the effect of age on the physiological variables, the data were grouped into three age groups as follows:

1st group, 2 to 3 years inclusive;

2nd group, 4 to 6 years inclusive; and

3rd group, 7 years and older.

The grouping of such data is shown in the Appendix 4.

The data were then analysed into between herds, between age groups within herds and between cows within herd-age group variances, by the usual method used for disproportionate subclass numbers (Snedecor, 1946). The test of significance was done by the F-test and the average number of cows per sub-group needed to estimate the components of variance, was calculated by the method given by Graybill (1961). If the effect of age on any of these physiological variables reached a significant level, the data were further analysed to study whether there was a significant interaction between age groups and herds, before any decision was made on the method for correcting the data.

(ii) MODEL USED

In carrying out the test of interaction, the basic model used was:

$$Y_{ijk} = \mu + h_i + a_j + (ha)_{ij} + e_{ijk}$$

$$i = 1 \text{-----} 17$$

$j = 1 \text{-----} 3$

$k = 0, 1, 2 \text{------} n_{ij}$ (n_{ij} = number of cows in the $(ij)^{th}$ sub-class)

where, Y_{ijk} is the trait of k^{th} cow of j^{th} age group of i^{th} herd,

μ is the constant effect common to all cows in the sample,

h_i is an effect common to all the cows in i^{th} herd,

a_j is an effect common to all the cows in j^{th} age group,

$(ha)_{ij}$ is an interaction between the i^{th} herd and j^{th} age group, and

e_{ijk} is an error, or residual, peculiar to each observation.

h_i, a_j and μ are considered to be unknown, fixed constants. e_{ijk} are assumed to be normally and independently distributed with the same variance, $\sigma^2 e$ around a mean of zero.

For simplicity, in estimating the reduction in sums of squares due to fitting μ, h_i and a_j, μ and h_i were combined. The method of analysis as suggested by Professor A.L. Rae (1964) was that of fitting the constants by least squares (Kempthorne, 1952). The estimates so obtained have minimum variance and are unbiased.

The original least squares equations are shown in Table 5. In order to solve the least squares equations, the h equations were solved for $(\mu + h_i)$ in terms of a's. These expressions were then substituted in 'a' equations to give equations only in terms of a's. Putting $a_3 = 0$, two equations, in a_1 and a_2 were left. These equations were solved by the usual method used for solving simultaneous equations, thus estimating the value of a_1 and a_2. Knowing $\hat{a}_1$ and $\hat{a}_2$, and $\hat{a}_3 = 0$, and substituting these values in the original equations, values for $\widehat{(\mu + h_i)}$ were estimated. From these estimates, the reductions in sums

TABLE 5

The least squares equations for respiration rate data

$\mu +$	h_1	h_2	h_3	h_4	h_5	h_6	h_7	h_8	h_9	h_{10}	h_{11}	h_{12}	h_{13}	h_{14}	h_{15}	h_{16}	h_{17}	a_1	a_2	a_3	Σy
$+ h_1$	12																	5	4	3	197.0
h_2		9																3	4	2	140.0
h_3			12															5	5	2	190.0
h_4				13														6	3	4	222.0
h_5					10													5	3	2	163.0
h_6						10												4	4	2	123.0
h_7							26											8	8	10	462.0
h_8								17										7	6	4	292.0
h_9									16									5	6	5	214.0
h_{10}										27								9	12	6	433.0
h_{11}											16							0	12	4	254.0
h_{12}												18						0	9	9	301.0
h_{13}													16					8	6	2	292.0
h_{14}														22				8	9	5	343.0
h_{15}															8			0	0	8	111.0
h_{16}																14		6	5	3	220.0
h_{17}																	18	6	8	4	315.0
a_1																		85	0	0	1443.0
a_2																		0	104	0	1703.0
a_3																		0	0	75	1126.0

of squares due to fitting the constants, $R(\mu, h_i, a_j)$, were obtained.

The sums of squares due to interactions were estimated as the difference: i.e. between-sub-class sums of squares - $R(\mu, h_i, a_j)$ (Kempthorne, 1952) and were tested against the within-sub-class sums of squares as shown in Table 6. Interactions must be shown to be non-significant if the assumption of additivity, implied by the model, is to hold. Where the assumption of additivity does not hold, the analysis must be carried out within the interacting groups (Kempthorne, 1952; Rao, 1952).

TABLE 6

A tabular form of the analysis of variance for testing interactions

Sources	d.f.	s.s.	M.S.
Interaction	(p-1) (q-1) -m	S-R	
Error	n..-pq-m	T-S	

WHERE, p = no. of herds;

q = no. of age groups;

m = no. of herd-age sub-classes with no observations;

n..= total no. of observations;

T = uncorrected total sums of squares;

S = uncorrected between age-group sums of squares; and

R = reduction in sums of squares due to fitting (μ, h_i, a_j).

5.3 RESULTS

The results of analyses of variance on pulse rate, respiration rate and rectal temperature are shown in Tables 7, 8 and 10 respectively. The corresponding between herds, between age groups and error component of variance are shown in the same tables.

TABLE 7

Analysis of variance: pulse rate

Sources	d.f.	s.s.	M.S.	F-value and result	Components
Total	263	5584.1			
Between herds	16	1717.3	107.331	6.3622**	$\sigma^2c + 6.226\sigma^2b + 15.412\sigma^2a$
Between age-groups	30	506.1	16.870	1.0893(N.S.)	$\sigma^2c + 5.253\sigma^2b$
Error	217	3360.7	15.487		σ^2c

% of total variations; σ^2a = 6.013 = 27.6%
σ^2b = 0.263 = 1.2%
σ^2c =15.487 = 71.2%

** = significant at 1%

TABLE 8

Analysis of variance: respiration rate

Sources	d.f.	s.s.	M.S.	F-value and result	Components
Total	263	3981.28			
Between herds	16	535.50	33.468	1.2437(N.S.)	$\sigma^2c + 6.226\sigma^2b + 15.412\sigma^2a$
Between age-groups	30	807.30	26.910	2.2133**	$\sigma^2c + 5.253\sigma^2b$
Error	217	2638.48	12.158		σ^2c

% of total variations; σ^2a = 0.728 = 4.6%
σ^2b = 2.808 = 17.9%
σ^2c = 12.158= 77.9%

** = significant at 1%

TABLE 9

Test of interaction (herd x age group): respiration rate

Sources	d.f.	s.s.	M.S.	F-value and result
Interaction	28	69654.23	2487.6510	7.66012**
Error	217	70471.52	324.7535	

** = significant at 1%

TABLE 10

Analysis of variance: rectal temperature

Sources	d.f.	s.s.	M.S.	F-value and result	Components
Total	255	66.120			
Between herds	16	15.694	0.98087	6.2675**	$\sigma^2 c + 6.054\,\sigma^2 b + 14.933\,\sigma^2 a$
Between age-groups	30	4.695	0.15650	0.74948(N.S.)	$\sigma^2 c + 5.081\,\sigma^2 b$
Error	219	45.731	0.20881		$\sigma^2 c$

% of total variance: $\sigma^2 a$ = 0.0476 = 19.3%

$\sigma^2 b$ = -0.0101 = -4.1%

$\sigma^2 c$ = 0.2088 = 84.8%   ** = significant at 1%

Pulse rate (Table 7) Between herds variance was statistically significant at the 1% level and between age groups was non-significant. Table 7 also shows that 72.4% of total variance was due to within herd variance, of which 1.2% was due to between age group variance and the remaining 27.6% was due to between herds variance.

Respiration Rate (Table 8) The between herds variance was statistically non-significant and the between age groups variance was highly significant. Interaction between herds and age groups (Table 9) was highly significant.

Rectal Temperature (Table 10) Between herds variance was highly significant and between age groups variance was non-significant. Of the total variance, 84.8%, -4.1% and 19.3% were due to error, between age groups and between herds variances respectively.

5.4 DISCUSSION

(i) BETWEEN HERDS VARIANCE

Between herds variance was highly significant in the case of pulse rate and rectal temperature and constituted 27.6% and 19.3% of total variance, respectively. Such variations between herds might be due mainly to variations in climatic conditions prevailing at the time of observation, management, and/or level of nutrition among the herds. Because of very low total variance in the case of rectal temperature and the low air temperature range prevailing at the time of observation, the contribution of the genetic variability to this source of variation would probably be negligible in this case. However, there might be a small portion of genetic variance contributing to this source of variation in the case of pulse rate.

(ii) WITHIN HERD VARIANCE

In all cases within herd variance contributed the highest proportion to total variance (pulse rate, 72.4%; respiration rate, 95.8%; rectal temperature, 80.7%). 1.2%, 17.9% and -4.1% of this source of variation for pulse rate, respiration rate and rectal temperature respectively, could be accounted for by variations in the age of cows within herds. The rest would comprise genetic differences among the cows with respect to these physiological variables and uncontrolled environmental variance between cows. In the case of rectal temperature, the contribution to this source of variation from variations in age, was zero as signified by its negative value. Therefore, within herd variance, if any, would most probably be due to genetic causes and unaccountable sampling error.

Reports of Gaalaas (1947), Rhoad (1944a) and Asker <u>et al</u>. (1952) from field studies made under tropical conditions, and Robinson and Klemm (1953) from the climatic chamber, indicated that large variability existed, within the Jersey breed, in heat tolerance measured in terms of both the Rhoad Coefficient and Benezra Coefficient. The present study indicates that variability in rectal temperature and respiration rate exists within the Jersey breed under temperate field conditions, but to a much lesser extent than observed under tropical conditions. This was especially so in the case of rectal temperature.

Large variability also seemed to exist among cows within herds in the case of pulse rate under temperate conditions. Significant differences between dairy stock in the responses of their physiological variables were also reported by Patchell (1951) and Quartermain (1959) from temperate field studies on a small number of animals.

It is the belief of this author, that variability in the case of rectal temperature and respiration rate would have been enhanced had these cows been subjected to heat stress either by artificial or natural means, whereas the reverse might have been the case with pulse rate.

(iii) BETWEEN AGE GROUPS WITHIN HERDS VARIANCE

Not only were the differences between age groups not significant at the 5% level, but the mean squares of pulse rate and rectal temperature were also very similar to that for error. So there was no suggestion at all of an age affect. This indicated that uncorrected raw data could be used for genetic investigations.

A highly significant influence of age on respiration rate indicated that the raw data must be corrected for the variations in age of cows. However, a common correction factor could not be used for all herds because of the highly significant interaction between herds and age groups. Instead, individual correction factors had to be calculated for all the herds.

SUMMARY

Raw data were analysed to study the contribution of different sources of variation, with the following results:

(1) between herds variances were highly significant in the case of pulse rate and rectal temperature, and non-significant in the case of respiration rate;

(2) between age groups within herd variance was non-significant in the case of pulse rate and rectal temperature and highly significant in the case of respiration rate; and

(3) a highly significant interaction was found between age groups and herds for respiration rate.

CHAPTER VI

HERITABILITY OF THE PHYSIOLOGICAL VARIABLES

6.1 INTRODUCTION

The importance of knowledge of the degree of heritability of a character in the choice of an efficient breeding system, to estimate gains to be expected under mass selection and to construct selection indices (Hazel, 1943), has been emphasized in most of the text books on animal breeding (Lush, 1945; Falconer, 1960; Learner, 1958, and others).

(i) THE CONCEPT OF HERITABILITY

The concept of heritability used in most animal breeding terminology has been the one that Lush (1945) defined in the "narrow sense". This has been expressed by workers in this field in various ways, all conveying the same meaning. It is expressed as a ratio of the additive genetic variance to the phenotypic variance ($h^2 = V_A/V_P$, where h^2 = heritability, V_A = additive variance and V_P = phenotypic variance); as a regression of breeding value on phenotypic value ($h^2 = b_{AP}$ where b = regression coefficient, A = breeding value and P = phenotypic value), and as a proportion of total variance that is attributable to the average effect of genes determining the degree of resemblance among relatives. From the practical point of view heritability of a trait expresses the reliability of an animal's phenotypic value as a guide to its breeding value. As heritability is the property of a character, population and environmental circumstances to which the population is subjected, and since its value depends on the magnitude of environmental and genetic components of variance, a change in any of these factors will affect it. As genetic components of variance (in the "narrow sense") are influenced by gene frequency, and the environmental component by non-additive genetic and environmental differences, and since these factors differ from one population to another, the values for heritability of a particular character estimated in different populations under different environments will differ accordingly. More variable environmental conditions reduce the heritability estimate and more uniform conditions increase it.

(ii) METHODS FOR ESTIMATION OF HERITABILITY

All the methods for estimating heritability are based on measuring the resemblance among closely related animals. But a suitable technique for doing so, varies with the material and depends on whether environmental correlations between the relatives and any peculiarities of their mating systems (if non-random) can be measured and discounted by other means. Lush (1940, 1948, 1949), Lerner (1958) and Falconer (1960) have critically discussed the different methods for estimating heritability and Kempthorne and Tandan (1953) have described and discussed the use of weighting factors in the case where a large proportion of dams having more than one daughter.

(iii) DECISION ON THE METHOD FOR THE PRESENT STUDY

After considering the advantages and disadvantages of different methods of estimation, as discussed by these authors, and the nature of the present data, it was decided that the measure of degree of similarity between dams and daughters would be the most suitable method for estimating heritability in the present study. When the variances within dam and daughter groups are equal, the regression of daughter on dam is equal to the correlation between them and each of the corresponding coefficients is equal to half the heritability. However, when the dams' group is a selected one, and therefore has a lower variance than the daughters' group because of this selection, regression analyses are most popular to estimate heritability in preference to correlation analyses, because the former are not affected by selection of the dams as co-variance is reduced to the same extent as the variance of the dams' group.

Though the characters under study were not directly selected for, there was a possibility of their being genetically correlated to any of the productive characters under selection, and thus being subjected to indirect selection. Therefore, to be on the safe side, linear regression analyses have been used in the present study in preference to correlation analyses. Kempthorne and Tandan(1953) did not find any apparent difference in the heritability estimated from linear regression analyses by:

(a) repeating dam's record with each of her daughter's; and

(b) using weighting factors,

when large proportions of records, as in the present study, were from dams with only one offspring. The first method has been used consequently, in the present study for the linear regression and correlation analyses.

6.2 MATERIALS AND METHODS

Data on pulse rate (140 dam - daughter pairs), respiration rate (137 dam - daughters pairs) and rectal temperature (134 dam - daughters pairs) were collected simultaneously from 17 herds (6 Massey herds and 11 commercial herds) in the manner described in Chapter II. Considering the characteristics of these herds and their management (see Chapter IV) plus the result of preliminary investigations, the data on respiration rate were corrected for the differences in age among cows by calculating additive correction factors for each of the 17 herds. In doing so, the 1st and 3rd age groups were corrected with respect to the 2nd group which had the largest number of cows. The correction factors for the 1st and 3rd groups of each herd were estimated by taking the difference between the means of the standard (2nd) group and each of these groups as follows:
$a_1 = (\bar{x}_2 - \bar{x}_1)$ and $a_3 = (\bar{x}_2 - \bar{x}_3)$ where, a_1 and a_3 are the correction factors for age groups 1 and 3 respectively, and $\bar{x}_1$, $\bar{x}_2$ and $\bar{x}_3$ are the mean respiration rates of groups 1, 2 and 3 respectively. The grouping of cows into three age groups and the correction factors calculated are shown in Appendix 5.

The data on pulse rate and rectal temperature were used uncorrected (see Chapter V). Heritability was then estimated as twice the intra-herd-regression of daughters on dams and the standard error of heritability, as twice the standard error of the regression. Within-herd sums of squares and cross-products and the standard error of regression were calculated by the method recommended by Snedecor (1946) for dealing with disproportionate sub-class numbers.

6.3 RESULTS

The analyses of variance and those of the corresponding error variance for pulse rate, respiration rate (corrected data) and rectal temperature are shown respectively in Tables 11, 12 and 13. The tables also show the corresponding heritabilities and standard errors of heritability.

TABLE 11

Intra-herd heritability of pulse rate: dam's record repeated with each daughter's record

TABLE 11a
Analysis of variance: pulse rate

Sources	d.f.	$s.s.x^2$	s.p.xy.	$s.s.y^2$
Total	139	3132.98	1323.83	3105.98
Between herds	16	1059.63	753.71	1092.16
Within herds	123	2073.35	570.12	2013.82

$$b = 0.275 \pm 0.0856$$

$$h^2 = 0.55 \pm 0.17$$

TABLE 11b
Analysis of error variance: pulse rate

Sources	d.f.	s.s.	M.S.	F-value and Result
Total within herd	123	2013.82		
Due to regression	1	156.77	156.77	10.30**
Deviation	122	1857.05	15.22	

TABLE 12

Intra-herd heritability of respiration rate (age corrected): dam's record repeated with each daughter's record.

TABLE 12a

Analysis of variance: respiration rate (age-corrected)

Sources	d.f.	s.s.x^2	s.p.xy.	s.s.y^2
Total	136	1824.79	692.63	1862.56
Between herds	16	637.88	521.31	527.31
Within herds	120	1186.91	171.52	1335.25

$b = 0.144 \pm 0.0966$

$h^2 = 0.29 \pm 0.19$

TABLE 12b

Analysis of error variance: respiration rate (age-corrected)

Sources	d.f.	s.s.	M.S.	F-value and Result
Total within herd	120	1335.25		
Due to regression	1	24.73	24.73	2.2461(N.S.)
Deviation	119	1310.52	11.01	

TABLE 13

Intra-herd heritability of rectal temperature. Dam's records repeated with each daughter's record.

TABLE 13a

Analysis of variance: rectal temperature

Sources	d.f.	s.s.x^2	s.p.xy	s.s.y^2
Total	133	33.76	7.70	32.36
Between herds	16	14.13	6.14	7.10
Within herds	117	19.63	1.56	25.26

$$b = 0.079 \pm 0.104$$

$$h^2 = 0.16 \pm 0.21$$

TABLE 13b

Analysis of error variance: rectal temperature

Sources	d.f.	s.s.	M.S.	F-value and Result
Total within herd	117	25.26		
Due to regression	1	0.12	0.12	0.5454(N.S.)
Deviation	116	25.14	0.22	

These results show that pulse rate has the highest heritability (0.55 ± 0.17); rectal temperature the lowest (0.16 ± 0.21), respiration rate is intermediate (0.29 ± 0.19). The standard errors of heritability have the reverse order with the highest for rectal temperature, lowest for pulse rate and intermediate for respiration rate.

6.4 DISCUSSION

(i) CORRECTION FACTORS

The value of corrections for any factor is the reduction in the non-genetic variability which the correction produces, because this increases the value of heritability. (See Table 14 - Page 80). Comparison of means and variances of the corrected and uncorrected respiration rates (Table 14) shows that there is some reduction of variance in the corrected data both in dams' and daughters' groups in most herds. But the heritability estimates obtained from corrected and uncorrected respiration rate data (see Table 15) did not differ greatly.

TABLE 15

Intra-herd heritability of respiration rate (uncorrected data): dam's record repeated with each daugher's record.

TABLE 15a

Analysis of variance: respiration rate (uncorrected data)

Sources	d.f.	s.s.x^2	s.p.xy	s.s.y^2
Total	136	1732.0	403.5	2218.3
Between herds	16	332.0	208.0	458.9
Within herds	120	1400.0	195.5	1759.4

$b = 0.1396 \pm 0.1019$

$h^2 = 0.27 \pm 0.20$

TABLE 15b

Analysis of error variance: respiration rate (uncorrected data)

Sources	d.f.	s.s.	M.S.	F-value and Result
Total within herd	120	1759.4		
Due to regression	1	27.3	27.3	1.8699(N.S.)
Deviation	119	1732.1	14.6	

TABLE 14

Comparison of the mean and variance of age-corrected and uncorrected respiration rate data.

Herd No.	1		2		3		4		5		6		7		8		9	
	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr
Uncorrected mean	15.3	17.5	15.6	15.6	14.3	16.3	16.6	17.0	15.0	16.8	11.3	12.5	15.0	20.6	17.2	16.7	12.7	14.0
Corrected mean	16.0	15.6	15.3	16.2	16.3	16.3	14.9	14.2	14.3	15.0	11.0	13.0	16.5	16.3	20.3	19.1	13.4	13.0
Corrected variance	11.7	15.8	17.4	11.2	19.1	12.2	26.4	16.6	3.1	3.8	2.4	6.4	4.9	21.7	14.8	17.9	5.4	3.7
Uncorrected variance	8.6	16.2	25.0	13.2	31.7	12.3	30.2	21.6	3.6	4.6	4.6	8.6	6.2	44.8	29.4	16.5	9.5	4.2

Herd No.	10		11		12		13		14		15		16		17	
	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr	D	Dtr
Uncorrected mean	16.4	15.9	16.0	15.7	16.4	17.0	18.0	18.5	15.4	15.8	13.5	14.3	15.1	16.3	17.3	17.7
Corrected mean	17.3	15.2	16.1	15.8	17.0	17.0	18.7	18.7	15.4	15.5	13.5	14.3	14.8	15.6	19.6	20.6
Corrected variance	9.0	10.6	4.0	5.9	4.8	16.8	9.3	11.7	11.8	3.8	3.7	8.9	4.0	3.8	17.8	9.4
Uncorrected variance	9.8	9.9	4.0	6.0	4.7	16.7	10.8	11.7	11.9	3.8	3.6	9.0	4.5	3.3	22.5	17.7

On the basis of the reduction in the variance in both dams' and daughters' groups and slightly higher heritability from corrected respiration rate data, it could be said that correction factors had been reasonably effective.

(ii) HERITABILITY

Comparison of the heritability estimates of the present study and that of Seath (1947) and of the corresponding climatic conditions, is shown in Table 16.

TABLE 16

Comparison of the heritability estimates of the physiological variables, estimated in hot and cold environments.

		Seath		Author
Temperature range (°F)		1945	1946	
		86 - 93	87 - 91	58 - 76
Temperature mean (°F)		89	89	66
Numbers of cows used		52	68	274
Method used		Sire-progeny differences.		Regression of daughters on dams
Heritability	Pulse rate	-	-	0.55
	Respiration rate	0.766	0.843	0.29
	Rectal temperature	0.151	0.309	0.16

(a) Rectal temperature

The heritability estimate of rectal temperature is not reliable, in fact it was not clearly shown to be above zero. The high value for the standard error of heritability (0.16 $\pm$ 0.21) indicates that a large amount of sampling variance was involved.

Table 16 shows that the heritability estimate for rectal temperature is very similar to one reported by Seath (1947) for the year 1945 and is about half the value reported for 1946 by the same author. Because of the low variability observed in rectal temperature in the present study, such a low heritability estimate was quite expected. The factors that caused higher heritability (0.31) of rectal temperature in the year 1946 than the corresponding value in the year 1945 with the same mean air temperature (89°F) in both years, could not be explained on the basis of the results reported by Seath (1947). However, it is suspected that in the year 1945 the cows under observation were under less heat stress. This may be because of high wind or rain, or any factors causing less heat production or absorption, or greater heat dissipation from the cows than in 1946, thus lowering the variability and resulting in lower values for heritability. Had the cows in the present study been subject to higher atmospheric temperature, this author suspects that the value of the heritability would have been increased, due to increased variability resulting from a higher temperature. Unlike Seath (1947), heritability estimated is greater than the corresponding repeatability when the entire data was used (0.16 vs. 0.03). However, when repeatability estimates of individual herds were compared, four of the six herds had higher repeatability values, as expected.

(b) Respiration rate

The size of the standard error (0.29 ± 0.19) of heritability indicates that a large amount of sampling error was involved, but less than in the case of rectal temperature. The heritability estimate is probably unreliable. The heritability of respiration rate (0.29) was much smaller than those reported for the years 1945 and 1946 (see Table 16) by Seath (1947). Unlike Seath's results, the value of repeatability as expected, was higher than that for heritability (0.32 vs. 0.28).

(c) Pulse Rate

The heritability of pulse rate, not previously reported, was the highest (0.55 ± 0.17) of all the physiological variables studied. The standard error, at less than 1/3 the value for heritability, indicates that this value is significant, and that little sampling error was involved in the estimations. Heritability of pulse rate is much higher than the corresponding repeatability estimates (0.20) when the entire data were used, but it is lower than that for herd No. 5 whose value is (0.62).

SUMMARY

Data collected from 17 herds were used to estimate the heritability of the physiological variables. Age correction factors for respiration rate were calculated from the data at hand. Heritability of the physiological variables, estimated as twice the intra-herd regression of daughters on dams, are as follows:

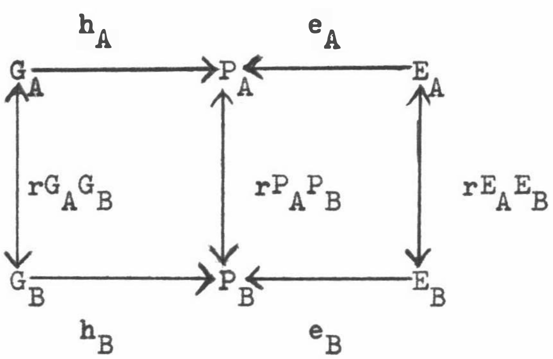
pulse rate	0.55 ± 0.17
respiration rate (uncorrected)	0.27 ± 0.20
respiration rate (age-corrected)	0.29 ± 0.19
rectal temperature	0.16 ± 0.21

CHAPTER VII

PHENOTYPIC AND GENETIC CORRELATIONS BETWEEN THE PHYSIOLOGICAL VARIABLES

7.1 INTRODUCTION

The phenotypic correlation between two characters is the observed association between them, measured on the same animal. How this observed association is made up of genetic correlations (correlations between breeding values) and environmental correlations (correlations of the environmental deviations plus non-additive genetic deviations) is shown diagramatically as follows:



where, rP_AP_B = phenotypic correlation between characters A and B of an animal;

P_A and P_B = phenotypes of A and B respectively;

G_A and G_B = genotypes of A and B respectively;

h_A and h_B = square root of heritability of characters A and B;

rG_AG_B = genetic correlations between A and B;

E_A and E_B = environmental components associated with A and B respectively;

e_A and e_B = contribution of E_A and E_B to characters A and B respectively; and

rE_AE_B = correlations between the environmental components of A and B characters.

The diagram shows that the phenotype of a given character (A) is determined by both its genotype (G_A) and its environment (E_A). These are connected to A by paths h_A and e_A. Character B similarly has genetic and environmental components. Phenotypic correlation between characters A and B in a given individual may arise either because they are genetically correlated (i.e. pleiotropy, etc.), or simply because they developed in a common environment, or both.

The same fact can be shown from the following formula:

$$rP_AP_B = \frac{COV.AB}{\sigma A.\sigma B}$$

$$= \frac{COV.\ G_{AB} + COV.E_{AB}}{\sigma A\ .\ \sigma B}$$

$$= h_Ah_B \cdot \frac{COV.G_{AB}}{\sigma G_A.\sigma G_B} + e_Ae_B \cdot \frac{COV.E_{AB}}{\sigma E_A.\sigma E_B}$$

$$= h_Ah_B \cdot rG_AG_B + e_Ae_B \cdot rE_AE_B$$

where, COV.AB = phenotypic covariance of characters A and B;

σA and σB = phenotypic standard deviations of characters A and B;

$COV.G_{AB}$ = genetic covariance of characters A and B;

$COV.E_{AB}$ = environmental covariance of characters A and B;

σG_A and σG_B = genetic standard deviations of characters A and B; and

σE_A and σE_B = environmental standard deviations of characters A and B.

All other abbreviations are as used to explain the previous diagram.

As the methods of determining the genetic and phenotypic correlations used in the present study have been described in appropriate places, it is worthwhile noting here that though the phenotypic correlation between two characters includes genetic correlation between them, the magnitude or even the sign of the latter cannot be determined from the former, mainly because, as we have already seen, genetic and environmental covariances are confounded in such estimations. Therefore, a different method is used to determine the genetic correlations between characters. This involves the determination of covariance of a trait 'A' in individuals with another trait 'B' in their relatives, when the environment of the population is made random for all its members. Falconer (1960) has described different methods used to estimate the genetic correlations and Hazel (1943), Hazel et al. (1943), Reeve (1953) and Jerome et al. (1956) have discussed the various aspects of such genetic correlations.

7.2 COMMON MATERIALS

Data on pulse rate, respiration rate (corrected for age) and rectal temperature, recorded on 129 dam - daughter pairs from 16 herds, provided common material for the estimation of phenotypic and genetic correlations.

7.3 PHENOTYPIC CORRELATIONS BETWEEN THE PHYSIOLOGICAL VARIABLES

(i) METHOD

Using the usual formula: $r_{PR} = \frac{COV.PR}{\sqrt{\sigma^2 P . \sigma^2 R}}$

where, r_{PR} = correlation between pulse rate (P) and respiration rate (R);

COV.PR = covariance of pulse rate and respiration rate; and

$\sigma^2 P$ and $\sigma^2 R$ = variance of pulse rate and respiration rate;

phenotypic correlations were calculated on a within-herd basis for dams' and daughters' groups separately. Sums of squares and cross-products for the analyses of variance and covariance were calculated according to the method suggested by Snedecor (1946). The method for these estimations is shown in Appendix 6.

The test of the hypothesis, r = 0, was done by using the table of probability given by Fisher (1925).

(ii) RESULTS

The analyses of variance and covariance for dams' and daughters' groups are shown separately in Appendix 6. The correlation coefficients and tests of significance for these groups are shown in Table 17.

TABLE 17

Phenotypic correlations (within herds) between the physiological variables

	Correlation Coefficients	
Comparisons	Dams	Daughters
Pulse rate X respiration rate	0.34**	0.20*
Pulse rate X rectal temperature	0.19*	0.12(N.S.)
Respiration rate X rectal temperature	0.17*	0.19*

* = significant at 5%
** = significant at 1%

The results show the following:

(a) all these correlation coefficients have positive signs;

(b) all coefficients, except between pulse rate and rectal temperature of the daughters' group, are statistically significant, with a highly significant value for the coefficient between pulse rate and respiration rate of the dams' group; and

(c) in both groups the correlation coefficients between pulse rate and respiration rate are highest. Correlation between pulse rate and rectal temperature was approximately 1½ times greater for the dams' group than the corresponding value for the daughters' group, and between respiration rate and rectal temperature these values were similar for both groups.

7.4 DISCUSSION

TABLE 18 (see page 91)

Comparing these results with those reported previously, it appears (see Table 18) that the value for the correlation coefficient for pulse rate and respiration rate of dams' group is similar to the value obtained by Asker *et al*. (1952) and is smaller than the results reported by Quartermain (1959) and Patchell (1951).

The value of the correlation coefficient between pulse rate and rectal temperature of dams' group was in line with the result of Atmadilaga (1959) for Garti and Holstein breeds, when 10 a.m. readings were used in the computation, but is much smaller when only his 3 p.m. readings were used. This writer's estimate is also smaller than the result reported by the same author for the Bali breed when 10 a.m. readings were used and is greater than his result from 3 p.m. readings.

The value of the correlation coefficient between respiration rate and rectal temperature is smaller than corresponding values reported by Atmadilaga (1959) for all the breeds he studied, except for his 10 a.m. observations on the Garti breed, which value was smaller than the estimate obtained in this study.

On the basis of comparisons made, it appears that the values of such correlation co-efficients are smaller under low temperatures than under higher temperatures. Much higher values reported by Patchell (1951) and Quartermain (1959), under environmental conditions similar to this study, could be because of the small number of animals involved and/or the different experimental design used.

On the basis of the results obtained in this study it could

TABLE 18

Comparison of the phenotypic correlations between the physiological variables, estimated under various climatic conditions.

Authors	Present study		Quartermain (1959)	Patchell (1951	Asker et al. (1952)	Atmadilaga (1959)					
Breeds	Jersey		Jersey	Jersey	Egyptian	Garti		Bali		Holstein	
No. of animals	129	129	6	12	11	14		50		10	
Air Temp. Range (°F)	58.5 - 76.0		56.0 - 79.8	36.0-67.2	-	10am	3pm	10am	3pm	10am	3pm
Air Temp. Mean (°F)	66.3		-	-	94.5	89	95	86	86	90	93
Comparisons	Dam	Dtr.									
Pulse rate x respiration rate	0.345	0.199	0.535	0.439	0.323	-	-	-	-	-	-
Pulse rate x rectal temperature	0.188	0.124	-	-	-	0.200	0.400	0.392	0.076	0.206	0.667
Respiration rate x rectal temperature	0.173	0.194	0.531	0.359	0.310	-0.214	0.784	0.432	0.301	0.335	0.353

be said that, under the conditions prevailing during the observational period, a change in any of these physiological variables would be related to a change in the same direction in the other variables. However, the magnitude of such a change would depend on the strength of correlation between them.

This comparison of reports also shows that the strength of associations between the physiological variables were influenced by factors such as breed, age, climatic conditions prevailing at the time of observation, period of the day etc.

The present study also reveals a very interesting parallelism between the values for correlation coefficients in dams' group and the heritability estimates of the physiological variables. We have already noted that the heritability of pulse rate was highest, that of respiration rate intermediate, and that for rectal temperature lowest. Accordingly, the value of the correlation between pulse rate and respiration rate was highest, that between pulse rate and rectal temperature was intermediate, and between respiration rate and rectal temperature was lowest. Such similarity was not apparent, in the case of the daughters' group.

SUMMARY

Phenotypic correlations between the physiological variables studied were calculated from observations made on 129 dam - daughter pairs in 16 herds. The values were somewhat variable for all the studies reported and the present estimates are well within this range. Most of the estimates are positive, signifying that the variables measured generally vary in the same direction: e.g., as pulse rate rises, respiration rate and rectal temperature also rise.

CHAPTER VIII

GENETIC CORRELATIONS BETWEEN THE PHYSIOLOGICAL VARIABLES

8.1 METHODS

All methods of estimation of genetic correlations rely on the resemblance between relatives in a manner analogous to the estimation of heritability. The following formula from Hazel (1943) was used to estimate the genetic correlation between the physiological variables. According to the formula:

$$rg = \sqrt{\frac{\frac{1}{2}(rD_PO_R + rD_RO_P)}{rD_PO_P \cdot rD_RO_R}}$$

where, rg = genetic correlation between characters P and R; and

D and O = dam and daughter.

The method involved the calculation of two cross-correlations between P and R measured in both dams and daughters. The arithmetic mean of these cross-correlations was then divided by the square root of the product of the two straight correlations. However, in the present study, the denominator was $\frac{1}{2}$ the product of the square roots of the heritabilities of two characters (P and R), being twice the regression coefficient. This could be shown as follows:

the denominator of Hazel's formula

$$= \sqrt{rD_PO_P \times rD_RO_R}$$

$$= \sqrt{bD_PO_P \times bD_RO_R}$$

$$= \sqrt{\tfrac{1}{2}h^2_P \times \tfrac{1}{2}h^2_R}$$

$$= \sqrt{\tfrac{1}{4}h^2_P \cdot h^2_R}$$

$$= \tfrac{1}{2}h_P \cdot h_R$$

(assuming the dams' group to be an unselected population with regard to these characters, resulting in the same variance for these characters in both groups) where, b = regression coefficient; and

h^2 = heritability.

The test of significance of the genetic correlations was done on the mean cross-correlations in a manner similar to that used for phenotypic correlations.

8.2 RESULTS

The analyses of covariance are shown in Appendix 7, and the within herd cross-correlations calculated, are shown in Table 19.

TABLE 19

Cross-correlations (within herds) between the physiological variables

Dtr \ Dam	Pulse rate	Respiration rate	Rectal temperature
Pulse rate		0.051	0.078
Respiration rate	-0.020		0.123
Rectal temperature	0.002	-0.118	

TABLE 20

Within herd mean cross-correlations and within herd genetic correlations, between the physiological variables.

	Pulse rate	Respiration rate	Rectal temperature
		Mean cross-correlations	
Pulse rate		0.015	0.040
Respiration rate	0.08		0.003
Rectal temperature	0.27	0.02	
	Genetic correlations		

Table 20 shows the mean cross-correlations on the right hand side and genetic correlations on the left. From Table 19 it can be seen that the values of the cross-correlations are very small. The signs are negative where pulse rate was measured in dams and respiration rate in daughters, and when respiration rate was measured in dams and rectal temperatures in daughters. But when pairs of cross-correlations were averaged all mean cross-correlations and genetic correlations were positive (see Table 20). Tests of significance on the mean cross-correlations, showed that the genetic correlations between the physiological variables were not significantly different from zero. However, in comparative terms the genetic correlation involving pulse rate and rectal temperature was the highest (0.27).

8.3 DISCUSSION

The two estimates of the correlation between two traits of dam and daughter in an unselected population should, in theory, provide two independent estimates of the genetic correlations between the traits (Hazel, 1943). There was no evidence to suggest a genetic relationship between the physiological variables, as cross-correlations and mean cross-correlations were extremely close to zero in all cases. No report on genetic relationships between the physiological variables was located in the literature.

Phenotypic correlations, which include genetic correlation also, would be expected to be greater than the corresponding genetic correlations. But, in the present, study genetic correlations between pulse rate and rectal temperature are higher than the corresponding phenotypic correlations (0.27 vs. 0.19 and 0.12). Similar results have been reported in the past from poultry records (Lerner and Cruden, 1948), sheep records (Morley, 1951) and in dairy records (Van Vleck, 1960, and Searle, 1961b). Searle (1961c) showed that such results were expected when the ratio of environmental to genetic correlations was less than the value of $(1 - \sqrt{h^2_P h^2_R}) / \sqrt{(1-h^2_P) \cdot (1 - h^2_R)}$ where h^2_P and h^2_R are the heritabilities of two traits.

SUMMARY

Genetic correlations between the physiological variables were calculated from observations made on 129 dam - daughter pairs in 16 herds. These estimates are positive and statistically non-significant, with the highest value (0.27) for pulse rate x rectal temperature, intermediate (0.08) for pulse rate x respiration rate and lowest (0.02)

for respiration rate x rectal temperature. The only genetic correlation appreciably greater than zero is between pulse rate and rectal temperature (0.27), but because all the mean cross-correlations do not differ significantly from zero, none of the estimates of genetic correlation can be regarded as indicative of a real genetic relationship between the physiological variables.

PART IV

CHAPTER IX

PHENOTYPIC AND GENETIC CORRELATIONS BETWEEN PHYSIOLOGICAL VARIABLES AND PRODUCTIVE VARIABLES

9.1 INTRODUCTION

Rectal temperature (Rhoad, 1944b) and its combination with respiration rate (Benezra, 1954) have been used extensively in the past as criteria for selecting heat-tolerant dairy cattle. The author failed to locate any report on the genetic and phenotypic relationships between the physiological variables and the productive characters, whose improvement is the main purpose of dairy cattle breeding in the tropics. One cannot deny the importance of this knowledge in any rational breeding programme. Does selection of dairy cattle for heat tolerance on the basis of respiration rate, rectal temperature etc., affect productivity in the desired direction, or is there a genetically antagonistic relationship? The present study is an attempt to answer this question.

9.2 MATERIALS

Data on the productive variables (lactation milk and fat yield and milk and fat yield for the month of observation) have already been described in Chapter IV. Corresponding data on the physiological variables (pulse rate, respiration rate and rectal temperature) were used to study genetic and phenotypic relationships between them. The different kinds of data collected and the methods used to collect them have been described in Chapter II. These data provided material for the following investigations.

9.3 METHODS

The effects of non-genetic causes of variance were reduced by doing the calculations on a within-herd basis and correcting for age.

In the case of lactational length, 305 day records were used and when the length of lactation was less than 305, the actual records were used. Records which were abnormally low due to some factor such as sickness, early abortion, accident etc., were not included in the actual calculations.

The methods used in the estimation of the heritability of the productive variables, and phenotypic and the genetic correlations between productive variables and physiological variables, together with the estimation of the standard error of heritability and the tests of significance for phenotypic and genetic correlations, have been described in Chapters VI - VII respectively.

9.4 CORRECTION FOR AGE

(i) LACTATION MILK AND FAT YIELD

The latest age correction factors for lactation fat yield evolved by the Dairy Board (1961) for Jersey cows in the Wellington district, were used to correct for the lactation milk and fat yield. According to this method 20%, 13%, 4% and 8% of the age-corrected herd average were added respectively to the records of 2 years, 3 years, 4 years and 10 years and over age groups to standardize with respect to the Mature Equivalent (5 to 9 years, both inclusive, age group). Age corrected herd averages were calculated according to the following formula (Searle and Henderson, 1959):

$$h = \frac{N\bar{X}}{N - (0.20n_2 + 0.13n_3 + 0.04n_4 + 0.08n_{10})}$$

where, h = age-corrected herd average;

N = number of cows in the herd;

n_2, n_3, n_4 and n_{10} = number of cows in 2 years, 3 years, 4 years, and 10 years and older age groups respectively; and

$\bar{X}$ = actual herd average (uncorrected for age).

In this case N was the actual number of the cows recorded in each herd and $\bar{X}$ was based on the production of these cows only. An example of such a calculation is given in Appendix 8.

(ii) MONTH'S MILK AND FAT YIELD

Although three reports (Searle, 1961a, 1963; Van Vleck and Henderson, 1961) on age correction factors for monthly yield, taking into account stage of lactation, have appeared recently, because of very little variation (see Appendix 3) in the stage of lactation among the cows in the present study at the time of observation, it was considered that only age differences had to be corrected. Before any decision on the type of correction factor was made, the raw data was grouped into 4 age groups as follows:

2 years;

3 years;

4 years; and

5 years and over,

and the effect of age was investigated by the use of the method as described in Chapter V. When the effect of age was statistically significant, the same data were further analysed to investigate the interaction between age group and herd, by using the following basic model for both month's milk and fat yield.

$$Y_{ijk} = \mu + h_i + a_j + (ha)_{ij} + e_{ijk}$$

$i = 1 ----- 8$

$j = 1 ----- 4$

$k = o, 1, 2 -- n_{ij}$ (n_{ij} = no. in the $(ij)^{th}$ subclass)

where, Y_{ijk} is the yield of the k^{th} cow of the j^{th} age group in the i^{th} herd;

μ is a constant common to all cows in the sample;

h_i is a constant common to all the cows in the i^{th} herd;

a_j is a constant common to all the cows in the j^{th} age group;

$(ha)_{ij}$ is the interaction between the i^{th} herd and the j^{th} age group; and

e_{ijk} is an error or residual peculiar to all observations.

h_i, a_j and μ are considered to be unknown constants.

This model is very similar to the one used in the case of respiration rate. The assumptions and methods of analysis in this case are, therefore, as already described. In the present analysis also, μ and h_i are combined and estimation of a_j is the main purpose. The original least squares equations for both month's milk and fat yields are shown in Table 21.

If there are no interactions, constants for the 1st, 2nd and 3rd age groups obtained by solving the simultaneous equations will be the unbiased age correction factors for all the herds to standardize the above age groups with respect to the 4th age group (5 years and older) which had the highest number of cows.

Dairy Board age correction factors used in the case of lactation milk and fat yield were also used to correct the month's milk and fat yield so that these two types of correction factor could be compared.

TABLE 21

Least squares equations for month's milk and fat yields

	μ+(h_1	h_2	h_3	h_4	h_5	h_6	h_7	h_8)	a_1	a_2	a_3	a_4	Milk yield Σy	Fat yield Σy
h_1	12								4	1	0	7	232.0	392.0
h_2		10							2	1	2	5	148.0	258.0
h_3			12						2	3	2	5	208.0	383.0
h_4				11					1	4	1	5	203.0	385.0
h_5					9				4	1	2	2	165.0	278.0
h_6						10			2	2	2	4	196.0	319.0
h_7							6		2	1	1	2	99.0	160.0
h_8								17	5	2	2	8	177.0	441.0
a_1									22	0	0	0	291.0	552.0
a_2									0	15	0	0	241.0	442.0
a_3									0	0	12	0	219.0	390.0
a_4									0	0	0	38	677.0	1232.0

9.5 RESULTS

(i) VARIATION IN MONTH'S MILK AND FAT YIELDS

Table 22 shows that between herd differences are highly significant in the case of milk yield and non-significant in the case of fat yield. Table 22 also shows that the differences between age groups are statistically significant at the 5% level in both milk and fat yield, the former approaching the 1% level.

TABLE 22

Analysis of variance: month's milk and fat yields

Sources	d.f.	S.S.		M.S.		F-Value & result	
		milk	fat	milk	fat	milk	fat
Total	86	2267.1	4769.6				
Between herds	7	931.5	970.4	133.0714	138.6286	4.9357**	1.9974(N.S.)
Between age groups	23	620.1	1596.3	26.9609	69.4043	2.1101*	1.7643*
Error	56	715.5	2202.9	12.7768	39.3375		

* = significant at 5%

** = significant at 1%

TABLE 23

Test for interactions (herd x age group): month's milk and fat yield

Sources	d.f.	S.S.		M.S.		F-value and result	
		milk	fat	milk	fat	milk	fat
Interaction	20	264.979929	767.054585	13.248996	38.3527292	1.03695 (N.S.)	0.9749 (N.S.)
Error	56	715.500000	2202.900000	12.776785	39.337500		

Table 23 shows that the interaction between age group and herd is statistically far below the 5% level of significance in both milk and fat yield. Raw and corrected data on these four productive characters have been deposited in the Dairy Husbandry Department. On this basis, it was decided to use the constants for the 1st, 2nd and 3rd age groups to correct month's milk and fat yield data.

(ii) HERITABILITY

TABLE 24

Intra-herd heritability of lactation milk yield (corrected for age); dam's record repeated with each daughter's record.

TABLE 24a

Analysis of variance: lactation milk yield

Sources	d.f.	sx^2	sxy	sy^2
Total	67	102632.58	40008.35	120369.74
Between herds	9	28517.79	17853.83	21497.53
Within herds	58	74114.79	22154.52	98872.21

$b = 0.2989 \pm 0.147 \quad \therefore \quad h^2 = 0.60 \pm 0.29$

TABLE 24b

Analysis of error variance: lactation milk yield

Sources	d.f.	s.s.	M.S.	F-value and result
Within herd	58	98872.21	1704.6932	
Due to regression	1	6622.44	6622.44	F = 4.0919*
Error	57	92249.77	1618.4170	

* = significant at 5%

TABLE 25

Intra-herd heritability of lactation fat yield (corrected for age); dam's record repeated with each daughter's record.

TABLE 25a

Analysis of variance: lactation fat yield

Sources	sx^2	sxy	sy^2
Total	262560.79	51008.76	298794.05
Between herds	57473.41	33303.33	47571.16
Within herds	205087.38	17705.43	251222.89

$$b = 0.0863 \pm 0.146$$

$$h^2 = 0.17 \pm 0.29$$

TABLE 25b

Analysis of error variance: lactation fat yield

Sources	s.s.	M.S.	F-value and result
Within herd	251222.89	4331.4291	
Due to regression	1528.53	1528.5301	F = 0.3489(N.S.)
Error	249694.36	4380.6027	

TABLE 26

Intra-herd heritability of month's milk yield (corrected for age): dam's record repeated with each daughter's record.

TABLE 26a

Analysis of variance: milk yield

Sources	d.f.	sx^2	sxy	sy^2
Total	46	838.05	531.65	1170.23
Between herds	7	465.76	474.38	567.17
Within herds	39	372.29	57.27	603.06

$b = 0.1538 \pm 0.204$

$h^2 = 0.31 \pm 0.41$

TABLE 26b

Analysis of error variance: month's milk yield

Sources	d.f.	s.s.	M.S.	F-value and result
Within herds	39	603.06	15.4631	
Due to regression	1	8.81	8.8103	F = 0.5633(N.S.)
Error	38	594.25	15.6382	

TABLE 27

Intra-herd heritability of month's fat yield (corrected for age): dam's record repeated with each daughter's record

TABLE 27a

Analysis of variance: month's fat yield

Sources	sx^2	sxy	sy^2
Total	1810.47	562.10	2179.83
Between herds	695.74	461.65	531.13
Within herds	1114.73	100.45	1648.70

$$b = 0.09011 \pm 0.196$$

$$h^2 = 0.18 \pm 0.39$$

TABLE 27b

Analysis of error variance: month's fat yield

Sources	s.s.	M.S.	F-value and result
Within herds	1648.70	42.2744	
Due to regression	9.05	9.0500	F = 0.2097 (N.S.)
Error	1639.65	43.1487	

Analyses of variance, and of error variance, for lactation milk and fat yield and month's milk and fat yield are shown in Tables 24, 25, 26 and 27. These tables also give the corresponding heritability estimates and their standard errors, which are as follows:

lactation milk yield, 0.60 ± 0.29;

lactation fat yield, 0.17 ± 0.29;

month's milk yield, 0.31 ± 0.41; and

month's fat yield, 0.18 ± 0.39.

(iii) PHENOTYPIC CORRELATIONS

The phenotypic correlations between the physiological variables and the productive variables together with the test of significance for both dams' and daughters' groups separately are shown in Table 28.

TABLE 28

Phenotypic correlations (within herd) between the physiological variables and the productive variables.

Comparisons			Dams	Daughters
Pulse rate	x milk	(lactation)	-0.27*	-0.05
" "	x fat	(lactation)	-0.15	0.06
" "	x milk	(month's)	-0.08	0.09
" "	x fat	(month's)	0.22	0.19
Respiration rate	x milk	(lactation)	-0.14	0.06
" "	x fat	(lactation)	-0.04	-0.13
" "	x milk	(month's)	-0.19	0.08
" "	x fat	(month's)	-0.09	0.19
Rectal temperature	x milk	(lactation)	0.03	-0.22
" "	x fat	(lactation)	0.01	-0.13
" "	x milk	(month's)	-0.05	-0.28*
" "	x fat	(month's)	0.06	-0.12

* = significant at 5%

This table shows that except for the correlations between pulse rate and lactation milk yield (-0.27) of dams' group, and between rectal temperature and month's milk yield (-0.28) of daughters' group, both of which are significant at the 5% level, all correlations are not significantly different from zero. Correlations involving pulse rate and respiration rate are mostly negative in the case of the dams' group and positive in the daughters' group. Whereas those involving rectal temperature are positive in the dams' group and negative in the daughters' group. As there is no consistency in these results, all that can be concluded is that the correlations are statistically non-significant in both the dams' and daughters' groups.

(iv) GENETIC CORRELATIONS

The cross-correlations are shown in Table 29, and the mean cross-correlations and genetic correlations in Table 30, the former on the right hand side and the latter on the left hand side.

TABLE 29

Cross-correlation (within herd) between the physiological and productive variables.

Dams \ Daughters		Pulse rate	Respiration rate	Rectal temp.	Lactation Milk yield	Lactation Fat yield	Month's Milk yield	Month's Fat yield
Pulse rate					-0.192	-0.170	-0.086	-0.091
Respiration rate					0.176	-0.033	-0.017	-0.073
Rectal temperature					-0.094	-0.036	0.064	0.008
Lactat.	Milk yield	-0.004	-0.272	-0.056				
Lactat.	Fat yield	-0.026	-0.202	0.12				
Months	Milk yield	0.013	-0.247	-0.012				
Months	Fat yield	0.131						

TABLE 30

Within herd mean cross-correlations and genetic correlations between the physiological variables and the productive variables.

		Pulse rate	Respiration rate	Rectal temp.	Lactation		Months	
					Milk yield	Fat yield	Milk yield	Fat yield
Pulse rate					-0.0981	-0.0982	-0.0366	0.0203
Respiration rate					-0.0480	-0.1175	-0.1320	-0.1082
Rectal temperature					-0.0750	-0.0119	0.0263	0.0655
Lactation	Milk yield	-0.34	-0.23	-0.49				
	Fat yield	-0.64	-1.02	-0.14				
Months	Milk yield	-0.18	-0.87	0.24				
	Fat yield	0.13	-0.95	0.78				
Genetic Correlations					Mean cross-correlations			

The tests of significance performed on the mean cross-correlations showed that none of the genetic correlations is statistically different from zero.

Table 30 also shows that the signs of most of the genetic correlations involving all the physiological variables are negative.

9.6 DISCUSSION

(i) CORRECTION FACTORS

Comparison of the variances of corrected and uncorrected data for all the productive variables shows the real advantage of correction, as seen by reduction in the variance of both dams' and daughters' groups.

TABLE 31

Comparison between the age correction factors used and those of the Dairy Board.

		Month's							
		Milk yield				Fat yield			
	Herd no.	2yr	3yr	4yr	10 yrs and over	2yr	3yr	4yr	10 yrs and over
Correction factors calculated using the Dairy Board's method.	1	4.2	2.8	0.8	1.8	7.3	4.7	1.5	2.9
	2	3.2	2.1	0.6	1.3	5.6	3.7	1.1	2.2
	3	3.7	2.4	0.7	1.5	7.0	4.5	1.4	2.8
	4	4.2	2.8	0.8	1.7	7.7	5.0	1.5	3.0
	5	4.2	2.8	0.8	1.7	6.9	4.5	1.4	2.8
	6	4.4	2.8	0.9	1.8	7.0	4.6	1.4	2.8
	7	3.6	2.3	0.7	1.4	6.0	3.9	1.2	2.4
	8	2.2	1.4	0.4	0.9	5.7	3.7	1.1	2.3
Mean Dairy Board correction factor		3.7	2.4	0.7	1.5	6.6	4.3	1.3	2.6
Correction factor used in this study		4.7	2.4	-0.4		7.1	4.0	-0.6	

The great similarity between the Dairy Board correction factors used for monthly milk and fat yields, and the correction factors used in the present study shows that the Dairy Board correction factors for lactation fat yield, could also be used for correcting monthly milk and fat yields (see Table 31). There was a difference between the mean Dairy Board age correction factor and the one used in the present study, in the 4 years' age group. In the former case, the correction factor was added to, and in the latter case it was subtracted from, the records of this group to standardize them to mature equivalent. This difference may have been caused by the fact that in the case of the Dairy Board the mature group comprised cows from 5 to 9 years inclusive, as opposed to 5 years and older in the present study. The correction factor used for the 4 years' age group for milk (-0.39lb) and fat (-0.60lb) indicated that this group in the present study had the highest productivity in terms of month's milk and fat yield, little different from the mature group (5 years and older) which was used as the standard. In the case of the Dairy Board's method the mature group has the highest productivity, as a result of which correction factors have to be added to the records of all other age groups to standardize them to mature equivalent. Had the present data been grouped in exactly the same way, corresponding age groups would have had a similar level of production and most probably would have had age correction factors very similar to those of the Dairy Board. The reason for not grouping the data in that way was that only a very small percentage of cows were more than 10 years of age.

(ii) HERITABILITY

Heritability estimates for both lactation and month's milk yields (0.60 and 0.31) are higher than the corresponding fat yield estimates (0.17 and 0.18). The size of the standard error of heritability indicates that in all cases, except that of lactation milk yield, a large amount of sampling error was involved and such estimates are not significant. This is not surprising considering the small number of dam - daughter pairs involved in this study. In the case of lactation milk yield, the standard error was approximately half the heritability value. A small increment in these values of heritability might have been expected had the data on lactation milk and fat yields been corrected for variations in length of lactational period among the cows.

(a) Lactation Milk and Fat Yield

Comparing present results with those reported earlier (see Table 32) it seems that this value for lactation milk yield is greater than those reported from field studies (Tyler and Hyatt, 1947; Tabler and Touchberry, 1959; Rendel et al., 1957; Mahadevan, 1951; Fattah El-Shimy, 1957). On the other hand, the estimate for heritability of lactation fat yield is much smaller than those reported by Johansson (1953) and Searle (1963); similar to those reported by Lush and Schultz (1936) and Legates and Lush (1954), and greater than that of Searle (1963).

TABLE 32

Comparison of the heritability coefficients for the productive variables, estimated in the present study, with those reported previously.

Breed and location	Lactation		Monthly		Authors
	Milk yield	Fat yield	Milk yield	Fat yield	
Various dairy breeds (U.S.A.)		0.25(a)			Lush and Schultz (1936)
Ayrshire (U.S.A)	0.31(a)				Taylor and Hyatt (1947)
Holstein-Friesian (U.S.A.)	0.27(a)				Tabler and Touchberry (1959)
Jersey (U.S.A.)		0.20(a)			Legates and Lush (1954)
6 dairy breeds (Great Britain)	0.43(a)				Rendel et al. (1957)
Ayrshire (Great Britain)	0.31(a)				Mahadevan (1951)
Red & White cattle (Sweden)		0.39(a)			Johansson (1953)

Table 32 (continued) Page/116.....

TABLE 32 (continued)

Breed and location	Lactation Milk yield	Lactation Fat yield	Monthly Milk yield	Monthly Fat yield	Authors
Jersey (New Zealand)		0.12(a) 0.36(b)		0.10(a) 0.23-0.28(b)	Searle (1963)
Jersey (New Zealand)	0.60(a)	0.17(a)	0.31(a)	0.18(a)	Present Study

(a) = h^2 calculated from regression of daughters on dams within herd-sire

(b) = h^2 calculated from paternal half-sibs analysis.

(b) Month's Milk and Fat Yield

The heritability value for month's milk yield is similar to those reported for lactation milk yield by Tyler and Hyatt (1947) and Mahadevan (1951). Due to lack of other reports, direct comparison cannot be made.

The heritability of month's fat yield is smaller than the value of Searle (1963), when calculated by paternal half-sibs analysis, and is greater than that reported by the same author when the same data were analysed by linear regression ~~and~~ analysis.

(iii) PHENOTYPIC CORRELATIONS

Statistically significant negative correlations between pulse rate and lactation milk yield in the dams' group, and between rectal temperature and month's milk yield in the daughters' group, indicate that cows with higher production have lower pulse rates and rectal temperatures. All other correlation coefficients are statistically not different from zero suggesting no evidence for any relationship between the other physiological and productive variables.

These results also confirm the well known fact that younger animals are at higher levels of metabolic activity and consequently have higher pulse and respiration rates than older cows under normal environmental conditions. This is suggested by the fact that most of the correlation coefficients, involving pulse rate and respiration rate, are positive in the daughters' group and negative in the dams'. In the case of correlations involving rectal temperature, it appears that with older cows productivity has no relationship, whereas in the case of the daughters' group there is a clear tendency for high producing animals to have lower rectal temperatures and vice versa.

As this is the first investigation into these interrelationships between the physiological and productive variables, conclusions made entirely on the basis of the present investigation should not be over-emphasized until they are confirmed in the future by similar investigations.

(iv) GENETIC CORRELATIONS

Non-significant values for all the mean cross-correlations (highest, 0.12) suggests no evidence for the existence of a real genetic relationship between the physiological and productive variables studied, under the conditions prevailing during observation. High values for many of these genetic correlations are shown in Table 30. These high values resulted from a very low value for heritability estimates of the variables, which were used in the denominator of the formula for genetic correlations, and a large amount of sampling error involved in their estimation.

This study, therefore, gives no indication that the present system of selection in dairy stock on the basis of milk or fat yield affects the physiological variables significantly. However, the tendency would be for selected cows to have lower rectal temperatures, pulse rates and respiration rates, as indicated by negative signs for almost all the mean cross-correlations and genetic correlations.

As the author could not locate in the literature reports on similar investigations, these conclusions are based entirely on the results of the present study and, therefore, may apply only in situations such as were met during this study.

SUMMARY

The following conclusions were drawn from this investigation.

1. The effect of age was significant at the 5% level in both month's milk and fat yield and there were no interactions between age groups and herds in both cases.
2. The age correction factors used in this study were very similar to those of the Dairy Board generally used in the case of lactation fat yield only.
3. The heritability estimates, and their standard errors, for productive characters were as follows:

   lactation milk yield, 0.60 ± 0.29;

   lactation fat yield, 0.17 ± 0.29;

   month's milk yield, 0.31 ± 0.41; and

   month's fat yield, 0.18 ± 0.39.
4. All phenotypic correlation coefficients were not significantly different from zero, except between pulse rate and lactation milk yield (-0.27) of the dams' group and between rectal temperature and month's milk yield (-0.28) of the daughters' group, both being significant at the 5% level.
5. All combinations of genetic correlations between physiological and productive variables were not significantly different from zero.

CHAPTER X

SUMMARY AND CONCLUSIONS

A. Field studies were made on mixed age, lactating Jersey cows (130 dams and 143 daughters) from 18 herds in the district of Manawatu (New Zealand) during the summer of 1963-64 with the following objectives:

(i) to measure the variation present in the physiological variables;

(ii) to estimate the heritability of the physiological variables;

(iii) to estimate phenotypic correlations between the physiological variables;

(iv) to estimate genetic correlations between the physiological variables;

(v) to estimate phenotypic correlations between the physiological variables and the productive variables; and

(vi) to estimate genetic correlations between the physiological variables and the productive variables.

B. PRELIMINARY STUDIES IN THE MASSEY UNIVERSITY HERDS

(i) In the preliminary studies made in the Massey University herds decisions on the following points were reached:

(a) time of recording;

(b) place of recording;

(c) method of handling the cows;

(d) treatment of the cows; and

(e) method of recording.

These decisions were important in developing a reliable recording system to be used to collect data for the main investigations.

(ii) The reliability of the recording system was assessed by taking two consecutive readings on each of the physiological variables. The resulting repeatability estimates were very high in all cases (pulse rate, 0.70 - 0.98; respiration rate, 0.85 - 0.99; rectal temperature, 0.44 - 1.0).

(iii) Repeatability of the physiological variables when observations were taken at a longer interval (1 month) was low (pulse rate, 0.20; respiration rate, 0.32; rectal temperature 0.03) when the entire data were used. A wide range of such estimates was observed (pulse rate, -0.32 to 0.62; respiration rate, -0.15 to 0.61; rectal temperature, -0.27 to ~~0.37~~ 0.67) when individual herds were analysed separately.

C. COMMERCIAL HERD STUDY

(i) The characteristics of stock and their management in these herds in relation to the present study were discussed and raw data were considered for the possible effect of environmental factors on the physiological variables. It was concluded that the only correctable non-genetic environmental factor that could affect the physiological variables was age, the influence of which was investigated.

(ii) Variation in the physiological variables

The raw data on the physiological variables were subjected to statistical analyses to study the variance between herds, between age groups within herds and between cows within herds and age groups. Such analyses of variance, tests of significance and components of variances are presented in tables.

The following main results were obtained:

(a) Between herd differences were highly significant in the case of pulse rate and rectal temperature and non-significant in the case of respiration rate.

(b) Between age group within herd differences were highly significant in the case of respiration rate and non-significant in the case of pulse rate and rectal temperature. There was a highly significant interaction between age groups and herds in the case of respiration rate.

(c) Within-herd variance contributed the highest proportion to total variance in all cases (pulse rate, 72.4%; respiration rate, 95.8%; rectal temperature, 80.7%).

D. MAIN INVESTIGATIONS

(i) Additive age correction factors for respiration rate were calculated from the data at hand. Raw data on pulse rate and rectal temperature and age-corrected data on respiration rate were used in the investigations that followed.

(ii) Heritability Estimates

Heritability values for the physiological variables were estimated as twice the intra-herd regression of daughter on dam, and standard errors of heritability, as twice the standard error of the regression co-efficient.

The estimates of heritability and their standard errors were:

pulse rate, 0.55 ± 0.17;
respiration rate, 0.29 ± 0.19; and
rectal temperature, 0.16 ± 0.21.

(iii) Phenotypic correlations

Phenotypic correlations between the physiological variables were estimated for dams' and daughters' groups separately. All phenotypic correlations, except between pulse rate and rectal temperature of the daughters' group, were statistically significant.

(iv) Genetic correlations

Genetic correlations between the physiological variables estimated in the study gave no evidence for the existence of any genetic relationship between them. Mean cross-correlations were extremely close to zero in all cases.

E. INTER-RELATIONSHIP BETWEEN THE PHYSIOLOGICAL VARIABLES AND THE PRODUCTIVE VARIABLES

10 herds consisting of 68 dam-daughter pairs provided data on lactation milk and fat yields; eight of these herds (47 dam-daughter pairs), data on month's milk and fat yields.

(i) Preliminary investigations on the raw data

The raw data on the productive variables were considered for the possible influence of environmental factors and it was concluded that age was the only correctable non-genetic environmental factor that needed correction when the computations were done on a within-herd basis.

(ii) Age-correction factors

Lactation milk and fat yield were corrected for age by using appropriate age correction factors recently evolved by the New Zealand Dairy Board. Month's milk and fat yields were corrected for age by using the correction factors calculated in this study. To decide on the type of correction factors to be used, very similar steps were followed as in the case of respiration rate.

The corrected data on the productive variables and corresponding corrected data on respiration rate and raw data on pulse rate and rectal temperature were used in the investigations that followed.

(iii) Heritability estimates

Heritability estimates for the productive variables, a necessary step to estimate the genetic correlations, were estimated as already described, with the following results:

lactation milk yield, 0.60 ± 0.29;
lactation fat yield, 0.17 ± 0.29;
month's milk yield, 0.31 ± 0.41; and
month's fat yield, 0.18 ± 0.39.

(iv) Phenotypic correlations

Phenotypic correlations between the physiological variables and the productive variables were estimated for dams' and daughters' groups separately. Correlations between pulse rate and lactation milk yield (-0.27) of dams' group and between rectal temperature and month's milk yield (-0.28) of daughters' group were significant at the 5% level. All other correlations were not statistically different from zero.

(v) Genetic correlations

None of the genetic correlations between physiological and productive variables were statistically different from zero.

F. TABLE OF RESULTS

The climatic conditions during the experimental period and the main results of this study are presented in Table 33.

Practical significances of these results have been discussed in appropriate sections.

TABLE 33

Estimates of repeatability, heritability, phenotypic and genetic correlations

		Pulse rate	Respiration rate	Rectal temperature	Lactation: Milk yield	Lactation: Fat yield	Month's: Milk yield	Month's: Fat yield
Pulse rate	rP Dam		0.345**	0.188*	-0.27*	-0.15	-0.08	0.22
	rP Dtr.		0.199*	0.124	-0.05	0.06	0.09	0.19
	rg		0.08	0.27	-0.34	-0.64	-0.18	0.13
Respiration rate	rP Dam			0.173*	-0.14	-0.04	-0.19	-0.09
	rP Dtr.			0.194*	0.06	-0.13	0.08	0.19
	rg			0.02	-0.23	-1.00	-0.87	-0.95
Rectal temperature	rP Dam				0.03	0.01	-0.05	0.06
	rP Dtr.				-0.22	-0.13	-0.28*	-0.12
	rg				-0.49	-0.14	0.24	0.78
Heritability		0.55 ± 0.17	0.29 ± 0.19	0.16 ± 0.21	0.60 ± 0.29	0.17 ± 0.29	0.31 ± 0.41	0.18 ± 0.39
Repeatability (a)	Dam	0.89 to 0.98	0.88 to 0.98	0.44 to 0.99				
	Dtr.	0.70 to 0.95	0.85 to 0.99	0.90 to 0.996				
Repeatability (b)		0.20	0.32	0.03				
No. Herds		16			10		8	
No. Pairs		129			68		47	

* = significant at 5%
** = significant at 1%
rP = phenotypic correlation
rg = genetic correlation
(a) = repeatability of consecutive observations
(b) = repeatability of records observed at a longer interval.
Dam = dams' group
Dtr. = daughters' group

Air temperature

Range: 58° - 76°F
Mean: 66°F

Relative humidity

Range: 51.7% - 87.2%
Mean: 67.4%

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APPENDIX 1

Example: estimation of the repeatability of the physiological variables.

Herd No. 3

Daughter Group

Pulse rate

Cow No.	1st reading	2nd reading	ΣX_i
1	42	41	83
2	36	38	74
3	31	31	62
4	35	40	75
5	37	38	75
6	40	45	85
	221	233	454

$$\text{c.f.} = \frac{(454)^2}{12} = 17176.3$$

Total s.s. = 17370.0

c.f. = 17176.3

Between cows s.s. = 193.7

$$\text{Between readings s.s.} = \frac{(83)^2 + (74)^2 + \ldots\ldots + (85)^2}{2} = 17342.0$$

Between readings s.s. = 17342.0 - 17176.3 = 165.7

Analysis of variance

Sources	d.f.	s.s.	M.S.	Components of variance
Total	11	193.7		
Between cows	5	165.7	33.14	$\sigma^2_e + 2\sigma^2_s$
Within cows	6	28.0	4.66	σ^2_e

$$\sigma^2_s = \frac{33.14 - 4.66}{2} = 14.24$$

$$R = \frac{\sigma^2_s}{\sigma^2_s + \sigma^2_e} = \frac{14.24}{14.24 + 4.66} = \underline{0.75}$$

where, σ^2_e = error variance

σ^2_s = between cows variance.

APPENDIX 2

Repeatability: analyses of variance for the entire data on the physiological variables.

Sources	d.f	S.S.			M.S.		
		Pulse rate	Resp.rate	Rect.temp.	Pulse rate	Resp.rate	Rect.temp.
Total	101	1987.59	1337.55	32.366			
Between cows	50	1188.09	875.80	20.478	23.76	17.52	0.4096
Within cows	51	799.50	461.75	11.888	15.68	9.05	0.2331

	Pulse rate	Resp.rate	Rect.temp.
σ^2_s	4.04	4.23	0.08825
R	0.2049	0.3185	0.02746

APPENDIX 3

Complete summary of the data collected during the investigation

Herd no.	Number D	Number Dtr	Age (year) $\bar{X}$ D	Age $\bar{X}$ Dtr	Age s^2 D	Age s^2 Dtr	Pulse rate (per 30 seconds) $\bar{X}$ D	Pulse $\bar{X}$ Dtr	Pulse s^2 D	Pulse s^2 Dtr	Respiration rate (per 30 seconds) $\bar{X}$ D	Resp. $\bar{X}$ Dtr	Resp. s^2 D	Resp. s^2 Dtr	Rectal temperature $\bar{X}$ D	Rectal $\bar{X}$ Dtr	Rectal s^2 D	Rectal s^2 Dtr
1	6	6	7.2	2.7	5.4	1.4	36.0	35.0	5.0	12.2	15.0	18.0	9.0	16.0	101.60	101.81	0.064	0.106
2	4	5	6.7	3.4	7.0	2.7	37.0	38.0	13.6	20.2	16.0	16.0	25.0	13.0	100.88	101.82	0.003	0.302
3	5	7	6.0	3.1	3.5	4.5	37.4	38.4	18.7	21.0	15.0	16.0	32.0	12.0	101.24	101.57	0.062	0.070
4	6	7	7.6	2.8	3.8	0.5	41.0	38.0	24.0	39.6	17.0	17.0	30.0	22.0	101.33	101.45	0.120	0.196
5	4	6	6.0	2.5	3.3	0.6	37.2	40.0	51.6	10.0	16.0	17.0	4.0	5.0	101.70	101.73	0.013	0.230
6	4	6	7.2	3.0	5.0	0.8	40.7	38.6	9.0	12.2	12.0	12.5	4.6	8.6	101.35	101.68	0.190	0.178
7	3	3	5.0	2.3	1.0	0.5	38.3	38.6	10.5	8.5	12.0	12.0	4.0	16.0	101.80	101.63	0.010	0.165
8	12	15	7.6	3.3 (14	3.7	1.3	36.0	40.4	24.4	16.0	15.0	20.0	6.2	44.8	101.43	101.90	0.175	0.210
9	8	9	6.7	2.6	4.8	0.7	34.6	34.3	11.7	19.7	18.0	17.0	29.4	16.5	102.08	101.80	0.055	0.282
10	9	9	7.0 (8)	3.2 (8)	2.5	1.1	37.4	36.5	17.7	11.0	13.0	14.0	9.5	4.2	101.51	101.88	0.558	0.143
11	13	14	6.5	3.1	4.7	1.3	42.4	43.4	13.7	9.8	16.0	16.0	9.8	9.9	101.59	101.48	0.110	0.236
12	8	8	5.8	2.1	1.8	0.1	34.7	38.2	12.5	9.4	18.0	18.0	10.8	11.7	101.30	101.52	0.082	0.085
13	11	11	6.9	2.7	6.5	0.8	34.1	35.5	7.4	12.3	15.0	16.0	11.9	3.8	101.05	101.40	0.213	0.288
14	4	4	11.0	7.5	6.0	0.3	30.5	30.7	5.6	23.6	14.0	16.0	3.6	9.0	100.72	101.02	0.083	0.183
15	7	7	7.2	2.5	9.1	0.6	36.2	40.2	10.6	23.3	15.0	16.0	4.5	3.3	101.77	101.95	0.176	0.330
16	9	9	7.5	2.7	5.5	1.0	37.4	37.6	22.0	12.7	17.0	18.0	22.5	17.7	101.90 (6)	102.12 (4)	0.200	0.013
17	9	9	9.4	4.6	1.0	0.2	36.3	36.2	27.0	18.2	16.0	17.0	4.7	16.7	101.73	102.01	0.132	0.206
18	8	8	8.0	4.8	6.0	1.0	38.3	36.8	15.4	21.8	16.0	16.0	4.0	6.0	101.80	101.68	0.450	0.390
Herd average	7.2	7.9	7.18	3.27	4.47	1.07	37.0	37.5	16.6	16.7	15.0	16.0	12.5	13.1	101.48	101.69	0.149	0.200

Herd no.	Lactation: Milk yield* (lbs) $\bar{X}$ D	Milk $\bar{X}$ Dtr	Milk s^2 D	Milk s^2 Dtr	Lactation: Fat yield (lbs) $\bar{X}$ D	Fat $\bar{X}$ Dtr	Fat s^2 D	Fat s^2 Dtr	Lactational length (days) $\bar{X}$ D	Length $\bar{X}$ Dtr	Length s^2 D	Length s^2 Dtr
1	235.0	204.5	1114.4	1676.2	359.6	320.6	647.4	3378.6	283.1	279.1	811.0	1131.4
2	216.5	200.4	339.6	1924.2	331.2	334.6	561.6	6654.7	298.5	278.0	99.0	607.5
3	215.8	200.5	3717.7	3445.3	364.0	341.8	7723.5	9406.5	276.6	280.0	406.3	487.3
4	247.8	209.0	1167.4	793.6	419.3	358.8	3863.8	5987.5	285.1	290.5	424.6	403.6
5	243.0	205.5	3964.0	1462.6	392.0	326.5	6840.6	1479.4	294.0	267.8	161.3	649.4
6	225.7	222.3	937.6	1640.4	329.2	374.5	1061.6	4959.5	283.2	278.6	259.0	444.6
7	225.6	208.0	3537.5	2964.0	362.6	322.0	1194.5	12181.0	281.3	282.0	212.5	637.0
8												
9	211.1	174.6	1570.1	461.0	351.2	310.4	2469.5	1520.5				
10	238.4	206.0	1555.7	4481.8	380.8	310.2	2475.8	7419.5				
11	193.3	181.7 (13)	603.0	2564.4	318.6	309.0 (13)	2424.5	7017.0				
12												
13												
14												
15												
16												
17					385.0	279.5 (6)	1698.2	7954.6				
18					355.1	362.2 (4)	6590.1	1163.0				
Herd average	225.2	201.2	1850.7	2141.3	362.3	326.1	5690.9	5743.4	271.6	279.4	339.0	622.9

Herd no.	Month's: Milk yield (lbs)† $\bar{X}$ D	Milk $\bar{X}$ Dtr	Milk s^2 D	Milk s^2 Dtr	Fat yield (lbs) $\bar{X}$ D	Fat $\bar{X}$ Dtr	Fat s^2 D	Fat s^2 Dtr	Stage of pregnancy (month) $\bar{X}$ D	Preg. $\bar{X}$ Dtr	Preg. s^2 D	Preg. s^2 Dtr	Stage of lactation (month) $\bar{X}$ D	Lact. $\bar{X}$ Dtr	Lact. s^2 D	Lact. s^2 Dtr	Mean air temperature (°F)	Mean relative humidity (%)
1	20.5	18.1	8.2	16.6	35.1	30.1	19.0	25.8	4.3	3.8	0.2	0.2	6.6	6.5	0.2	0.2	73.4	62.8
2	15.7	14.0	1.0	32.5	26.7	25.0	5.0	32.5	4.5	4.5 (4)	1.0	3.6	7.2	6.6	0.3	4.2	68.2	60.0
3	18.0	16.8	21.5	72.2	32.6	31.4	32.2	24.4	3.8	4.2 (5)	1.7	1.7	6.4	6.7	0.2	0.5	71.2	62.4
4	21.2 (5)	16.1 (6)	5.8	7.8	40.0 (5)	30.8 (6)	9.0	22.6	4.5 (4)	4.5	0.3	0.6	6.5 (6)	6.7 (7)	0.2	0.8	70.3	61.3
5	21.0 (3)	17.0	250	9.2	33.0 (3)	29.8	7.0	30.2	4.5	4.3	3.0	0.6	7.5	6.5	3.0	0.2	76.0	51.7
6	19.2	19.8	9.0	13.4	30.5	32.8	33.6	11.8	5.0	4.2 (5	0.0	0.2	6.7	6.5	0.3	1.0	63.0	87.2
7	17.3	15.6	16.5	10.5	28.3	25.0	26.5	28.0	4.3	3.6	0.5	0.5	7.0	7.3	1.0	0.5	61.50	66.5
8																	69.0	58.0
9	12.1	8.8	8.1	2.6	29.5	22.7	75.7	21.5	5.4	5.1	0.7	1.1	7.7	8.0	0.5	0.2	62.0	67.3
10									4.2	4.8	1.7	0.1	7.5	7.6	0.5	0.2	68.2	63.2
11									4.9 (12)	5.0 (11)	0.4	0.0	8.0	8.0 (13)	0.4	0.3	64.0	61.5
12																	68.0	74.6
13																	61.0	80.2
14																	60.0	69.5
15																	58.5	74.6
16																	72.0	70.0
17																	66.0	68.6
18																	61.5	74.5
Herd average	18.1	15.7	11.8	20.6	31.9	28.4	26.0	52.0	4.54	4.40	1.05	1.35	7.11	7.04	0.66	0.81	66.28	67.4

* multiply by 30 to get lactation milk yield

( ) number in bracket indicates the no. of animals involved.

† multiply by 30 to get month's milk yield

APPENDIX 4

Observations of the physiological variables, classified by age, to study the influence of age.

	$\sum y$			n_i	$\sum y^2$			Age groups: 2 - 3 years			n_{ij}	4 - 6 years			n_{ij}	7 years and over			n_{ij}
Herd No.	Pulse rate	Respiration rate	Rectal temperature		Pulse rate	Respiration rate	Rectal temperature	Pulse rate	Respiration rate	Rectal temperature		Pulse rate	Respiration rate	Rectal temperature		Pulse rate	Respiration rate	Rectal temperature	
1	425	197	20.5	12	15145	3373	36.01	174	89	8.7	5	146	62	6.6	4	105	46	5.2	3
2	339	140	12.6	9	12775	2306	20.84	113	42	5.5	3	157	60	5.4	4	69	38	1.7	2
3	456	190	17.2	12	17532	3212	25.64	189	83	8.2	5	198	83	6.9	5	69	24	2.1	2
4	512	222	18.2	13	20552	4072	27.30	234	108	9.3	6	123	44	4.2	3	155	70	4.7	4
5	389	163	17.2	10	15355	2695	30.78	201	86	9.1	5	115	45	4.7	3	73	32	3.4	2
6	395	123	15.5	10	15701	1671	25.75	160	46	7.0	4	149	50	6.3	4	86	27	2.2	2
7	1008	462	42.9	26	39646	9066	75.65	325	192	15.3	8	323	128	13.4	8	360	142	14.2	10
8	586	292	32.9	17	20440	5356	66.67	243	117	12.5	7	206	118	12.6	6	137	57	7.8	4
9	597	214	26.9	16	22483	2944	51.31	185	74	9.1	5	230	79	10.3	6	182	61	7.5	5
10	1160	433	41.5	27	50136	7191	68.27	395	141	12.0	9	516	202	19.9	12	249	90	9.6	6
11	602	254	27.9	16	22920	4102	54.65	-	-	-	0	456	191	22.3	12	146	63	5.6	4
12	653	301	33.7	18	24051	5207	66.15	-	-	-	0	326	153	18.1	9	327	148	15.6	9
13	584	292	22.6	16	21518	5488	33.30	306	148	12.2	8	211	112	7.0	6	67	32	3.4	2
14	767	343	27.0	22	26947	5505	38.80	285	127	11.2	8	307	139	9.7	9	175	77	6.1	5
15	247	111	7.0	8	7591	1579	7.10	-	-	-	0	-	-	-	0	247	111	7.0	8
16	536	220	26.1	14	20780	3508	51.83	234	96	11.0	6	200	76	9.8	5	102	48	5.3	3
17	676	315	19.9 (10)*	18	25666	5835	41.43 (10)*	223	94	4.4 (2)*	6	314	161	8.1 (4)*	8	139	60	7.4	4
Sum	9932	4272	409.6	264	379238	73110	721.48	3267	1443	135.5	85	3977	1703	165.3	104	2688	1126	108.8	75

* ( ) = number of animals involved.

APPENDIX 5

A tabular form of the methods used to calculate age correction factors for respiration rate.

Herd no.	Group 1			Group 2			Group 3			Correction factors	
	X_1	n_1	$\bar{X}_1$	X_2	n_2	$\bar{X}_2$	X_3	n_3	$\bar{X}_3$	$\bar{X}_2 - \bar{X}_1$	$\bar{X}_2 - \bar{X}_3$
										a_1	a_3
1	89	5	17.8	62	4	15.5	46	3	15.3	-2.3	0.2
2	42	3	14.0	60	4	15.0	38	2	19.0	1.0	-4.0
3	83	5	16.6	83	5	16.6	24	2	12.0	0.0	4.6
4	108	6	18.0	44	3	14.7	70	4	17.5	-3.3	-2.8
5	86	5	17.2	45	3	15.0	32	2	16.0	-2.2	-1.0
6	46	4	11.5	50	4	12.5	27	2	13.5	1.0	-1.0
7	192	8	24.0	128	8	16.0	142	10	14.2	-8.0	1.8
8	117	7	16.7	118	6	19.7	57	4	14.2	3.0	5.5
9	74	5	14.8	79	6	13.2	61	5	12.2	-1.6	1.0
10	141	9	15.7	202	12	16.8	90	6	15.0	1.1	1.8
11	-	-	-	191	12	15.9	63	4	15.7	-	0.2
12	-	-	-	153	9	17.0	148	9	16.4	-	0.6
13	148	8	18.5	112	6	18.7	32	2	16.0	0.2	2.7
14	127	8	15.9	139	9	15.4	77	5	15.4	-0.5	0.0
15	-	-	-	-	-	-	111	8	13.9	-	-
16	96	6	16.0	76	5	15.2	48	3	16.0	-0.8	-0.8
17	94	6	15.7	161	8	20.1	60	4	15.0	4.4	5.1

APPENDIX 6

Analysis of covariance for pulse rate, respiration rate (age-corrected) and rectal temperature and methods for estimating phenotypic correlation coefficients.

APPENDIX 6(a)

Dams' Group

Source	Variates	Sums of the squares and products		
		Pulse rate	Respiration rate	Rectal temperature
Total		2946.0	442.9	69.3
Between herds	Pulse rate	1055.6	-43.7	33.7
Within herds		1890.4	485.6	35.6
Total			1576.3	56.3
Between herds	Respiration rate		530.5	31.9
Within herds			1045.8	24.4
Total				31.4
Between herds	Rectal temperature			12.5
Within herds				18.9

Hence, (i) $rPR = \dfrac{485.6}{\sqrt{1890.4 \times 1045.8}} = \underline{\underline{0.345}}$

(ii) $rPT = \dfrac{35.6}{\sqrt{1890.4 \times 18.9}} = \underline{\underline{0.188}}$

(iii) $rRT = \dfrac{24.4}{\sqrt{1048.8 \times 18.9}} = \underline{\underline{0.173}}$

APPENDIX 6(b)

Daughters' Group

Source	Variates	Sums of squares and products		
		Pulse rate	Respiration rate	Rectal Temperature
Total		2951.0	212.1	34.8
Between herds	Pulse rate	1065.0	-95.9	8.4
Within herds		1886.0	308.0	26.4
Total			1593.8	42.4
Between herds	Respiration rate		332.1	8.6
Within herds			1261.7	33.8
Total				30.4
Between herds	Rectal temperature			6.2
Within herds				24.1

Hence, (i) rPR = 0.199

(ii) rPT = 0.123

(iii) rRT = 0.193

APPENDIX 7

Analysis of cross-products used to estimate within herd cross-correlation.

			Sums of cross-products		
			DAUGHTER		
Source	Variates		Pulse rate	Respiration rate	Rectal temperature
Total		DAM		-253.3	-1.0
Between herds	Pulse rate			-221.6	-1.4
Within herds				- 31.7	0.4
Total			81.4		-13.64
Between herds	Respiration rate		9.8		5.05
Within herds			71.5		-18.69
Total			32.3	37.71	
Between herds	Rectal temperature		17.5	18.71	
Within herds			14.8	19.00	

APPENDIX 8

Method used to calculate age-corrected herd average for lactation milk and fat yield.

Example

Let, N (total no. of cows) = 10

$\bar{X}$ (actual herd average) = 370lbs.

n_2 (2-year-old cows) = 2

n_3 (3-year-old cows) = 2

n_4 (4-year-old cows) = 1

n_{10} (cows 10 years and over) = 0

According to formula

h (age-corrected herd average) =

$$\frac{N\bar{X}}{N - (0.20n_2 + 0.13n_3 + 0.04n_4 + 0.08n_{10})}$$

$$= \frac{370 \times 10}{10 - (2 \times 0.20 + 2 \times 0.13 + 0.04 \times 1 + 0)}$$

= 405lbs. (to the nearest lb.)