THE FEEDING OF THYROPROTEIN TO LACTATING DAIRY COWS IN HOT ENVIRONMENTS.

ANDRE L. RAFF

A dissertation in part fulfilment of
the requirements for the degree:
M.Sc. (Tropical Animal Health and Production)
UNIVERSITY OF EDINBURGH
1980.

ACKNOWLEDGEMENTS

I would particularly like to thank Dr. J. I. Richards for his valuable guidance and assistance in the preparation of this dissertation, for access to unpublished data, and for the many hours he set aside on my behalf.

My thanks are also due to:

1) Drs. Ruth Gatenby, P. Lawrence and A. J. Smith for their advice and assistance.

2) Messrs. G. Spence, R. Archibald, I. Campbell and Mrs. J. Edwards for technical assistance.

3) Mr. P. McCluskey and his stockmen.

4) Other members of staff of the Centre for Tropical Veterinary Medicine.

Lastly, special thanks go to my wife, Sue, for her patience, and the care taken in typing.

CONTENTS

I. SOME ABBREVIATIONS USED

Å	-	Angstrom
ad lib	-	*ad libitum*
ACTH	-	Adrenocorticotropic hormone
ARC	-	Animal Research Council
Btu	-	British thermal unit
c	-	centi
cal	-	calorie
d	-	deci
Db	-	Dry bulb (temperature)
DM	-	Dry matter
DMD	-	Dry matter digestibility
DIT	-	Diiodotyrosine
ECG	-	Electrocardiogram
EDTA	-	Ethylenediaminetetra acetic acid
EUN	-	Endogenous urinary nitrogen
FTI	-	Free thyroxine index
g	-	gram
G.H.	-	Growth hormone
HAC	-	Heat absorption capacity
Hb	-	Haemoglobin
Ht	-	Haematocrit
IC	-	Iodinated casein
J	-	Joule
k	-	kilo
l	-	litre
lb	-	pound
m	-	metre or milli
M	-	Mega
M.A.F.F.	-	Ministry of Agriculture, Fisheries and Food
MIT	-	Monoiodotyrosine
mol	-	mole
n	-	nano
PBI	-	Protein bound iodine
PCV	-	Packed cell volume
PVC	-	Polyvinyl chloride
RBC	-	Red blood cell (count)
RH	-	Relative humidity
RQ	-	Respiratory quotient
T_A	-	Ambient temperature
THI	-	Temperature humidity index
T_R	-	Rectal temperature
TRH	-	Thyrotropin releasing hormone
TSH	-	Thyroid stimulating hormone
T_3	-	Triiodothyronine
T_4	-	Thyroxine
VFA	-	Volatile fatty acid
Wb	-	Wet bulb (temperature)
WBC	-	White blood cell (count)
θ	-	Equivalent temperature
μ	-	micro
21	-	Treatment 21
37	-	Treatment 37
37+IC	-	Treatment 37+IC

II. ABSTRACT

A review of the literature revealed that the use of thyroproteins in hot environments was contra-indicated, but that there was little experimental evidence to support this contention. Four lactating Friesian cows were exposed to two 3 week periods of heat stress; 37°C (70 - 90% RH) for six hours by day, and 21°C or less by night. They were fed to requirement, and during one period of heat exposure 7.5g iodinated casein was added daily to each cow's feed. During thyroprotein supplementation milk production was increased by approximately 8% ($p < 0.05$) but severe liveweight losses incurred. On cessation of thyroprotein administration milk production declined, but not to levels significantly below normal ($p > 0.05$), and liveweight was rapidly regained. Although metabolic heat production was increased when feeding thyroprotein ($p < 0.05$), clinical parameters indicated that the cows were not more distressed by the hot environments whether fed thyroprotein or not. Dry matter digestibility investigations were inconclusive, and measurements of sweat rate confirmed that iodinated casein did not exacerbate hyperthermia. Rectal temperatures and respiratory rates were correlated to various heat stress indices, viz. Wet bulb temperature, Bianca's wet bulb: dry bulb equation, Equivalent temperature, Temperature humidity index, and Heat absorption capacity. The best correlation was between dry bulb temperature *per se* and respiratory rate. Routine haematology was carried out, and radioimmunassays of plasma thyroid hormones were done. Heat stress clearly depressed

thyroid function, but feeding iodinated casein elevated plasma T_3 and T_4 levels, as well as the FTI. It was concluded that the use of thyroproteins in hot environments is not necessarily to be condemned, and that field trials feeding low levels of iodinated casein to lactating dairy cows in the tropics would be justified.

III. GENERAL INTRODUCTION.

The productivity of livestock in the tropics is low. In view of the need to provide more protein for human consumption all over the world, this problem has been receiving attention for many years. Animal productionists have identified a number of reasons for the poor performance of good cows in tropical areas. The factors involved include management, nutrition, disease, economics and marketing, sociology and climate.

Our interest centres on climate. In some countries, like Israel, a most impressive dairy industry has been developed in spite of high ambient temperatures. The average yield of Israeli Friesians is 6 600 l/cow/year, (Volcani, 1973). Of course, two corrolaries deserve mention: (a) The climate is hot and dry, and (b) Israel is an exceptional case. But it does show what can be done. The record elsewhere in the tropics is not so good, as consecutive F.A.O. yearbooks show. It is notable that, especially in the humid tropics, the performance of dairy cows is most disappointing. Compared to the ca. 4 000 l/cow/year produced in Britain (Ansell, 1976; Craven & Kilkenny, 1976) the 1 000 - 2 000kg/cow/year reported for tropical areas (Mason, 1975) appears quite poor. Taken at face value this implies that British (temperate region) cows are better than their tropical counterparts. This may be true, but it gives no indication of profitability nor efficiency of production. Never the less, breeds such as the Friesian and Holstein are still among the best dairy cows in temperate or tropical areas. Unfortunately, when high yielding Bos Taurus animals are introduced into areas with high ambient temperatures, their milk production plummets (Williamson & Payne, 1978).

Ways and means of alleviating the effects of an unfavourable environment on animal production are clearly limited by economics. Relief of heat stress in dairy cows still relies on obvious methods like providing shade, wetting animals, and promoting air movement about them. Ansell (1976) and Volcani (1973) have had remarkable success with these methods. Selection of heat tolerant animals often implies the concommitant selection of the lowest yielders. This is counter-productive (Webster, 1976; Turton, 1980).

There is no substitute for good management. That is easy to say, but "good management" is by no means easy to put into practice, even in favourable conditions. Thus the search for simple but effective techniques of improving animal production goes on. Many such techniques are already in use, but there is as yet no cheap and easy way of alleviating the effects of a hot climate. A feed supplement which could do this would be invaluable.

IV. INTRODUCTION

Hot environments and heat stress have long been the subjects of research (Blagden, 1774). More recently Bianca (1965), McDowell (1972), Mount (1979), and Schmidt-Nielsen (1979) are among those who have distinguished themselves as authors in this field. On the other hand, the use of thyroproteins is a relatively new, poorly understood, and obscure subject. A brief introduction is thus warranted.

A thyroprotein is a protein which has thyroxine-like properties or contains thyroxine (McDonald, 1977). Iodinated casein is the most common one but there are other iodinated proteins. According to Pitt Rivers and Randall (1945) the first iodinated proteins were prepared in 1898, but it was only in the late 1930s that iodinated casein emerged as the best of the thyroproteins available. A series of papers in the Journal of Endocrinology 1944-1946 indicates that a team of experts in Britain thoroughly examined iodinated casein at that time. Towards the end of the 1940s and in the 1950s numerous papers were written, many published in the Journal of Dairy Science. It was clear that feeding iodinated casein to dairy cows did increase their milk yield. But there were drawbacks, as will be seen later. Since then relatively few reports seem to have been published, but they do indicate a worldwide spread of the idea. Apart from Britain and the United States, thyroproteins have also been tried in the Soviet Union (Stepanov, Kuchenev and Razmakhin, 1976), Greece (Colaghis, 1969), Yugoslavia (Djurdevic, Jovanovic, Pantio, Velickovic, Sinadinovic and Gembavec, 1974), Sweden (Dyrendahl, 1949), and elsewhere. Also, in many species: Zwolinski, Lipinska and Sindzinski (1971) in horses; Gilette (1977) in Muscovy ducks; Newcomer (1977) in chickens; Weitz, Houtman and Roborgh (1953) in goats - goats often serve as models for cows in lactation trials; and Giraud and Coignet (1954) used iodinated casein for secondary hypogalactia in women.

Why then is iodinated casein not in everyday use? Few reliable investigations into the economic pros and cons of feeding iodinated casein are available. Blaxter (1946), and Thomas, Copland, Keyes, van Horn and Moore (1954) appear the most authoritative. Their generally unfavourable conclusions are likely to be responsible for the decline of interest in thyroproteins. In this context Thomas's N.R.C. report of 1953 also deserves mention since it is quoted verbatim by other authors like McDonald (1977). "The available data suggest no definite economic advantage of feeding thyroprotein to dairy cows under most farm conditions." Maymone and Regenburger (1960) using a few cows and high doses of iodinated casein also concluded that the use of thyroproteins is uneconomical. Stepanov et al, (1976) are the only ones who say that iodinated casein is financially worthwhile, but since they **do not** mention factors like the cost of extra feed, and live weight losses in treated cows, their conclusion can be ignored.

Not all researchers seem convinced that iodinated casein is a complete failure. Schmidt, Deverna and Kilmer (1973) have come up with the promising idea of intermittent feeding of thyroproteins. Richards (1979) thought that iodinated casein could be used to increase milk production by heat stressed dairy cows. Very few other scientific publications dealing with the use of iodinated casein in hot environments could be found. The commercial manufacturers of iodinated casein feed additives obviously feel that they have a worthwhile product. Their advertising pamphlets must be viewed with scepticism, but they do indicate that iodinated casein is actually used by farmers in southern California. Blaxter (1946), McDonald (1977) and others contend that theoretically the use of thyroproteins in hot environments is contra-indicated. A closer look at this concept is thus undertaken.

V. LITERATURE REVIEW

V(a) Heat Stress

The environmental factors which may contribute to a state of heat stress in cattle are listed in most publications on this subject. McDowell (1972) represents them and other factors in the form of spokes in a wheel indicating the interaction between them. The wheel includes temperature, radiation, feed, wind, humidity and rainfall, light, altitude, disease, ectoparasites, endoparasites, soil pH, soil fertility, management, the animal, and man. Ambient temperature (T_A) is the most important environmental factor in heat stress studies (McDowell, 1972; Hancock, 1954). Solar radiation is obviously an important source of heat for animals (Harris, Shrode, Rupel and Leighton, 1960), but cattle can escape this by standing in the shade (Bonsma, Scholtz and Badenhorst, 1940; Holder, 1960). The Metabolisable Energy (ME) system clarifies the role of feed in heat production (M.A.F.F., 1975). Ansell (1976) minimizes the effect of the Heat Increment by feeding cows in the cool early mornings and late afternoons. Air movement becomes important when ambient temperatures are extremely high (or low) or when evaporative cooling comes into play (Bianca, 1965). Because cattle do not rely on sweating like man does (Mount, 1979) there is a tendency to underestimate the effect of humidity. Kibler and Brody (1953), and Thompson, Worstell and Brody (1953) show quite clearly that Relative Humidity (RH) cannot be ignored. Up to

21°C, 10 - 50% of a cow's heat dissipation is by evaporative cooling. At 41°C, 100% of heat loss in cattle is by vaporisation.

V(a) 1 Heat Stress Indices. A number of attempts have been made at quantifying the relative effect of ambient temperature and relative humidity on cattle. The approach has been to compose formulae which would reduce various environmental factors to one workable figure or index. This would then indicate to what degree any given environment was similar to other environments which are known to cause (heat) stress. As yet, no index of heat stress is quite satisfactory (Belding, 1970). A few are listed below:

1) Wet-bulb temperature (Wb) (Mount, 1979, after Haldane* 1905).

2) (Db x 0.35) + (Wb x o.65) where Db = Dry-bulb temperature in °C, and Wb is in °C too (Bianca, 1962)*.

3) Equivalent Temperature (θ) (Mount, 1979).

4) Temperature Humidity Index (THI) (McDowell, 1972) Note that Cargill, Stewart, and Johnson (1962) say that THI is synonymous with Discomfort Index (DI), but use a different formula to derive it. These two must not be confused with the Cumulative Discomfort Index of Tennenbaum, Sohar, Adav, and Gilat (1961).

5) Heat Absorption Capacity (HAC) (Lawrence, 1978)*. Since this is based on unpublished data, a definition of HAC is included: HAC is the amount of heat required (in k cals) to bring one cubic metre of air to a temperature

21°C, 10 - 50% of a cow's heat dissipation is by evaporative cooling. At 41°C, 100% of heat loss in cattle is by vaporisation.

V(a) 1 Heat Stress Indices. A number of attempts have been made at quantifying the relative effect of ambient temperature and relative humidity on cattle. The approach has been to compose formulae which would reduce various environmental factors to one workable figure or index. This would then indicate to what degree any given environment was similar to other environments which are known to cause (heat) stress. As yet, no index of heat stress is quite satisfactory (Belding, 1970). A few are listed below:

1) Wet-bulb temperature (Wb) (Mount, 1979, after Haldane* 1905).

2) (Db x 0.35) + (Wb x 0.65) where Db = Dry-bulb temperature in °C, and Wb is in °C too (Bianca, 1962)*.

3) Equivalent Temperature (Θ) (Mount, 1979).

4) Temperature Humidity Index (THI) (McDowell, 1972) Note that Cargill, Stewart, and Johnson (1962) say that THI is synonymous with Discomfort Index (DI), but use a different formula to derive it. These two must not be confused with the Cumulative Discomfort Index of Tennenbaum, Sohar, Adav, and Gilat (1961).

5) Heat Absorption Capacity (HAC) (Lawrence, 1978)*. Since this is based on unpublished data, a definition of HAC is included: HAC is the amount of heat required (in k cals) to bring one cubic metre of air to a temperature

of 37°C and 100% RH.

* denotes original proposer.

The reason for none of the above or any other indices being universally acceptable is the number and complexity of variable factors which contribute to a state of heat stress (Belding, 1970). Men working in mines and factories formed the background for much of this information. Since laboratory trials with cattle are also limited to temperature, humidity and wind effects, the above mentioned equations are deemed applicable.

V(a) 2 Clinical Effects of Heat Stress. Another aspect which seems unresolved is the question of specifying the point at which an animal may be considered to be heat stressed. Does one rely solely on rectal temperature (T_R), or respiration rate, or pulse, or behaviour, or sweat rate, or electrocardiograms (ECG), a combination of these, or some other index? T_R and respiration rates seem to be the clear favourites (Bianca, 1963). In man pulse rate, blood pressure, and ECGs are of great value (Ganong, 1975). In cattle ECGs are rarely used, relatively little is known about them, and they are expensive and impractical (Dukes, 1970; Blood, Henderson and Radostits, 1979; Ward, 1978). Judgement of behaviour is subjective, and sweat rates fall into the same category as ECGs.

Respiration rate is extremely sensitive to thermoregulatory changes, and can be measured at a distance without disturbing the animal (Kelly, 1976). Rectal temperature is a reliable indicator of body (core) temperature (Bianca, 1965). While respiration rate quickly responds to changes in ambient temperature, rectal temperature shows a delayed response (Bianca, 1965). This can be explained in terms of the basic laws of physics. Convection, conduction, radiation and evaporation are constantly taking place but it takes a while for their effects to be reflected in rectal temperature. The most serious ill-effect of exposure to heat is a displacement of body temperature from the normal range (Bianca, 1963). Cattle production is optimal when normal temperatures are maintained (Schmidt-Nielsen, 1979). Yet, it is interesting that heat tolerant animals like the camel allow their body temperatures to fluctuate 4 - 6°C; the heat of the day is stored and then dissipated by sensible heat loss mechanisms at night so as to conserve water (Schmidt-Nielsen, Schmidt-Nielsen, Jarnum and Houpt, 1957). Since some cattle, donkeys and antelope species seem to do this too (Webster, 1976; Schmidt-Nielsen, 1979; Hutchinson and Mabon, 1954; Bligh and Lampkin, 1965) the significance of a raised rectal temperature is brought into question. This does not mean that the very definition of homeothermy is challenged. It is merely the range of so-called normal body temperatures which may have to be qualified by a time dimension. A rectal temperature of 40°C for 24 hours is not the same as 40°C for 5 hours (Ansell, 1976). Schmidt-Nielsen (1979) says cattle can endure rectal temperatures of 42°C for short periods. Lability of body temperature does however devalue the Iberia Heat Tolerance Test (Rhoad, 1944), the Walking Test (Bonsma, 1949), and the Rainsby Test (Dowling, 1956). In contrast to this, very small changes in T_R can be extremely serious (Blood et al, 1979; Anon, 1979), yet statistically not significant.

V(a) 3 Heat Stress and Production. Many physiological parameters are well correlated with production traits. The rise in T_R as T_A increases is negatively correlated to milk yield (Bianca, 1965). Numerous field studies have confirmed that unfavourable environments depress milk yield, growth, calf viability, and reproduction (Bonsma et al, 1940; Ansell, 1976; Folman, Berman, Herz, Kaim, Rosenberg, Mamen and Gordin, 1980). Specific facts and figures are often published, but it is hard to repeat field trials and get the same results. Thus figures given in Table 1 are derived mainly from climate chamber studies.

Table 1

Ambient Temperatures at which Decreased Milk Yield has been Reported.

Breed	Temperature	Reference
Holsteins & Jerseys	21 - 27°C	Williamson & Payne (1978)
Dairy breeds	24 - 29°C	Bianca (1965)
Brahman	35°C	Bianca (1965)
Holsteins	Diurnal 21 to 38°C	Bianca (1965)
Dairy breeds	18°C, 50% RH	Mount (1979)
Dairy breeds	30°C, 50% RH	Vanjonack & Johnson (1975)
B. taurus	25°C	Webster (1976)

Experts base their opinions on different criteria and derive their facts and figures from different procedures. The apparent disagreement displayed in Table 1 should be seen in this light.

The general concensus is that heat stress also decreases butterfat yields, and solids-not-fat (Bianca, 1965). Occasionally an increase in butterfat percent is reported (Bianca, 1965) but this can often be due to the decrease in milk yield being greater than the decrease in butterfat yield - especially at very high ambient temperatures - which raises the butterfat %.

V(a) 4 <u>Climate Chambers</u>. Virtually all references to climate room studies on cattle can be traced back to work done at the University of Missouri Agricultural Experimental Station. Yeck and Stewart (1959) summarized much of this work, which was a valuable contribution to the literature. They do, however, perpetuate a point which cannot be accepted without discussion: In environments with diurnal fluctuations, the effect on cattle is the same as the effect of a constant ambient temperature equal to the average of the diurnal extremes. For example, 21 - 37°C diurnally has the same effect as a constant 29°C. This has been proved in Missouri, but there is a case against it. Ansell (1976) contends that it is quite acceptable for cattle to reach rectal temperatures of 40.5°C and respiration rates of 120/minute by day, if they can cool off at night. Holder (1960) and Berman (1968) are of the opinion that indoor climate trials do not elicit the same response from cattle as field trials. Tasmanian experiments reported in Bianca's review (1965) (after Rees, 1964) corroborate this.

But climate chambers do have a role to fulfill. Experiments can be more precise, and the exact role of each component of the climate investigated (Williamson and Payne, 1978).

V(a) 5 A Summary of the Effects of a Hot Climate on Cattle. A brief summary of the generally accepted facts follows. This is largely taken from Bianca (1965), McDowell (1972), Mount (1979), Thompson (1976) and Webster (1976). Additional references are given where applicable.

V(a) 5.1 Rectal Temperature normally lies between 37.8 - 39.2°C (Kelly, 1976). It is elevated during hyperthermia. Once T_R begins to rise it can be taken as an indication that other heat dissipating mechanisms are inadequate. $T_R = 41°C$ is very high, and treatment should be instituted (Ansell, 1976). This may include wetting the animal, promoting air movement, and keeping the patient quiet. Tubing cold water into the rumen and the intravenous administration of chilled saline drips may be life saving in acute cases.
(Bianca, 1963; Kibler & Brody, 1953; Yeck & Stewart, 1959; Blood *et al* 1979).

V(a) 5.2 Respiration rate is a sensitive gauge of heat stress. Kelly (1976) gives the normal range as 10 - 30 in- or ex-pirations/minute. In a hot environment it goes up to 120 - 200/min (Bianca, 1965) but thereafter respiration slows and the prognosis becomes very grave.

At $T_A = 15^oC$ the respiratory system is responsible for 54% of evaporative heat loss, but at $T_A = 35^oC$ this is only 38% (McLean and Calvert, 1972). With increased respiration rate in hot environments there is certainly more moisture loss from breathing, but in relation to sweating this is a small increase and explains why its contribution to insensible heat loss decreases to 38%. With hyperpnoea there is a danger of respiratory alkalosis but this is not a hazard to the animal (Bianca and Findlay, 1962). Blood et al, (1979) agree, and explain that the tidal volume is decreased sufficiently to prevent large blood pH shifts.
(Ansell, 1976; Kibler and Brody, 1953).

V(a) 5.3 Pulse rate is not considered a reliable indicator of heat stress. Its response to changes in ambient temperature and RH is inconsistent (Kibler and Brody, 1953). 55-80 beats/min is the normal range; high yielding dairy cows may be 10% faster (Kelly, 1976).

V(a) 5.4 The heart itself is difficult to examine. Auscultation and ECGs may reveal cardiac disturbances during heat stress but their interpretation, especially in cattle, is not easy.
(Dukes, 1970; Kelly, 1976; Ward, 1978).

V(a) 5.5 Haematology is often done on heat stressed cattle, and the following trends are usually found:

Red Blood Cells (RBC) - decreased

Haematocrit (Ht) - decreased

White Blood Cells (WBC) - increased or decreased, but extremely variable. A comparison between the leucocyte types would be more meaningful, especially lymphocytes, neutrophils and eosinophils. It is not unexpected that white cell trends reported in acute heat stress resemble those found in any other stress condition (Schalm, Jaim & Carrol, 1975).

The theory that extracellular fluid volume expands in heat stress, partly at the expense of intracellular fluid with the resultant dilution of erythrocytes (McDowell, Moody, van Soest, Lehmann and Ford, 1969) explains the decreased RBC and Ht reported.

It will be noted that after long periods in a hot environment the animals' blood picture is not dissimilar to that of a hypothyroid case.

(Anon, 1979; Kelly, 1976; Lee, Roussel & Beatty, 1976; Paape, Schultze, Miller & Smith, 1973; Wegner, Schuh, Nelson & Stott, 1976)

V(a) 5.6 Blood glucocorticoids initially rise on exposure to high T_A (four fold increase reported by Abilay, Mitra & Johnson, 1975), but later (48 hrs) drop back to normal or below.

(Alvarez & Johnson, 1973; Lee *et al*, 1976; Thompson, Johnston, Breidenstein, Guidry, Banarjee & Burnett, 1963; Trenkle, 1978).

V(a) 5.7 Catecholamines like adrenaline (= epinephrine) and noradrenaline (= norepinephrine) are involved in any alarm reaction. This is found in heat stress too. Even after 24 days, when the "shock" of the hot environment should have been over, some high catecholamine levels (100% above normal) are found (Alvarez & Johnson, 1973; Alvarez, Robertson, Hahn, Yousef & Johnson, 1967).

V(a) 5.8 Growth Hormone (G.H.) values in blood are low during chronic heat stress. This has often been investigated because of the role of G.H. in animal production. (Bines & Hart, 1978; Machlin, 1973; Mitra, Christison & Johnson, 1972; Trenkle, 1978)

V(a) 5.9 Thyroid function is decreased in heat stress (Thompson *et al*, 1963). This is such a well recognised phenomenon that Magdub, Khoja, Ganaba and Johnson (1980) have investigated the value of thyroid hormone assays as indicators of heat stress. See section V(b).

V(a) 5.10 Behaviour is clearly affected by environment. In the heat of the day cattle seek shade, become irritable (in response to flies), and prefer to stand. Huddling is a well documented paradox in very hot conditions. (Bonsma *et al*, 1940; Eley, Collier, Bruss, van Horn & Wilcox, 1978)

V(a) 5.11 Appetite is poor in hot weather, largely as a result of thyroid depression. Poor production in hot environments is largely accounted for by low feed intake (Hancock, 1954; Johnston, 1958; Wayman, Johnson, Merilan & Berry, 1962). Placing refused feed into the rumen, through a fistula or cannula, does not then increase metabolic rate (Johnson, Wayman, Kibler, Ragsdale, Berry & Merilan, 1961), although there may be hormonal changes (Webster, 1976). Theoretically there must be more heat produced when more food is consumed even if not at a higher rate. This has been verified (Blaxter & Wainman, 1961), and Hancock (1954) goes on to suggest that due to the amount of feed consumed by lactating dairy cows heat emission is one of their most serious problems. A high yielding dairy cow produces more heat than any other bovine (Webster, 1976). 1 lb of milk produced means that a 1 000 lb cow generates an extra 16 Btu metabolic heat/ hour (Yeck & Stewart, 1959). That is 1kg of milk from a 450kg cow causes an extra 37kJ/hour to be generated.

The heat produced in digestion of poor quality roughage is more than that from good quality concentrates (M.A.F.F., 1975). This is as a result of a relative increase in rumen acetic acid. It is evident from the literature that high ambient temperatures depress total and individual volatile fatty acid (VFA) concentrations in rumen fluid, but there is a variable effect on the relative proportions of the individual VFAs (Evans, 1975). Weldy, McDowell, van Soest & Bond (1964) showed that the decline in acetic acid was greater than in propionic acid. This could contribute to the decrease in butterfat (Annison, 1976) reported when T_A rises. However, Weldy _et_ _al_ (1964) could not specifically attribute their results to climate. Changes in feed quality, and feed and water intake may be largely responsible for rumen VFA changes reported in hot environments (Yousri, 1976).

The issue is further confused by some disagreement as to whether feed digestibility increases or decreases in hot weather. McDowell _et_ _al_ (1969), are among those who believe that digestibility decreases. There is no doubt that the dry matter digestibility of tropical pastures can be very low in the hot season (Osbourn, 1976). However, most publications consulted seem to report that when cattle are exposed to high ambient temperatures the digestibility of the feed increases slightly (Blaxter & Wainman, 1961; Attebery & Johnson, 1969; Bianca, 1965).

V(a) 5.12 _Water intake:_ Contrary to expectations, water intake does not always increase when ambient temperature rises. This is partly due to the decrease in feed intake lowering the animal's water requirement, which sometimes outweighs the increased demand due to evaporative cooling (Bianca, 1965; Yousri, 1976).

V(a) 5.13 _Sweat rates_ are increased in hot climates. The evaporation of 1 l/hr is equivalent to the loss of 600 kcal/hr (= 2.51 MJ/hr) (Belding, 1970). At 32 - 35°C cows lose about 2 lb/hr by evaporation (Bianca, 1965) which means nearly 2.5 MJ/hr is dissipated thus.

At low temperatures evaporative heat loss is insignificant but at an ambient temperature of 35°C it is responsible for 84% of a cow's heat emission. Of this, 38% is from the lungs and so almost 62% is by sweating (McLean & Calvert, 1972). Bos indicus breeds are more efficient sweaters than B. taurus breeds although they only start to rely on sweating at higher temperatures (Kibler & Brody, 1953). Dairy cows are the best sweaters of the B. taurus breeds (Webster, 1976).

V(a) 5.14 Other factors which are decreased in hot environments include blood glucose (Magembe, 1977), insulin (Trenkle, 1978), prolactin (Trenkle, 1978), and blood calcium (Bianca, 1965). Body pH may rise slightly (Bianca & Findlay, 1962). This list is by no means complete.

V(a) 6 Productivity and Hyperthermia: As with all disorders, heat stress can be inapparent, mild, moderate, or severe. It is also divided into acute and chronic phases. "Acute" is inconsistently used in the literature to mean "for a short period", "initially", and/or "severe". "Chronic" may mean "long term", and/or "mild". Various dictionaries give all the above mentioned variations and do not clarify the situation, so care should be exercised when encountering these words in publications. It would be useful to reserve "acute" for "short time", and "chronic" for "long time", as pathologists do.

At first exposure to high temperatures there is a typical shock response (Yousef et al, 1967). The adrenal cortex and medulla, and the sympathetic nervous system are responsible for many of the symptoms seen (Lee et al, 1976).

In fact, the resultant raised metabolic rate (up to a 50% increase - Blood et al, 1979) due to catecholamines, corticosteroids, (Alvarez and Johnson, 1973), the van't Hoff effect, and the increased metabolic cost of breathing (Bianca, 1965) is paradoxical. Later - a matter of hours (Yousef et al, 1967) - it becomes clear that the above response is not coping with the situation. Calorigenic hormones become depressed, metabolic heat production slows, and within a week or more (Yousef et al, 1967) the animal settles into the long term effects of the environment. This is all co-ordinated by the thermoregulatory centre in the hypothalamus (Edwards, 1976; Ganong, 1975; Thompson, 1976).

The chronic situation is the one that bothers animal productionists the most. Milk production, growth and fertility is depressed (Bianca, 1965). Johnston (1958) divides the causes into direct and indirect, and discusses nutrition as the prime indirect factor. If cows are fed good quality rations and at high levels, milk yield depression can be prevented (Johnston, 1958; Vohnhout & Bateman, 1972). Others (Carstairs, 1980; Dudyzev, 1980; Hancock, 1954; Webster, 1976) have reported that extra feed does not restore milk production to normal in heat stressed cows. This is likely, since unfavourable environmental conditions upset hormonal balances in the body, and this according to Webster (1976) is partly responsible for the decrease in milk secretion.

High ambient temperature per se can depress milk production (Wayman, Johnson, Merilan & Berry, 1962). Ansell (1976) states that only 2.7% of the decrease in milk yield was directly as a result of heat.

In discussing metabolic rate, appetite, heat stress, and milk secretion, it becomes evident that the thyroid hormones deserve special mention.

V(b) The Thyroid

V(b) 1 Physiology. Standard text-books like the ones by Ganong (1975), and McDonald (1975), serve as references for this discussion of thyroid function:

The thyroid controls the level of tissue metabolism, is involved in carbohydrate and lipid metabolism, and is critical in normal growth and maturation. It is not essential for life. Hypothyroidism is associated with poor resistance to cold, and mental and physical slowing. Excess thyroid hormones cause body wasting, nervousness, tachycardia, tremor and increased heat production. On a cellular level these effects are due to changes in the phosphorylation reactions in the mitochondria and may rely on increased membrane permeability. The Respiratory Quotient (RQ) is not changed although oxygen consumption is increased. Thyrotropin Releasing Hormone (TRH) is the neurohumoral mediator from the hypothalamus which controls the anterior pituitary (= aden~~p~~ohypophysis), which in turn releases Thyroid Stimulating Hormone (TSH) into the blood and so controls the thyroid gland. Thyroxine (T_4) and triiodothyronine (T_3) have a negative feedback effect on the pituitary and hypothalamus. Cold stimulates TRH release and heat inhibits it.

The thyroid gland traps iodine, and binds it to tyrosine molecules which are linked to form T_3 and T_4. These are stored in the thyroid colloid attached to thyroglobin, which must not be confused with Thyroid Binding Globulin (TBG) which is the major carrier of thyroid hormones in the blood. Virtually all T_3 and T_4 is protein bound (99.7% and 99.95% respectively - Anon, 1976b). The term "thyroid hormone" usually refers to thyroxine because there is about 7 times more free T_4 than free T_3, and in total T_4:T_3 is a ratio of about 40:1 (Anon, 1976b). None the less T_3 is much more potent than T_4 and accounts for about 2/3 of the metabolic activity due to thyroid hormones (Evered, Vice & Clark, 1976). Only the free form is physiologically active. T_4 may be a prohormone being converted to T_3 in peripheral tissues (Anon, 1976b). Figures mentioned above are in man, since publications on human physiology and medicine seem to be more detailed and complete than those pertaining to cattle. In cows the same general principles apply (Dickson, 1970), and Turner (1970) may be consulted for specific figures. It seems that cattle have lower plasma T_3 and T_4 levels, and relatively inactive thyroid glands.

Ever since 1899 when Hertoghe drew attention to the stimulatory role of the thyroid on lactation (Robertson, 1945), dairy scientists have shown an interest therein. Only a few of the many research workers who have investigated this phenomenon have reported that there is no significant relationship between thyroid hormone levels and milk yield, among them is Djurdevic, Milicevic & Krdzalit (1979).

V(b) 2 Measuring Thyroid Function: Previously, measuring thyroid function was not easy. Working on the theory that virtually all the iodine in blood is attached to protein, which is almost entirely thyroid protein, the Protein Bound Iodine (PBI) test was devised. However, it did not indicate the rate of thyroid secretion, hormone disappearance from the blood, hormone activity, amount of unbound active hormone, nor T_3:T_4 ratios (Greig, Boyle & Boyle, 1967). Hence the development of radioimmunoassays which are more specific (Evered et al, 1976; Anon, 1976a). A further step was the introduction of the Free Thyroxine Index (FTI) which is now considered the best general thyroid function test available (Anon, 1976a; Anon, 1976b; Anon, 1978). This has still not eliminated the problem of different values being recorded at different laboratories and it is advisable for every Institute to find its own normal values (Anon, 1976a). Magdub, et al, (1980), who, it will be remembered, investigated T_3 and T_4 values as indicators of heat stress, also reported good correlations between milk T_4 and plasma T_4, and between urine T_4 and plasma T_4. Instead of drawing blood, animal productionists could possibly use milk or urine samples for basic thyroid tests.

V(b) 3 The Thyroid and Milk Secretion. How thyroid hormones promote milk secretion is still not clear. It is true that the indirect effects must be important. Increased metabolic rate, increased feed intake, increased blood flow (to the udder), and more efficient digestion are among the factors suggested by Carroll (1975), and Ganong (1975). There is no apparent reason why the thyroid hormones should not act directly on the udder too. Indeed, mitochondria in mammary cells do respond to thyroxines

(Nadaliyak & Ovcharenko, 1976). Lactose Synthetase in the mammary tissue of mice is controlled by thyroxine (Vonderhaar, 1980). Casein synthesis is however independant of thyroid control (Enami, 1980). Other factors also affect milk secretion, which could be misinterpreted in thyroid studies. In vitro, prolactin was released from pituitary cells in response to TRH (Bogdanove, 1980), and TRH administration in cattle raised plasma T_4, prolactin, and growth hormone levels (Convey, Thomas, Tucker & Gill, 1973; Clark, 1975). Premachandra & Turner (1962) reported that thyroxine caused an increase in plasma G.H. levels.

Since the thyroid does, somehow, promote milk secretion one would expect high yielding cows to have high plasma thyroxine levels. This is not the case. Some investigators (Bines & Hart, 1978) report no significant difference between the thyroid hormone levels of high and low yielding cows. Others, like Magdub, El-Nouty & Johnson (1979), found that high yielding cows had decidedly lower T_3 and T_4 levels than low yielders. As individual animals respond differently to various drugs and hormones (Brander & Pugh, 1971) it is not impossible that the tissues of high yielding cows are more sensitive to T_3 and T_4 than other cows' tissues. This would explain why Blaxter (1945), and others, found high yielding cows more responsive to thyroproteins. Turner (1949) and Tucker & Reece (1961) are of the opinion that low thyroid hormone levels may be a limiting factor to milk production by high yielding cows. Another consideration is the extra heat generated in lactating cows (see Appendix 1) possibly contributing to thyroid suppression.

V(b) 4 Fluctuations in Thyroid Activity. Cyclic changes in thyroid function may be responsible for some of the variations in published thyroid hormone levels. Contrary to Trenkle (1978), diurnal fluctuations have been reported (Scott, Johnson & Hahn, 1976). Seasonal changes have long been recognised (Premachandra & Turner, 1962). Lowest levels are recorded at the warmest times. Thyroid function also changes according to stage of lactation and reproduction. Combining a few reports, the following picture emerges: The thyroxine blood levels of a cow are negatively correlated to milk yield (Hart, Bines & Morant, 1979). T_4 is at its lowest in early lactation when milk yield reaches a peak (Bines & Hart, 1978) and slowly rises as lactation progresses (Vanjonack & Johnson, 1975). If the cow is pregnant these levels may be slightly higher (Vanjonack & Johnson, 1975). Plasma thyroxine concentration is highest at the end of lactation or in dry cows (Bines & Hart, 1978). Towards the end of pregnancy - when dairy cows are usually dry - T_4 levels start to drop again, surge up at parturition, and then continue the decline until the peak of lactation is reached again (Heitzman & Mallison, 1972).

V(b) 5 Heat Stress and Thyroid Hormones. Exposure of cattle to high ambient temperatures depresses thyroid function. Environments causing a rectal temperature elevation of 0.6°C or more result in significant depressions in thyroid activity (Bianca, 1965). There may be an initial rise in PBI but after 60 hours hypothyroidism can be detected (Yousef, Kibler & Johnson, 1967). As ambient temperature rises the metabolism of thyroxine decreases (Yousef & Johnson, 1966), which means that the thyroid gland is secreting even less T_4 th~~e~~an plasma T_4 tests indicate. This may seem incongruous but is in fact quite plausible. The animal's metabolic rate is falling because of low T_3 and T_4 levels, so these very hormones are themselves secreted by the thyroid, metabolised in the liver and excreted by the kidneys (Ganong, 1975) at a slower rate. This also explains why the effective period (or half-life) of thyroid hormones is 4 - 5 days at T_A = 18°C, and 5 - 6 days at T_A = 32°C (Yousef & Johnson, 1966).

The decrease in thyroid secretion due to high ambient temperatures is attributed to a direct effect on the hypothalamus (Ganong, 1975) and cannot be prevented by force feeding (Yousef *et al*, 1967). There is a negative correlation ($p < 0.01$) between T_A and PBI (Boots, Ludwick & Rader, 1970). This is generally accepted. Goret, Johnson & Hahn (1973) found that high ambient temperature raised TSH levels, especially in high yielding cows. This was over 24 hours. Considering that heat depresses thyroid activity through an effect on the hypothalamus, this report of Goret *et al* (1973) can only apply to the acute case where increased thyroid secretion has been recorded (Yousef, Kibler & Johnson, 1967).

V(b) 6 *Thyroid Effects on Metabolism*. Thyroxine and triiodothyronine are potent stimulators of metabolism.

There is also a marked influence on metabolic heat production, as can be seen in Table 2.

Table 2

The Relationship Between Rectal Temperature, Heat Production and Thyroid Function Tests.

Factors			Correlation
Heat production	:	Rectal temperature	r = 0.8185
Thyroxine I^{131} disappearance	:	Rectal temperature	r = 0.9643
PBI	:	Rectal temperature	r = 0.9591
Thyroxine I^{131} disappearance	:	Heat production	r = 0.8717
PBI	:	Heat production	r = 0.8440

From Table 2 it is clearly in the animal's best interest to decrease thyroid activity when high ambient temperatures make heat dissipation difficult. This also reduces production (Webster, 1976). When thyroid hormones are administered, production may be improved; but the animal may also be subjected to unacceptable levels of hyperthermia. This line of thinking is not original (Blaxter, 1946; McDonald, 1975).

V(b) 7 Conclusion: Thyroid hormones play a vital role in successful animal production. In some cases it may be beneficial to supply cows with thyroid supplements. One of these, iodinated casein, is discussed in section V(c).

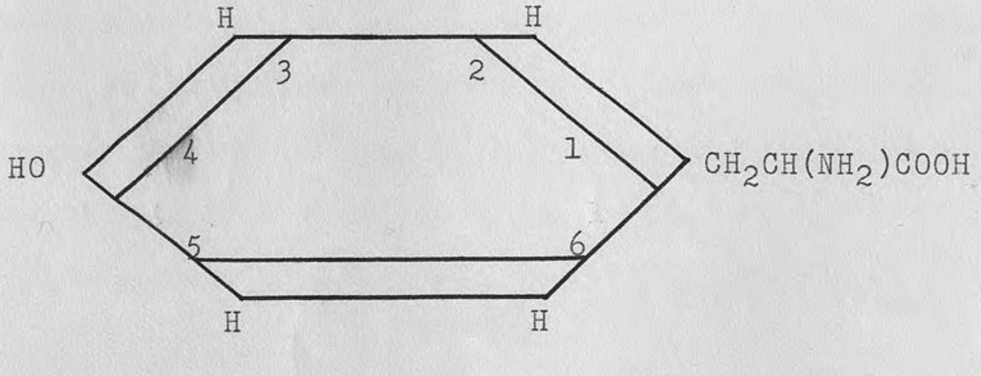
V(c) Thyroproteins

V(c) 1 Iodinated Casein. Consequent to the finding that feeding dried thyroid gland to cows, increased milk secretion (Barcroft, 1944), there was a rush to produce a synthetic product which would elicit the same effect. It had been demonstrated earlier that proteins could be easily iodinated, but it was only in the 1940's that casein emerged as the protein of choice. It was freely available, relatively cheap and once iodinated, was a good source of thyroprotein (Pitt Rivers & Randall, 1945). Reineke & Turner (1943) get credit for much of the early work on iodinated casein, as does Blaxter (1946) who conducted large scale field trials in England and Wales.

V(c) 2 Mechanism of Action. At first scientists had to be content with saying that thyroproteins had a "thyroid-like" action. Subsequent research has shown that the response to thyroprotein feeding does rely almost entirely on the iodinated tyrosine fraction.

Figure 1

Tyrosine (Turner, 1970)



Tyrosine may be iodinated in the 3 and/or 5 position to yield monoiodotyrosine (MIT) or diiodotyrosine (DIT).

MIT + DIT = Triiodothyronine (T_3)

DIT + DIT = Thyroxine (T_4)

6.2g of tyrosine can be produced by the hydrolysis of 100g whole casein (Manson, 1978).

Although Bailey, Bartlett and Folley (1949) thought that there was enough thyroxine in iodinated casein to account for all its effects, this may not be entirely so. Clark (1975) and Mepham (1976b) showed that non-iodinated amino acids could increase milk secretion too, albeit not as much as thyroprotein. Like the thyroid, the mammary gland also absorbs iodine from the blood and may produce diiodotyrosine (DIT) (Ganong, 1975). Whether there is a link between the feeding of certain amino acids and hormone production (in mammary tissue) is unclear. Oldham, Hart and Bines (1978) concluded that there was no evidence to prove that abomasal infusions of certain amino acids increased milk production due to hormonal changes. They did, however, report that abomasal casein administration resulted in significantly raised plasma G.H. levels ($p < 0.05$). Insulin, prolactin and thyroxine levels were unchanged. The role of an iodine supplement alone was investigated by Longimore and Swanson (1971) who concluded that it had no effect on lactation unless the animals' diet was deficient in iodine. In context, though, the small amounts of thyroprotein used (up to 20g) would hardly be enough for the protein <u>per se</u> to make a significant contribution to milk secretion.

A controversy which has only recently been resolved is the matter of how much thyroxine there is in iodinated casein (De Vleeschauwer & Hendrickx, 1949; Bailey et al, 1949; Reineke & Turner, 1943b). Initial contradictions may have been due to the questionable purity of the earlier products (Blaxter, 1945; Turner, 1970). Iodinated casein is now commercially available as "Protamone" (Agri-Tech, Inc., Kansas City) or "Protomone" (Sunset Feed and Grain Co., Buffalo, N.Y.). Yet another "Protamone" is mentioned by Booth, Elvehjem & Hart (1947), made by another firm in Kansas City, and presumably the forerunner of the new "Protamone". The modern product contains 1% thyroxine equivalent (Shaw, Convey, Tucker, Reineke, Thomas and Byrne, 1975). Note that Mischler and Reineke (1970) reported 3.28%, but Anderson (1978) and Turner (1970) confirm that "Protamone" contains 1% thyroxine. Although iodinated casein preparations may contain 10mg/g thyroxine (ie. 1%), only 10% of that is effective in the cow (Turner, 1970). The implication is that the feeding of 1g iodinated casein is the equivalent of the cow herself secreting 1mg thyroxine (Bauman, Hindery & Turner, 1965; Anderson, 1978). The normal thyroxine secretion rate (TSR) of a cow is 1 - 10mg/day (Turner, 1970). (See Appendix 8 for conversions of TSR to plasma T_4 concentrations).

When feeding thyroproteins to dairy cows there seems to be a 2 - 5 day lag period before a response can be seen (Schmidt et al, 1971). Whether this is due to a delay in uptake from the gastro-intestinal tract (20 hours - Turner, 1970), the time needed for ingested thyroxine to break free from its carrier protein in the blood, an adjustment period for cellular (mitochondrial) enzymes, a sluggishness in crossing cell membranes (injected thyroxine takes 20 minutes - Turner, 1970), and/or some other reason, is unknown at this stage. On cessation of thyroprotein feeding there may be a "carry over" effect for a few days. Djurdevic <u>et al</u> (1974) who used 25g iodinated casein/cow twice daily found this period to be seven days. The plasma half-life of thyroxine is 2½ days (Turner, 1970) which explains this continued effect.

Throughout the literature there seem to be contradictions. Many of these are due to the great individual variations found between cows (Blaxter, 1945; Thomas <u>et al</u>, 1954), a variable efficiency of utilisation of thyroproteins (Bailey <u>et al</u>, 1949), irregular absorption from the gastro-intestinal tract (Alexander, 1969) and the widely different methods used in experiments.

V(c) 3 <u>Rate of Supplementation</u>. Early workers used 30g of iodinated casein per cow, ran into problems with palatability due to the iodine, and cut down their dose rates (Blaxter, 1945). For some years 15 - 20g per cow was used (Dyrendahl, 1949; Swanson, 1949; Aitken, Boyne & Chrichton, 1953), but this was based on trial and error systems. Then Premachandra & Turner (1962) seemed to approach the problem in a rather sensible way. They investigated what the normal TSR levels were in summer and winter, found that the latter was higher (by 200%), and calculated summer supplements of iodinated casein so that total plasma thyroxine from all sources never exceded the maximum normal level recorded in winter. Turner (1970) issued a clear and authoratative guide to the use of thyroprotein. To push plasma T_4 levels above normal, all the thyroxine has to be from an exogenous source. This is because of the negative feedback mechanism which suppresses TSH release, so that when there is enough thyroxine in the blood, irrespective of its origin, the thyroid stops secreting hormones. Small doses of iodinated casein won't change plasma T_4 levels because the thyroid would compensate by secreting that much less T_4 itself (Shaw _et_ _al_, 1975; Turner, 1970). Premachandra and Turner (1962) found that feeding low levels of thyroprotein caused definite changes in production figures (milk yield increased by 27.6%, liveweight loss was 9.7%). Others, however, reported that small doses of iodinated casein were ineffective or elicited poor responses - Maymone & Regensburger (1960) using 1 - 2g/100kg LW; Swanson & Knoodt (1949) using less than 5g/cow; Stanley & Morita (1968) using 0.95g/100lb LW (= 0.95g/45kg LW).

Recent recommendations by Anderson (1978) and Turner (1970) suggest that the ideal amount of iodinated casein for a cow is 7 - 12g/cow or rather 10g/1000lb LW (= 1g/45kg LW). This is slightly above the normal TSR of 1 - 10mg discussed earlier in this chapter; it would be especially beneficial to cows in which milk production is inhibited by a low TSR.

V(c) 4 _Milk Production_. It is not seriously disputed that feeding iodinated casein to dairy cows increases milk production. Blaxter (1945) found that the stage of lactation was the most important factor determining the response to thyroproteins. The further from the peak of lactation, the better was the response, except at the very end of lactation. Moore (1958) confirms this. If fed before parturition, iodinated casein had no effect on the subsequent lactation (Swanson & Bearden, 1963). At the peak of lactation some increase in milk production (9.9%) has been recorded (Tucker & Reece, 1961). The termination of lactation cannot be prevented by feeding thyroprotein (Blaxter, 1945); in fact Aitken et al (1953), and Moore (1958) report that lactation periods may be shortened. This does not seem to be the rule with short-term supplementation (Thomas, 1953).

In response to iodinated casein, milk production may change -8 to +61% (Thomas, 1953) but usually about +15 to 30% (McDonald, 1977; Turner, 1970) can be expected. High yielding cows show a greater response than low yielders (Blaxter, 1946) although in percentage terms this is not always so (Thomas, 1953).

V(c) 5 Side-effects. High yielders also seem to suffer from side-effects more often and more severely than low yielders. Blaxter (1946) included over 1 000 cows in his trials. Table 3 is based on his findings. Other workers have also paid attention to side-effects. Aitken et al (1953) found no adverse effect on the health of the cows, although they mention (long term) thyroprotein supplementation

Table 3

Disorders Noted in Cows Fed Iodinated Casein (15 - 20g/cow)

(Blaxter, 1946)

Disorder	% more cases than controls
Liveweight loss	20
Iodinism	7
Nervousness	4
Digestive upset (scours)	5
Heart abnormalities	4
Respiration rate increase	3
Premature loss of winter coat	1.6
Mastitis	Not significant (n.s.)
Lameness	n.s.
Abortion	n.s.

by Van Landigham *et al* in which fertility was impaired. Prolonged use of iodinated casein has also been related to porosity of bones, joint stiffness and "poor digestion" (Dyrendahl, 1949). In retrospect, many of these anomalies may well have been due to the use of high doses (20g/cow) of iodinated casein. Schmidt, Warner, Tyrrell and Hansel(1971) used 20g/cow initially, followed by 10g/cow for most of the lactation and found statistically significant increases in the number of services required per conception ($p < 0.05$) and longer calving intervals ($p < 0.01$). Preliminary results from Edinburgh (Richards & Gatenby, 1980) indicate that plasma thyroxine levels fall precipitously at oestrus. Thus, whether conception rates can be improved if thyroprotein is withheld just before or during oestrus is open to speculation. Schmidt and co-workers (1971) further found no significant changes in "health related data", and no relative decrease in the milk yield in subsequent years of treatment as reported by Thomas & Moore (1951). Thomas & Moore (1951) themselves discount theories of premature udder senescence which Blaxter (1946) suspected. An increase in the incidence of teat injuries was attributed to hyperexcitability (McDonald, 1975). The increase in calf mortality which occurred when dams were fed thyroprotein for long periods was not found when short term supplementations were used (Thomas, 1953). The use of electrocardiography revealed that heart beat irregularities due to iodinated casein were of little consequence (Sykes, Thomas & Moore, 1952).

Accidental over-dosage (up to 60g/cow) caused transient symptoms of iodinism with no serious aftereffects (Blaxter, 1946). Attempting to prevent accidental overfeeding of iodinated casein by including it in a "self-limiting lick" seems impractical because individual cows may require different levels of thyroprotein, at different times. Diluting the supplement in the cows' concentrates or cereals would mean that the amount of thyroprotein offered to a cow depended on the amount of feed she was given. Reliance is therefore placed on the farmer or stockman's proficiency; therefore iodinated casein is only recommended for use on well managed farms where high yielding cows are properly fed (Blaxter, 1946; Thomas, 1953; Turner (by implication), 1970). Yugoslavian workers reported feeding 25g/cow twice daily for seven days and made no mention of untoward aftereffects (Djurdevic, Jovanovic, Pantio, Velickovic, Sinadinovic & Gembacev, 1974).

V(c) 6 Liveweight Changes. Apparently the most vexing of the side-effects of thyroprotein use is liveweight loss. Virtually every publication consulted has reported that feeding iodinated casein to cows resulted in weight loss. Most authors take a positive approach and discuss the value of providing extra feed to the cows. In view of the fact that cows normally gain weight towards the end of lactation (Swan, 1976) the pure maintenance of body weight should be seen as a loss anyway.

Moore (1958) provides a useful resumé of the role of nutrition in preventing liveweight decrease. It is clear that feeding cows more than their calculated requirements definitely minimizes their loss in condition, but does not completely eliminate it (Thomas et al, 1954). This is partly why the use of iodinated casein in heifers is not recommended (Blaxter, 1946). Blaxter (1946) points out that small cows lost more weight than large ones because iodinated casein dosages were not adjusted according to liveweight, and heifers thus received relatively higher doses than other cows. Moreover, heifers have an inherently high metabolic rate which aggravates the problem (Blaxter, 1946).

The relationship between liveweight and fertility is well established (Swan, 1976). Liveweight loss must certainly have contributed in no mean measure to subfertility reported with thyroprotein use (vide supra).

V(c) 7 Economic Considerations. Weight loss has also played a major role in evaluations of the profitability of feeding iodinated casein to dairy cows (Swanson, 1949; Thomas et al, 1954). Although the efficiency of subsequent weight gain is included in the calculations, it is interesting to note that the term "compensatory growth" (Prescott, 1976) is not used. Gardner & Millen (1950) remark on the rapidity of liveweight gain (79 - 119lb gained in 21 days, the equivalent of an average daily gain of 1.7 - 2.6kg) after cessation of thyroprotein treatment, and compare it to the very efficient growth of steers after partial thyroidectomy. Others, for example Blaxter (1945), Swanson (1949) and Premachandra and Turner (1962) have made similar reports. In contrast, Maymone & Regensburger (1960) had cows which did not regain bodyweight for a month after thyroprotein withdrawal from the diet.

Two other aspects are relevant to the financial aspects of using thyroproteins.

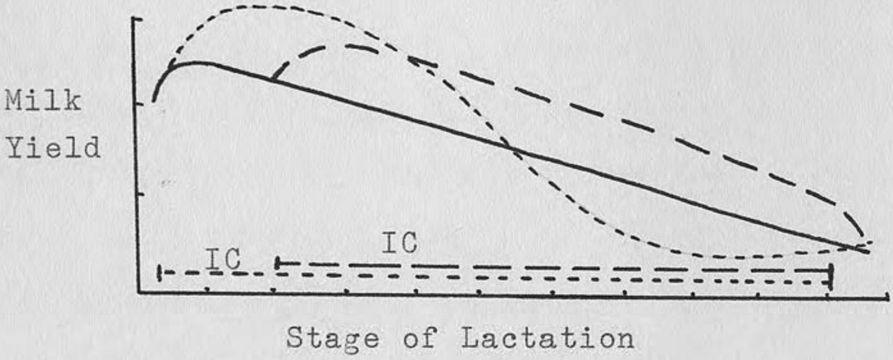
i) Appetite is increased (McDonald, 1977; Thomas, 1953) and additional feed, which may be expensive, should be provided (Blaxter, 1946; Thomas, 1953; Moore, 1958; Turner, 1970).

ii) Total milk yield over the whole lactation is not necessarily increased. Figures 2 (a, b, c) are hypothetical representations of what the literature suggests iodinated casein does to the lactation curve.

Figure 2. Milk Yield Changes in Response to Iodinated Casein (IC)

Normal lactation curves after Woods (1969) ————

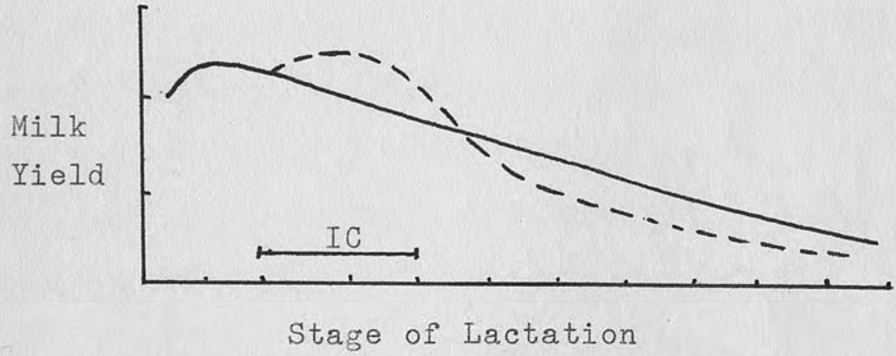
Fig. 2a



Turner (1970) — — — —

Schmidt *et al* (1971) ---------

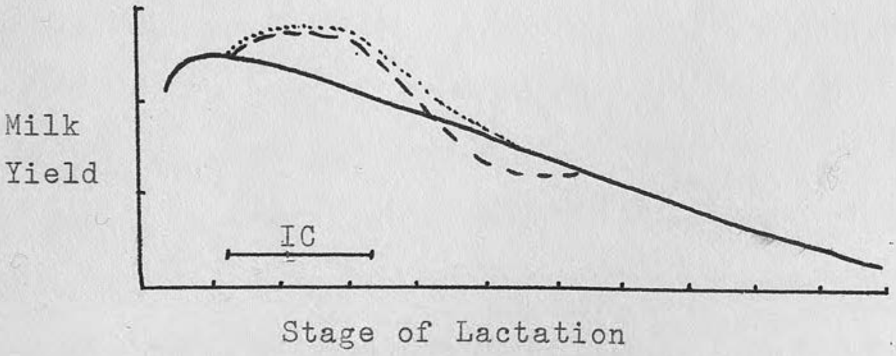
Fig. 2b



Moore (1958), Aitken *et al* (1953)

Thomas *et al* (1954) - - - - --

Fig. 2c



Blaxter (1945), Thomas *et al* (1954) -------

Moore (1958), Thomas *et al* (1954) ....

There are numerous conflicting reports as to whether daily milk yield returns to normal after thyroprotein administration is stopped, whether it goes below normal and stays there, or whether it drops and then rises to normal again. Turner (1970) is the most optimistic of the authorities (see fig. 2a). According to his method withdrawal of iodinated casein occurs shortly before drying off so that it becomes irrelevant what happens thereafter. Unfortunately there is evidence (Schmidt _et al_, 1971) that the response to thyroprotein is not always sustained for as long as Turner (1970) would like. According to Thomas (1953), other workers have found that before thyroprotein withdrawal, milk production had started to decline anyway (after 4 - 5 weeks of treatment) and other parameters indicated that cows were not responding to the thyroid supplement as they had initially. As with liveweight loss, the level of feeding largely determines how the lactation curve will look during and after iodinated casein treatment, although the dose of thyroprotein administered is obviously important too (Thomas _et al_, 1954). The situation can be summarised by saying that extra feed is essential for the prevention of a large drop in milk production when thyroprotein supplementation ceases. Thomas (1953) and Moore (1958) both mention cases where cows were put onto good pastures after thyroprotein supplementation had ceased, and these cows' milk yields declined until they were the same as control cows' yields. Blaxter (1946) showed that feeding extra concentrates (20% above requirement) sometimes had the same effect. In other cases his cows responded as in Fig. 2(c). Moore (1958) confirms this.

Special attention must be drawn to the article by Swan (1976) in which the role of nutrition (without thyroproteins) is discussed. Extra feed can certainly boost milk production, but not nearly to the extent of extra feed plus iodinated casein (Blaxter, 1946; Thomas _et al_, 1954; Moore, 1958; Tucker & Reece, 1961).

V(c) 8 _Termination of Treatment_. In a further attempt to prevent deleterious aftereffects like poor milk production, abrupt cessation has been compared to gradual withdrawal of thyroprotein from the diet. It is generally accepted that graded withdrawal is better (Thomas, 1953) because it gives the thyroid an opportunity to resume normal secretion (Bauman, Hindery & Turner, 1965). Normal thyroid function was found to occur about 3 - 4 weeks after the last thyroprotein treatment (Moore, 1958). In extreme cases, often after high doses of thyroprotein, thyroid suppression may last up to 140 days (Gardner & Millen, 1950), which is not dissimilar to iatrogenic adrenal suppression where ACTH therapy may be of use (Anon, 1979). This may be a good precedent for the administration of TSH when withdrawing iodinated casein from the diet.

Results obtained when the graded withdrawal method is used are variable, and largely dependent on nutrition levels and on the individual cow herself. In general, it is the method of choice, but does not completely prevent milk production dropping below normal. (Blaxter, 1946; Moore, 1958; Thomas et al, 1954).

V(c) 9 Milk Composition. Milk composition is also altered by feeding thyroprotein, but even among the more reliable recent publications, the exact changes seem inconsistent. Generally it seems that butterfat may be increased, milk nitrogen slightly decreased, and solids-not-fat increased (Alexander, 1969; Schmidt et al, 1973; Stanley & Morita, 1967; Turner, 1970).

V(c) 10 Public Health. Milk from cows fed thyroprotein is safe for human consumption (Alexander, 1969; Cowie & Swinburne, 1977; Robertson, 1945).

V(c) 11 Milk Recording Schemes. Fraudulent use of iodinated casein during milk recording or progeny testing, may be detected by examining iodine levels in the faeces (Francois, Balsac, Leroy & Parez, 1953). Turner (1970) feels that the feeding of thyroprotein during milk recording should be permitted on condition it is done openly. This would enable farmers to select cows which respond well to iodinated casein. The desirability of this has yet to be proved.

V(d) Thyroprotein Use in Hot Environments

V(d) 1 Trials with Iodinated Casein in Hot Environments. Early trials like those by Booth, Elvehjem and Hart (1947) involved the use of high doses of relatively impure iodinated casein. When feeding 15g/cow/day over six weeks, these Wisconsin workers found that cows were noticeably stressed if ambient temperatures rose above 90°F (32.2°C). Some feed was refused, and milk production did not reach the levels found in similar trials at lower temperatures.

The findings of Gardner and Millen (1950) were slightly different. Maximum daily temperatures were 30 - 35°C, and doses of 1.33 - 2.0g iodinated casein/45kg LW were used. Up to 32% increases in fat corrected milk (FCM) yields were recorded; liveweight loss was not prevented by supplying extra feed, but was rapidly regained on withdrawal of thyroprotein from the diet. Treated cows had higher rectal temperatures and respiratory rates than controls, but the figures quoted do not suggest that the cows were unduly stressed (T_R = 103.4°F (39.7°C) and respiration rate 77/min), except on very hot days. When ambient temperature reached 96°F (36°C) rectal temperatures went up to 105.1°F (40.6°C) in cows fed thyroprotein and to 102.3°F (39°C) in controls.

In Missouri summer conditions there were no problems with heat dissipation (Premachandra & Turner, 1962). This was when 10g/1 000 lb LW (1g/45kg) iodinated casein was used. In August, which is the hottest month in Missouri, average daily temperatures are about 26°C, with maximums of 45°C being reached (Bryson & Hart, 1974).

Richards (1979) fed 7.5g "Protamone"/500kg LW daily for three weeks. His Friesians were housed in climate chambers and exposed to temperatures of up to 37°C. Iodinated casein caused an increase in milk production, heat production, metabolic rate and plasma thyroid hormones. Considerable liveweight losses occurred, but clinical parameters (T_R, Respiration rate, Pulse) indicated that iodinated casein did not significantly exacerbate heat stress.

In Hawaii, field trials were conducted by Stanley and Morita (1968). They found that "Protamone" given at 1.12g/100lb LW/day (2.5g/100kg/day) for six weeks significantly increased milk yield. Feed consumption was not significantly affected, but liveweight loss was. Using 0.95g/100lb LW (2g/100kg) daily for six months caused no overall improvement in productive performance. If anything, total lactational yields were lower in treated cows than in controls and liveweight losses greater. Feeding thyroprotein caused an increase in rumen propionate and a decrease in butyrate content (Stanley & Morita, 1967); there was no change in acetate. This was contrary to Azimov's findings reported by Stanley & Morita (1968). According to the Meteorological Office (1966) maximum daily temperatures in Hawaii during August are 88°F (31°C), with daily averages of 68 - 82°F (20-28°C).

Kassab, El-Barbary, Mahmoud and El-Santiel (1980) and Magembe (1977) are among those who have administered thyroxine parenterally to lactating cows. The former group worked under field conditions in Egypt, while Magembe's cows were housed in climate chambers. Increased milk production resulted from the thyroxine injections.

V(d) 2 Conclusion. (i) Very few workers have specifically examined the effects of feeding iodinated casein to dairy cows in hot environments. This is illustrated by the fact that some authors do not relate their findings to specific ambient temperatures (Premachandra & Turner, 1962; Stanley & Morita, 1968; Swanson, 1949). In some cases the "heat stress" aspect was incidental to the whole experiment and not studied in any depth (Booth et al, 1947; Swanson, 1949).
(ii) At high ambient temperatures milk production is stimulated by feeding iodinated casein. Liveweight loss is a major problem, but varies in severity according to the plane of nutrition. (Booth et al, 1947; Gardner & Millen, 1950; Premachandra & Turner, 1962; Stanley & Morita, 1968; Richards, 1979).
(iii) The optimum dosage of iodinated casein for cows in hot environments is undecided. Premachandra & Turner (1962), Richards (1979) and Turner (1970) suggest relatively small amounts, about 7.5g/500kg LW. Stanley & Morita (1968) concluded that at least 1g/100 lbs (11g/500kg) was needed to elicit a response, which they said, would probably cause heat stress in cows under Hawaiin conditions.
(iv) Appetite may or may not be affected by adding iodinated casein to the feed. Booth et al (1947) seem to be the only ones who have found appetite suppression.
(v) It is still unknown whether feeding iodinated casein

to heat stressed dairy cows would be the proverbial "last straw" which forces the animals to succumb to hyperthermia. Booth et al (1947) found that it was, but they were using 15g/cow/day. Gardner & Millen (1950) indicated that thyroprotein feeding made no difference to cows in hot weather unless ambient temperatures rose above 36°C. It is unclear whether cows in some other experiments were actually heat stressed (Premachandra & Turner, 1962; Stanley & Morita, 1968; Swanson, 1949).

On the other hand, Richards (1979) found that the clinical symptoms of heat stress were not significantly different whether cows were fed thyroprotein or not at $T_A = 37^{\circ}C$. Booth et al (1947) suggest that this is in line with the findings of Seath et al in Louisiana prior to 1947.

(vi) Finally, it is apparently not known what the actual results would be if cows suffering from hyperthermia were fed thyroproteins. The symptoms may well have been described, but the long term effects on the cow have not. It would be aesthetically unacceptable to inflict unnecessary suffering, but there is some evidence to suggest that cows have a greater thermoregulatory capacity than certain hot environments demand (Schmidt-Nielsen, 1979).

Present knowledge about the use of thyroproteins in hot environments thus seems inadequate.

VI. OBJECTIVES OF THIS STUDY

From the foregoing literature review it is evident that the idea of feeding thyroprotein to dairy cows has been receiving attention for over 30 years. The use of iodinated casein in hot environments has not been recommended because it increases the animal's metabolic rate and heat production. In section V(d) it was shown that this may or may not be a valid argument, but that there is very little evidence either way. In theory, there is also a case supporting the use of thyroproteins when high ambient temperatures cause a decline in milk production. As was indicated in sections V(a) and V(b), thyroid depression contributes to the poor productivity of cattle in hot environments. It was shown in section V(c) that thyroid hormone supplements could increase milk production.

This study aims at providing some data which may help to clarify this indefinite situation. In order to simulate the conditions which dairy cows might encounter in parts of countries like Nigeria, Ghana, Mocambique, Brazil, Venezuela, Costa Rica, Malaysia, India, Thailand, U.S.A., Australia and elsewhere, four lactating Friesian cows were exposed to diurnal temperatures of 21 - 37°C, and RH = 60%+. They were fed a low dose of iodinated casein (7.5g/500kg LW) for three weeks so that some of the effects of thyroprotein on heat stressed cows could be examined.

Determining whether thyroprotein feeding exacerbates or alleviates "heat stress" would be one of the major aims of this experiment. Production parameters are of prime importance to farmers, thus

Milk yields
Liveweight changes and
Food digestibility

were examined.

Animal health is obviously related to production, and this could be monitored by:

Respiration rate measurements,
Rectal temperature and
Pulse rate.

More sophisticated techniques would be needed to detect sub-clinical disorders, and to understand the physiological changes which occurred. This involved the following:

Haematology,
Thyroid hormone assays,
Sweat rate measurements and
Heat production tests.

Since the cows had to be fed to requirement to permit the measurement of metabolic heat production, and facilitate the interpretation of statistical analyses, appetite could not be examined, but the following could:

Refusal of feed,
Water intake and
Behaviour.

In the short time available it would not be possible to include reproductive parameters, nor examine the above mentioned factors at different feeding levels. However, this trial is one of an on-going series at the Centre for

Tropical Veterinary Medicine, University of Edinburgh, and results of this experiment are complemented by those of previous work undertaken here and future work which is planned.

VII. MATERIALS & METHODS

VII(a) Animals

Four Friesian cows were used, two in early lactation (and thus high yielders) and two in late lactation (and thus low yielders).

Table 4

Details of Cows

Cow no.	Age yrs	Previous calving	Lactation no.	LW kg*	MY kg/day
1 (Y46)	4½	3.8.77	2	615	6
3 (Z70)	3½	?.7.78	2	585	17
4 (Y41)	4½	10.9.77**	2	595	7
6 (L729)	4-5	4.7.78	3	490	19.5

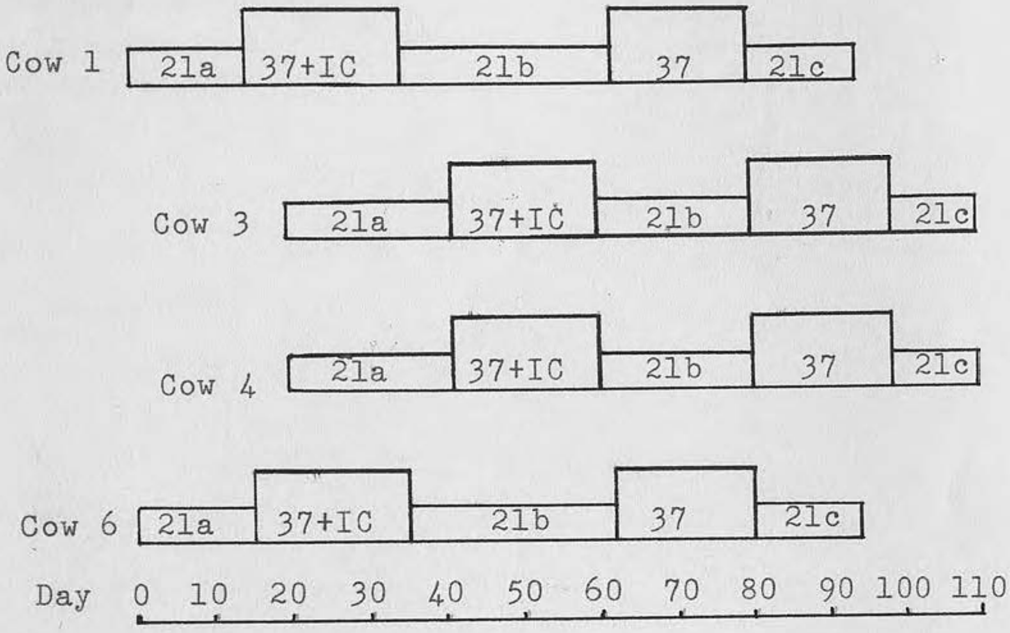
* = at the beginning of the experiment.
LW = liveweight.
MY = milk yield.
** = aborted 12.8.78.

VII(b) Experimental Design

Cows 1 & 6, and 3 & 4 were paired so as to compare a high yielder to a low yielder at every phase of the trial. Fig. 3 shows the order and duration of the experimental procedures.

"Full clinical" examinations (see section VII(k)) were carried out towards the end of each treatment when it was felt that results obtained would indicate the effect of that treamtment. This occurred on day 34, 57,

Figure 3. Experimental Design



Treatment 21 = Climate chamber kept at 21°C from 10h00 to 15h00 daily.

Treatment 37 = Climate chamber kept at 37°C from 10h00 to 15h00 daily.

Treatment 37+IC = Climate chamber kept at 37°C from 10h00 to 15h00 daily, and 7.5g iodinated casein added to the cow's feed.

Table 5 Details of "AA6" Complete Diet

(Seafield Mill, Lothianburn)

Formula (30% Roughage)	%
Barley Straw	30.00
Ext. Groundnut Meal	7.00
Barley	22.25
Wheatfeed	23.25
Molasses	10.00
Urea	1.00
Tallow	1.25
Salt	1.50
Dical. Phosphate	1.50
Sod. Bicarb.	2.00
Lime	0.25

Additives:	g/ton
Advitamix AD$_3$E	200
Cobalt Sulphate	17
Ferrous Sulphate	36
Manganese Sulphate	18
Potassium Iodine	2
Zinc Oxide	20

AD$_3$E (50 000 i.u.A p.g.
(10 000 i.u.D$_3$ p.g.
(52.5 i.u.E p.g.

Analytical Data:	%
Moisture	11.6
Oil	2.7
Protein	14.2
Fibre	16.1

Digestibility Data:	%
Digestibility of Dry Matter	66.60
Digestible Organic Matter in Dry Matter	62.70
Digestibility of Crude Protein	67.40

Metabolizable Energy 9.83 MJ/kg D.M.

71 (cows 1 & 6 only) and 98 (cows 3 & 4 only).

VII(c) Feeding

Cows were offered "Complete diet AA6" (Seafield Mill, Lothianburn, Scotland). Requirements were calculated according to M.A.F.F. (1975), and were not adjusted once the experiment started. Table 5 gives details of the diet, "AA6", while Table 6 shows the amount of feed offered.

Table 6

Feed Offered to Cows (kg).

Cow no.	07h00	16h00	Total/day
1	5	8	13
3	9	10	19
4	6	7	13
6	9.4	10.6	20

Any feed left was weighed and the cows' feed intake recorded.

"Protamone" (Agri-Tech, Inc., Kansas City) was added to the feed at 7.5g/cow every morning during Treatment 37 + IC. This was the dosage recommended by Turner (1970). "Protamone" is in a fine granular form and was simply sprinkled over the feed in the cows' troughs.

VII(d) Housing

The 4 cows were kept in pairs in 2 climate chambers (see Appendix 2). They were tethered individually so that they could lie or stand but could not interfere with each other's feed or water. Each cow could see its partner. Rubber cow-mats (Avon Rubber, Bradford-on-Avon) were supplied to prevent pressure necrosis over the bony prominences ("bed-sores"). Temperature and humidity were controlled automatically. Light was controlled by a time-switch, changing at 07h00 and 19h00. Room conditions were monitored with thermocouples (wet and dry) and wet and dry bulb thermometers.

Since the climate rooms were airtight, the doors were opened at 15h00 and left open until the next morning. This was to prevent mishaps should there be a technical malfunction. Thus cows were actually exposed to temperatures below 21°C at night but well above outside ambient temperatures* because the climate chambers were wholly contained within a larger building. Cows were not exposed to heat over weekends.

VII(e) Water

Drinking water was available <u>ad lib</u>, at all times. This was delivered automatically; meters in the supply lines were read every morning and afternoon.

VII(f) Behaviour

Any grossly abnormal behaviour was noted. On entering the room during periods of hourly observation ("full clinicals" section VII(k)) it was recorded whether the cows were found lying or standing.

---

* Footnote: Average daily temperature at Bush House (Edinburgh) range from 33.3 - 63.0°F (0.7 - 17.2°C), August to December (Plant, 1968).

VII(g) Milk Yield

Milking took place *in situ* at 07h00 and 16h00 every day. A movable Alfa-Laval bucket type machine was used, and the milk was weighed on a spring-balance, accurate to within 0.1kg.

VII(h) Liveweight

Body weights were recorded twice weekly during the experimental period, using a mobile crush-pen type cattle scale (Precision Weighters, Reading). Cows had to leave the climate chambers and walk ca. 100m to the scale, usually at about 09h00 - 10h00.

VII(i) Dry Matter Digestibility (DMD)

The quality of diet "AA6" is given in Table 5. Daily intake was measured as described in section VII(c). Large plastic sheets were placed on the floor behind the cows so that all the faeces excreted could be collected. Since the cows were on the same diet for a number of weeks, the usual pre-collection adaptation period was not necessary. It is usual to collect faeces for about one week (Henderson, 1979) but in view of the long period over which the cows were fed a constant diet, and the fact that a number of collections were made, three day collection periods were considered adequate. During these periods, which were towards the end of each phase of the experiment, faeces were collected every 24 hours and weighed. Samples were air dried at 60°C for 48 hours, and then oven dried at about 100 - 104°C until constant weights were recorded.

From this the moisture content and dry matter content were known, and DMD was calculated using the formula

$$DMD\% = \frac{\text{DM intake} - \text{faecal DM}}{\text{DM intake}} \times 100 \quad \text{(M.A.F.F., 1975).}$$

VII(j) Health

Rectal temperatures, respiration and pulse rates were recorded twice daily - prior to milking. An electronic digital thermometer (Model 82, IVAC Corp., San Diego) was used for T_R. Respiration rate was measured by counting flank movements and pulse rate by palpation of the ventral coccygeal artery at the base of the tail. Unusual findings, such as abnormal discharges or appearances, were reported.

The cows each received an injection of Vits. A,D and E (2 million iu, 30 000 iu and 200 iu respectively) on day 6 (Cows 3 & 4) and day 14 (Cows 1 & 6).

VII(k) "Full Clinicals"

Hourly measurements of T_R, respiration and heart rates were taken on days 34, 57, 71 and 98. This was done from 09h30 to 15h30 using methods described in section VII(j).

VII(l) Blood Tests

Blood samples were taken from the jugular vein using normal venipuncture techniques. This was done at least once from each cow towards the end of every phase of the experiment. Clear "vacutainers" (Becton - Dickson, New Jersey) were used for serum and EDTA "vacutainers" for plasma.

VII(l) 1 RBC, WBC, Ht and Haemoglobin were measured using a "Coulter Counter" (Model F_N, Coulter Electronics Ltd., Dunstable, England) with "Haemoglobinometer," "Dual Diluter III" and "Mean Cell Volume - Haematocrit" accessories.

VII(l) 2 Thyroid hormone tests were performed using radioimmunoassay kits available from The Radiochemical Centre, Amersham, England.

The "T_3 RIA" kit was used for serum T_3 assays. This method depends on the competition for binding sites on a T_3 specific anitibody between T_3 in serum and ^{125}I-labelled T_3.

Total serum T_4 was measured using the "T_4 RIA" kit, which also relies on a specific antibody reaction.

The "Thyopac-3" kit was used for T_3-uptake tests. It measures the capacity of serum to bind labelled T_3, which is then an indication of endogenous thyroid hormone levels. Since T_4 binds more firmly to TBG, and T_3 is displaced more easily from TBG, this test is mainly an indicator of serum T_4.

The FTI was calculated using the formula

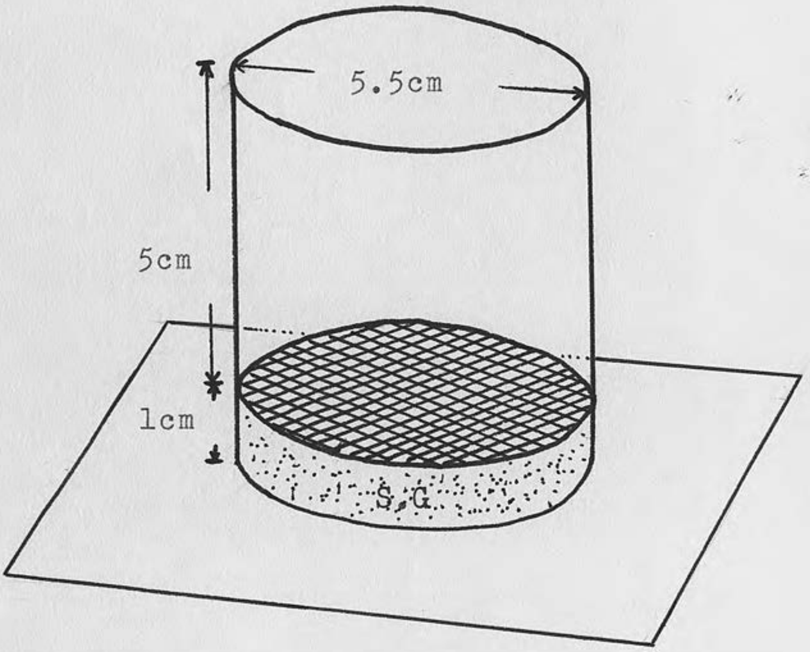
$$FTI = \frac{T_4 \text{ value}}{\text{Thyopac-3 value}} \times 100 \quad \text{(Anon, 1978)}$$

VII(m) Sweat rate

Sweat rates were measured in all cows on days 54, 79 and 98, at 09h30, 10h45, 11h45 and 13h45. Hair was clipped to 5mm in length, over an area of 10 x 10cm on the side of the chest just behind the elbow - a position which

Figure 5

Perspex Cup Used to Measure Sweat Rate



S.G: Silica gel.

The silica gel was held in the base of the cup by a wire mesh.

A diameter of 5.5cm means that the mouth of the cup covered an area of 23.77cm^2 on the animal's skin.

Figure 4a. A view of the gas analysis equipment: From left to right, the differential O_2 analyzer, the CO_2 analyzer, the sampling system and the entrance to one of the climate chambers.

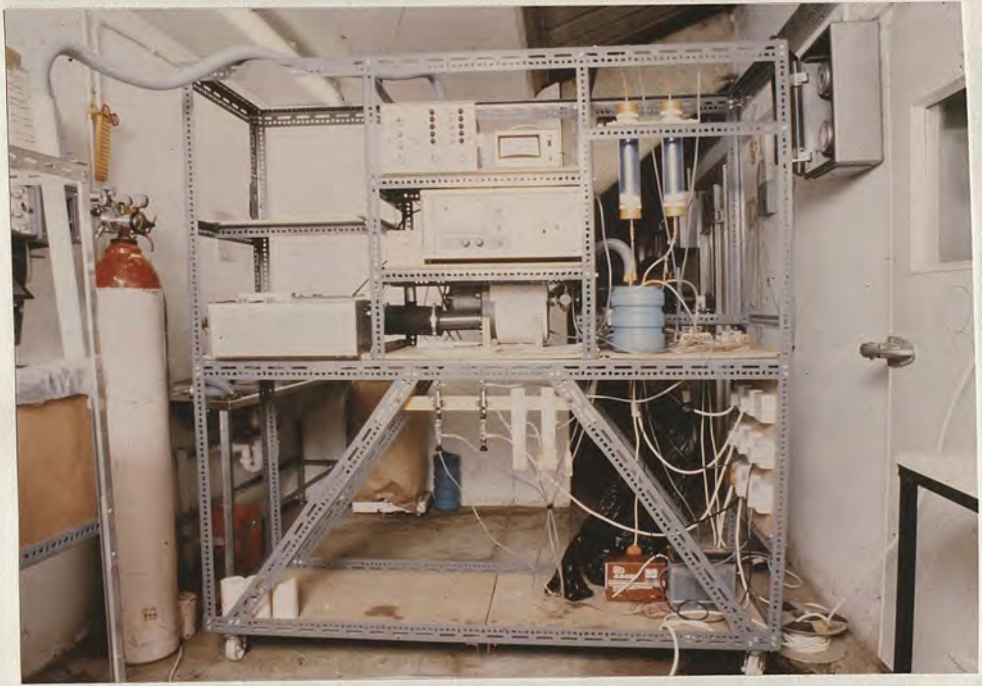


Figure 4b. A cow in the respiration tent.

Figure 4c. A cow inside the tent undergoing measurement of gaseous exchange.

Figure 4d. View from the front of the tent showing the outlet pipe.

is meant to give a good indication of total body sweat rate (Bianca, 1965). The skin was washed with tepid water, swabbed with alcohol (95% methanol) and left to dry for two minutes. Silica gel desiccant which had been weighed was placed in a perspex cup (fig. 5) which was held in place over the prepared area by hand for 5 minutes. "Parafilm" (Gallenkamp, England) was used to prevent air seaping in between cup and skin, and to seal the cup afterwards. Desiccants were reweighed and the weight of moisture absorbed calculated. This method was considered adequate for the comparative purposes of this experiment, although an absorption period longer than five minutes would have given a truer result.

VII(n) Heat Production

Metabolic heat production was determined once in every phase of the experiment using open circuit indirect calorimetry. Gaseous exchange data was obtained by placing the cow in a plastic "tent" inside the climate chamber, for 24 hours. The tent consisted of a steel ("Dexion") and wooden frame covered with transparent PVC sheeting (see fig. 4). Vinyl flooring material was used on the roof to prevent the PVC tearing, while polythene sheeting formed the ends and the base of the tent. The cow could enter or be removed through the back. A "velcro" seam was used to facilitate the removal of the tent covering when necessary. Internal fittings included a restraining chain and wet and dry bulb thermometers. Drinking water was supplied by placing measured quantities in a vessel in the tent. This was in excess of the cow's requirements and the water left at the end of the cow's sojourn in the tent was measured. The cow's own feed bin could fit into the front of the tent. The outer covering of the tent was protected from the cow by wire-mesh and boarding.

VII(n) 1 Oxygen and Carbon Dioxide Analysis. Air entered at the rear of the tent and the outlet pipe was at the front. The rate at which the air was removed from the tent was measured on a mass flowmeter ("Hastings", Teledyne - Raudist, Virginia, USA). Continuous monitoring of carbon dioxide (CO_2) in air entering and leaving the tent was carried out using an infra-red analyser ("INGRA 2001", Grubb Parsons Ltd, Newcastle). Oxygen (O_2) consumption was monitored continuously using a differential paramagnetic oxygen analyser (Model OA184, Taylor Servomex Ltd., Sussex). Since CO_2 and O_2 levels in experiments like this, vary tremendously over 24 hours, for example due to feeding (Lawrence, 1978), samples of gas were collected over the 24 hours in rubberized canvas (Douglas) bags. These samples were analysed using the above mentioned equipment, and taken as representative of the 24 hour period.

The reading on the O_2 analyser gave the percentage oxygen removed from the air by the animal, and this, multiplied by the reading on the mass flowmeter gave the animal's oxygen consumption in litres. CO_2 production was calculated in a similar manner.

VII(n) 2 Methane Production. Methane (CH_4) production was also determined from samples collected from the air leaving the tent. Three 50ml syringes were filled from the sample bag and the methane measured by gas chromatography (Heated dual flame ionization detector programmed chromatograph, Model 64, Pye Unican Ltd., Cambridge). Argon was used as a carrier gas, the chromatography column was packed with a 5 Å sieve maintained at 100°C, and methane was detected by a dual flame ionization detector kept at 125°C. Results were plotted on a chart recorder. The concentration of methane was deducted by cutting out the peaks on the recorder chart, weighing them, and comparing the weights with those of peaks produced by a standard gas mixture containing 0.092% methane.

VII(n) 3 Calculating Heat Production. Allowance was made for atmospheric pressure. Heat production was calculated using the equation $H = (16.176 \times O_2) + (5.021 \times CO_2) - (2.167 \times CH_4) - (5.99 \times N)$ (Brouwer, 1965).

H = heat produced

O_2 = volume of oxygen consumed (l)

CO_2 = volume of carbon dioxide produced (l)

CH_4 = volume of methane produced (l)

N = quantity of urinary nitrogen excreted (g)

N was not included in this study because its contribution to H is negligible (see Appendix 6).

Cows were placed in the tent half an hour before gas analysis and sampling started, to allow the whole system to equilibrate.

VIII. RESULTS

For ease of presentation the results are loosely arranged into three groups: (a) Production parameters, (b) Clinical and physiological parameters, and (c) Other parameters.

VIII(a) Production Parameters

VIII(a) 1 Milk Yield. Daily milk yields are tabulated in Appendix 5, but are difficult to interpret as such and are therefore represented graphically in Figure 6, and summarised in Table 7.

Table 7

Daily milk yields recorded during the experiment.

Mean daily yield over the entire experimental period	kg ± SD
Cow 1	5.1 ± 1.3
Cow 3	15.4 ± 0.9
Cow 4	7.4 ± 0.7
Cow 6	20.4 ± 0.2
Mean yields of the cows during each phase of the experiment	
Treatment 21a	12.2 ± 6.9
Treatment 37 + IC	12.9 ± 6.9
Treatment 21b	12.0 ± 7.1
Treatment 37	11.6 ± 7.2
Treatment 21c	10.9 ± 7.9

Figure 6 Milk Yield During the Experimental Period

Fig.6a

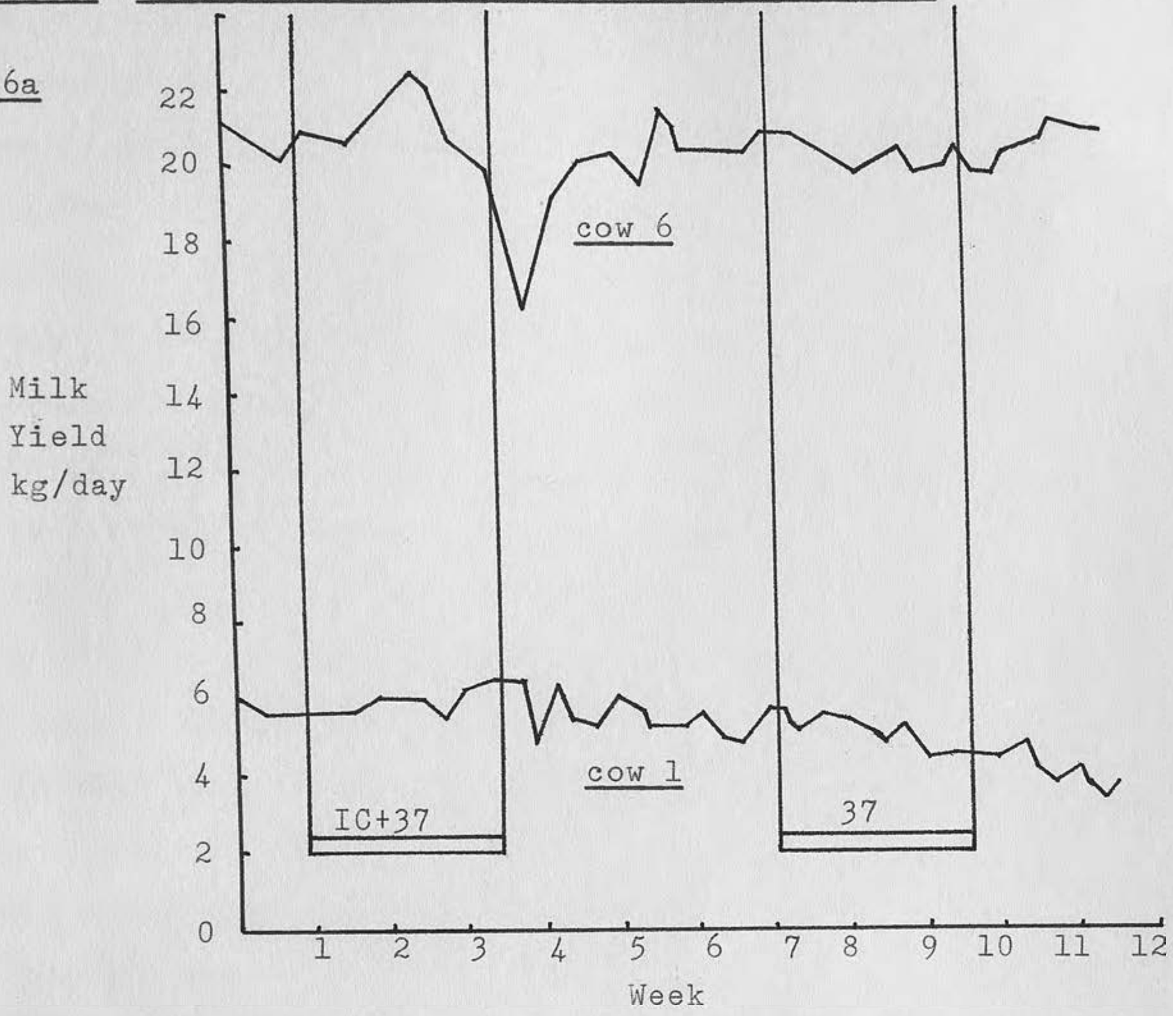
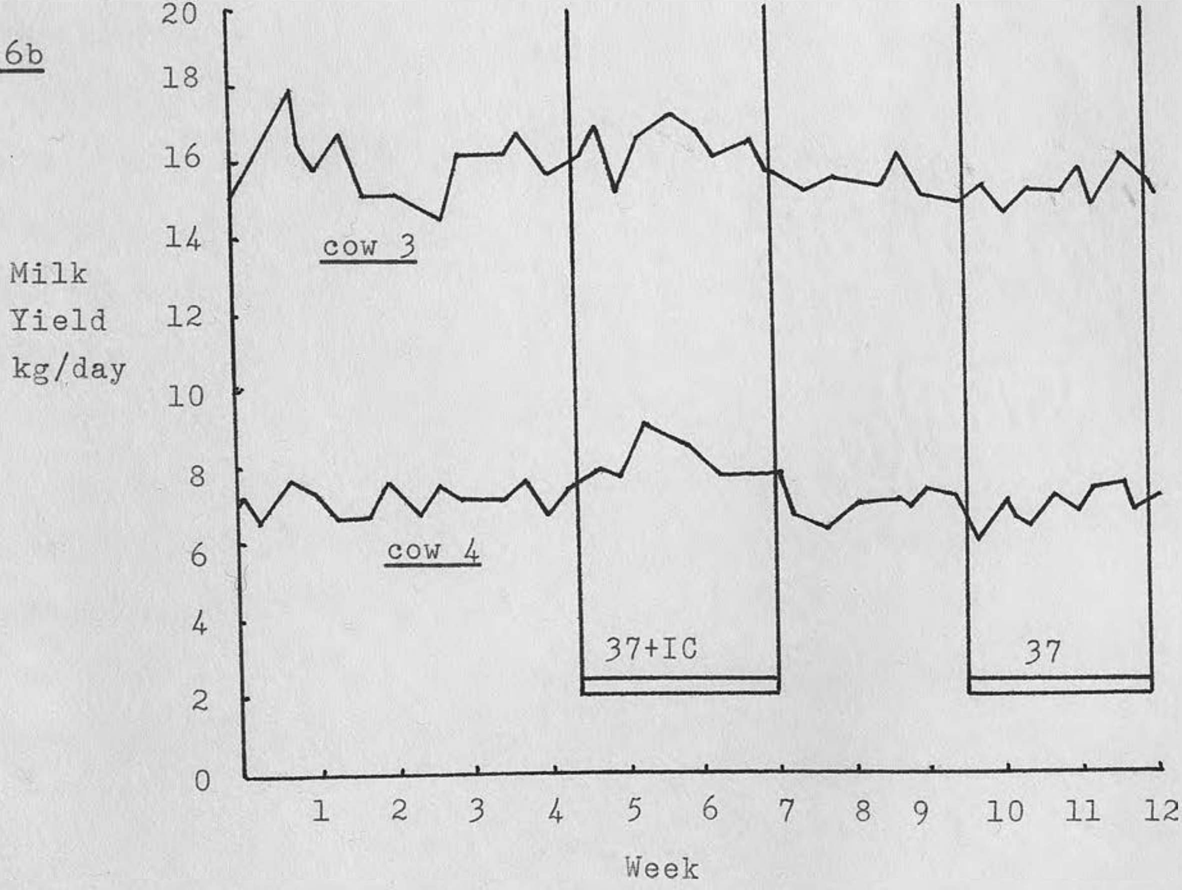


Fig.6b



A few introductory remarks must be made about the data: The sharp drop in milk yields of cows 1 and 6 at the end of the 4th week (see Fig. 6) was ascribed to the fact that drinking water was not available to them at that time. These two days' results are not included in the statistical analyses (Appendix 4). When it came to data evaluation, the milk yields recorded during Treatment 21c were largely ignored because cow 6 had developed mastitis and cow 1 showed a terminal decline in milk production after 16 months of lactation. The means of the cows' milk yields during Treatments 21a and 21b were therefore taken to be their "normal" levels.

In this experiment, our interest was to see whether iodinated casein alleviated the effects of a hot environment on milk production. It is thus necessary to consider Treatment 37 first to ascertain what the effects of the hot environment were. From Fig. 6 it can be seen that high ambient temperatures (Treatment 37) depressed milk production in cows 1 and 6, but not in cows 3 and 4. Partly due to the anomalous increase in milk production shown by cow 4 during Treatment 37, the effect of high ambient temperature could not be shown to be significantly deleterious to milk production ($p > 0.05$).

However, at high ambient temperatures, iodinated casein supplementation significantly increased milk production ($p < 0.01$). Cows 3, 4 and 6 reached a peak of response about 7 - 10 days after the onset of thyroprotein supplementation; each produced approximately 2kg/day more milk than their "normal" levels. During Treatment 37 + IC, cow 1 suffered a setback: In the 3rd week of the experiment a moderate vulvar discharge and early abortion occurred, which was reflected in milk production by a slight drop (see fig. 6) and subsequent recovery. Nevertheless, she produced an average of 5% more milk/day over the whole period of Treatment 37 + IC as compared to Treatments 21a and 21b. Similarly, cows 3, 4 and 6 produced 6%, 18% and 2% more milk/day, respectively. Milk yields started declining about 1 - 2 weeks before the end of Treatment 37 + IC, except in the case of cow 1.

On cessation of thyroprotein administration, milk yields declined to below normal in cows 4 and 6, with a subsequent recovery, while in cows 1 and 3 milk yields simply declined to normal (fig. 6). The average result for the four cows combined was that mean milk yields during Treatment 21b were not significantly lower than during Treatment 21a ($p > 0.05$), in spite of the effect of stage of lactation.

In view of the chronological sequence of the treatments, other significant differences (Treatment 37 + IC:Treatments 37 and 21c; and Treatments 21a and 21b: Treatment 21c) were likely to have been due to the stage of lactation and the above mentioned aberrations at the end of the experiment. In view of this, Treatment 21c was discarded from the analysis of variance, and Treatments 21a and 21b combined (Appendix 4b). This manipulation confirmed that, under the conditions of this experiment, iodinated casein had significantly increased milk production in spite of high ambient temperatures ($p < 0.01$), but that within 95%

confidence limits high ambient temperatures <u>per se</u> had not significantly depressed milk yield.

VIII(a) 2 <u>Liveweight</u>. The liveweights recorded during the experimental period are tabulated in Appendix 7. The mean liveweights of the cows over the experimental period were:

cow 1	603 ± 16 kg
cow 3	566 ± 6 kg
cow 4	576 ± 7 kg
cow 6	469 ± 12 kg

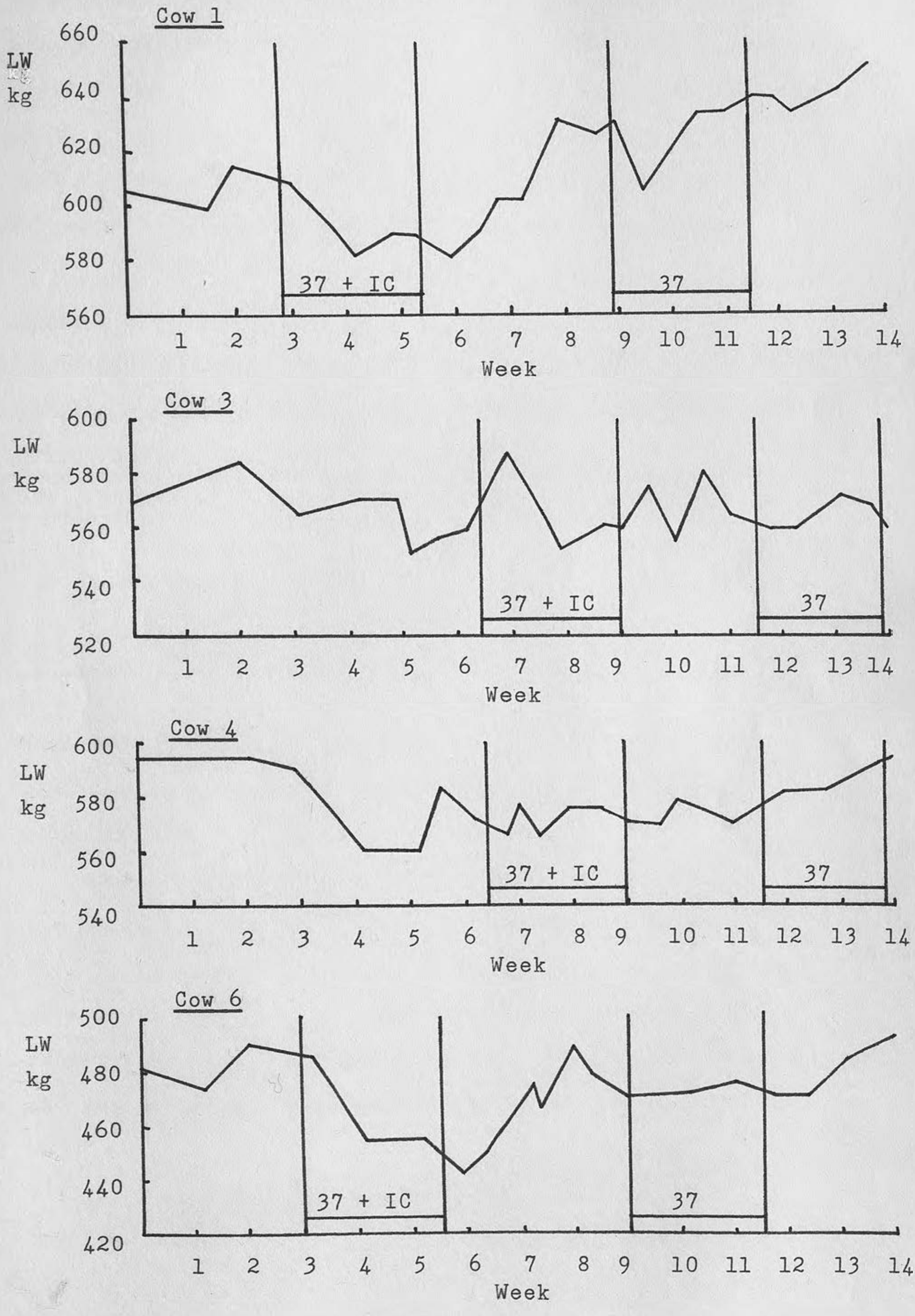
The large variation in body weights, as illustrated in Fig. 7, should be seen in context - on occassions the weigh crush gave different readings (up to 20kg different) when a cow was reweighed two or three times within a matter of minutes. Notwithstanding the unreliability of the scale, some trends can be detected in the liveweight changes, particularly in the cases of cows 1 and 6.

High ambient temperature does not seem to have had any adverse affect on the cows' body weights. On average the cows gained 8.3 ± 5.7 kg during Treatment 37.

Iodinated casein was responsible for a mean liveweight loss of 11.8 ± 16.8 kg over the three weeks of Treatment 37 + IC. The great variation between cows indicated by this large standard deviation (± 16.8kg), is due to the fact that while cows 1 and 6 lost 22kg and 30kg respectively, cows 3 and 4 actually gained 2kg and 3kg (Fig. 7). On withdrawal of thyroprotein from the diet, cows 1 and 6 rapidly regained condition while cows 3 and 4 showed hardly any change. However, none of these changes in body weight were statistically significant (Appendix 4(d)(i)).

Figure 7

Liveweight changes during the experimental period



Since the Coefficient of Variation was 312%, which is unacceptable, a simple transformation was applied but this simply confirmed the non-significance of the results, and their dubious reliability (Appendix 4(d)(ii)). Be that as it may, an average liveweight change of 32kg, in adult cattle, over a period of five weeks (almost 1kg/day lost or gained) is significant by any farmer's standards.

Table 8

Liveweight changes during supplementation with thyroprotein and thereafter, expressed as percentages of the cows' mean body weights for the whole experimental period.

Cow	Treatment 37+IC	Treatment 21b	Treatment 37
1	-3.6%	+6.1%	+1.6%
3	+0.4%	0.0%	+2.3%
4	0.0%	+1.7%	+1.7%
6	-6.4%	+6.8%	0.0%

When considering the data in Table 8 it must be borne in mind that cow 6 was the smallest cow, and the highest milk yielder.

Comparing the liveweights of the cows recorded at the beginning and the end of the experiment, as shown in Fig. 7, it is notable that cow 1 was the only one to show an overall weight gain; this would be consistent with the response of a cow in late lactation, and especially so if she was pregnant, as was suspected in the case of cow 1.

VIII(a) 3 Dry matter digestibility. Mean DMD% for all treatments was 65.49 ± 7.17%, which agrees fairly well with the value supplied by the manufacturer (66.6%, Seafield Mill, Lothianburn, Scotland).

Table 9

Dry matter digestibility (%) recorded at various stages of the experiment.

Cow	37 + IC	21	37	Mean for cow
1	50.0	55.6	68.9	58.16
3	73.8	69.7	62.2	68.58
4	65.7	62.7	66.0	64.82
6	78.4	68.6	64.1	70.39
Mean treatment effect	66.99	64.13	65.34	65.49

An analysis of variance indicated that none of these results were significantly different from each other (Appendix 4(e)). However, it must be pointed out that the two high yielding cows (cows 3 and 6) seemed to digest their feed more completely. Note also, that cow 1 returned unusually low DMD%'s during Treatments 37 + IC and 21.

VIII(b) Clinical and Physiological Parameters

Since rectal temperature, respiration and pulse rates are inextricably linked, they are presented together in Figures 12a - d, which facilitates data interpretation.

VIII(b) 1 Respiration rates. The respiration rates summarised in Table 10 are means for the four cows taken over the whole of each phase of the experiment, and serve as a guide to Figures 12a - d.

Figure 8

Average Respiratory Rate of 4 Cows Exposed to 21°C, 37°C, and 37°C + Iodinated Casein.

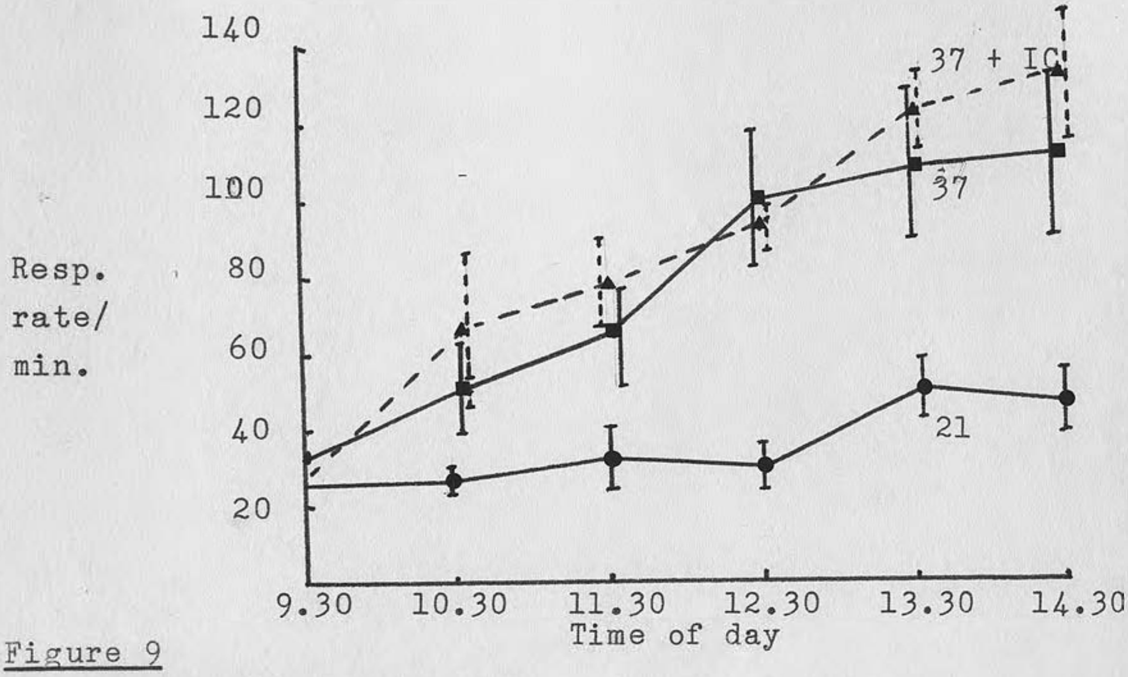


Figure 9

Average Rectal Temperature of 4 Cows Exposed to 21°C, 37°C, and 37°C + Iodinated Casein.

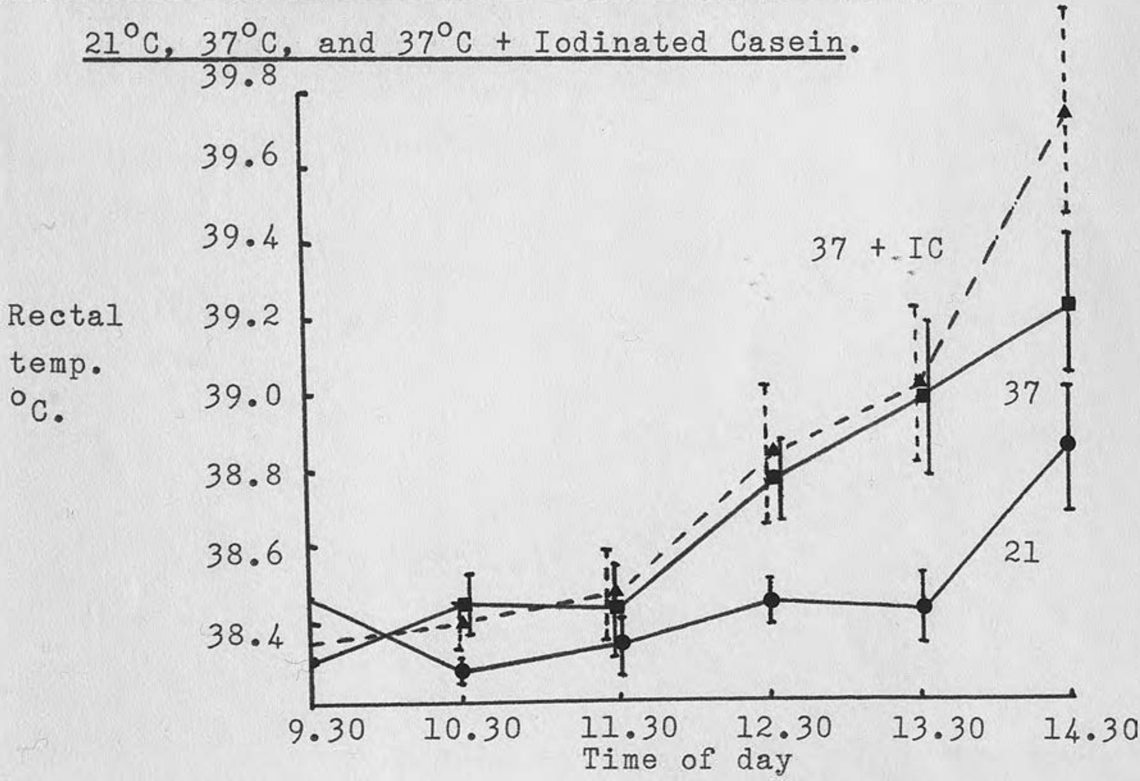


Figure 10

Average Pulse Rate of 4 Cows Exposed to 21°C, 37°C and 37°C + Iodinated Casein.

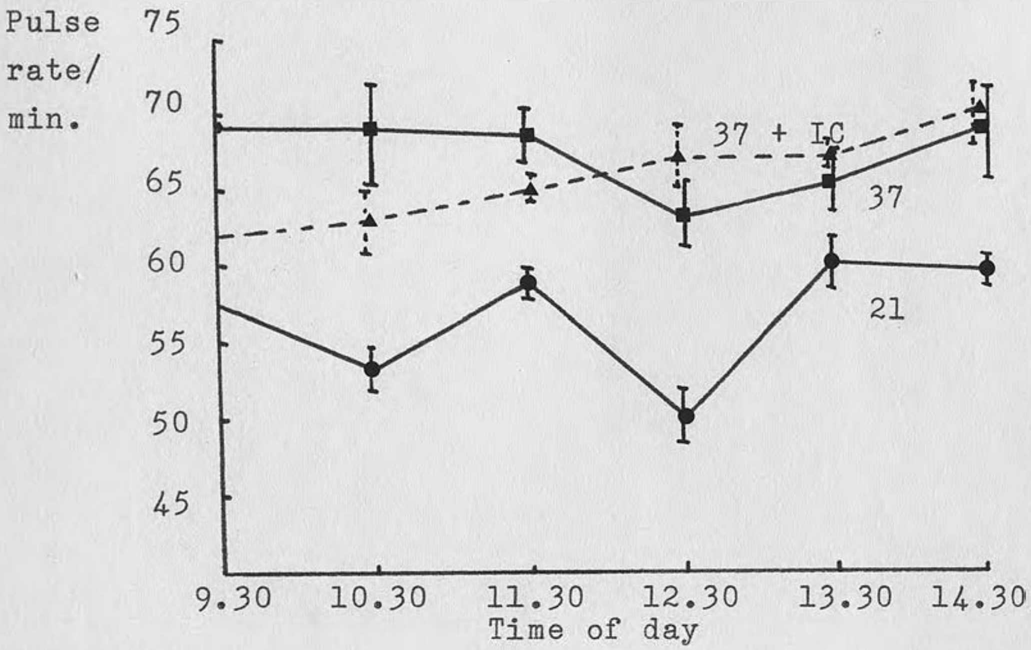


Figure 11

Average Sweat Rates of 4 Cows Exposed to 21°C, 37°C, and 37°C + Iodinated Casein.

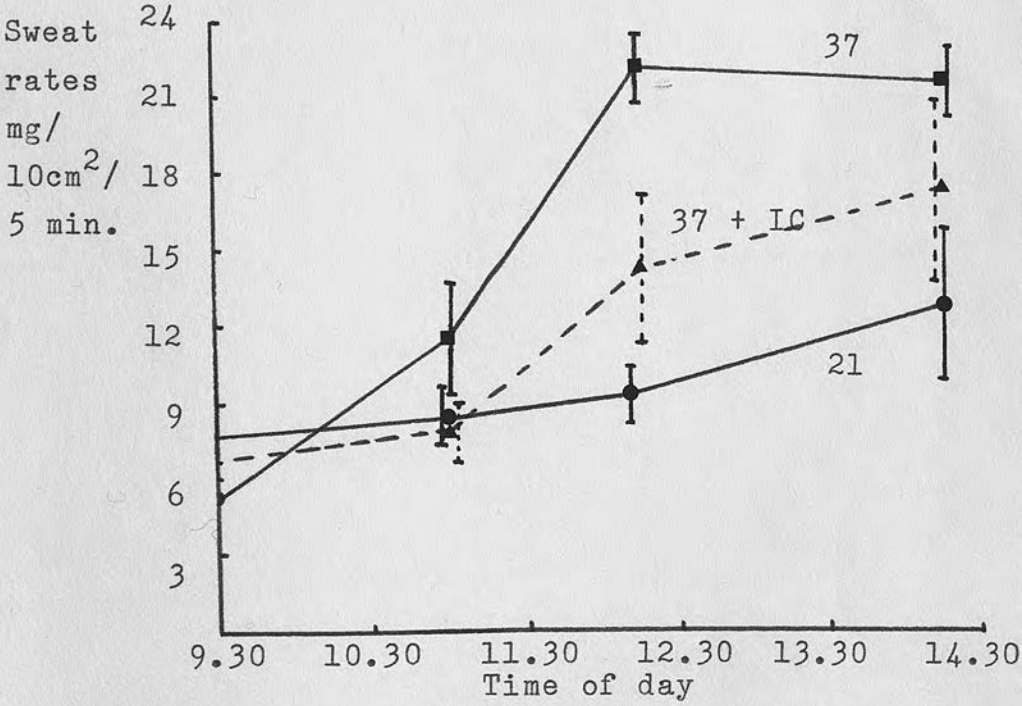


Figure 12 (a)

Clinical parameters of Cow 1 during the experimental period.

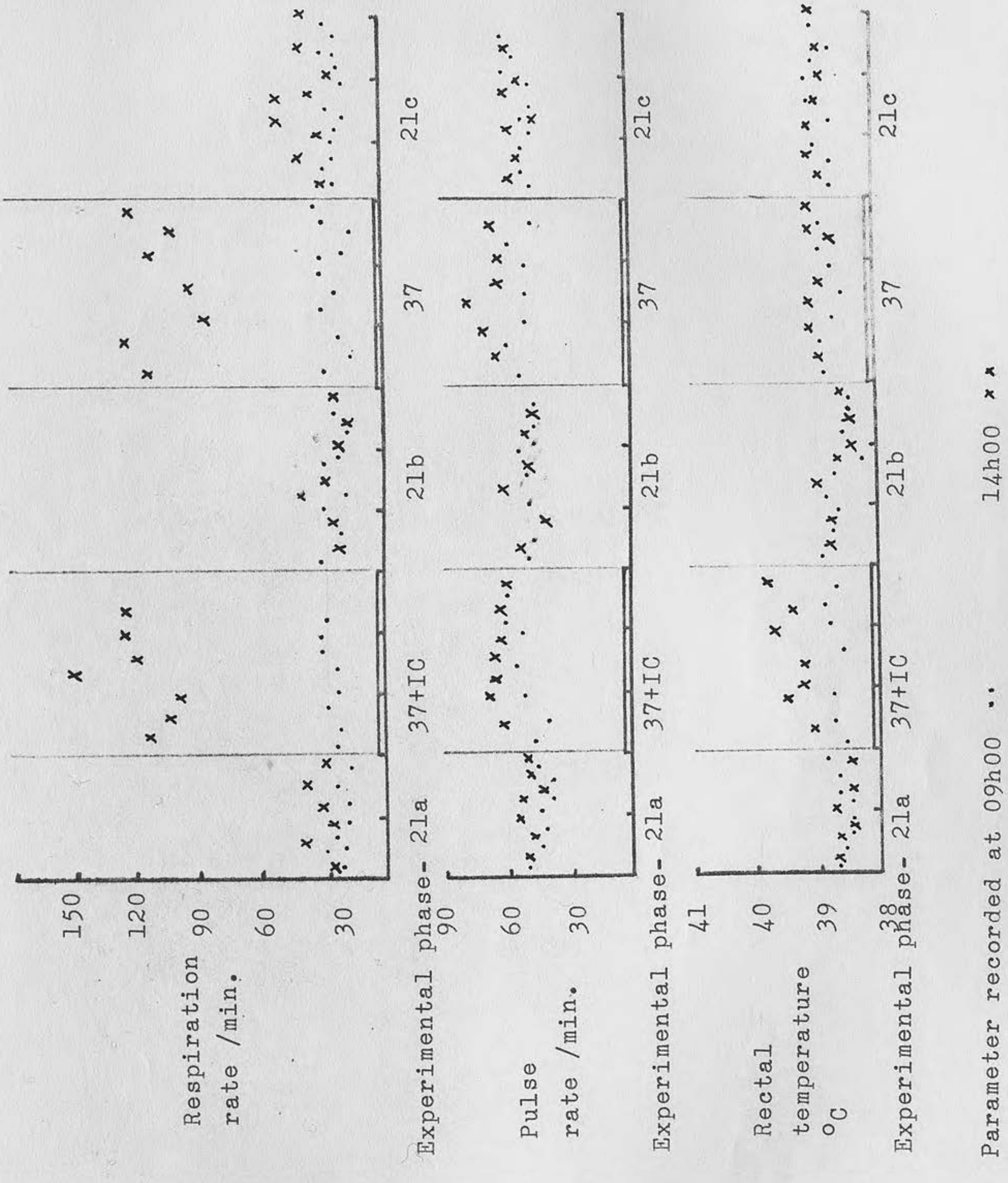


Figure 12 (b)

Clinical parameters of Cow 3 during the experimental period

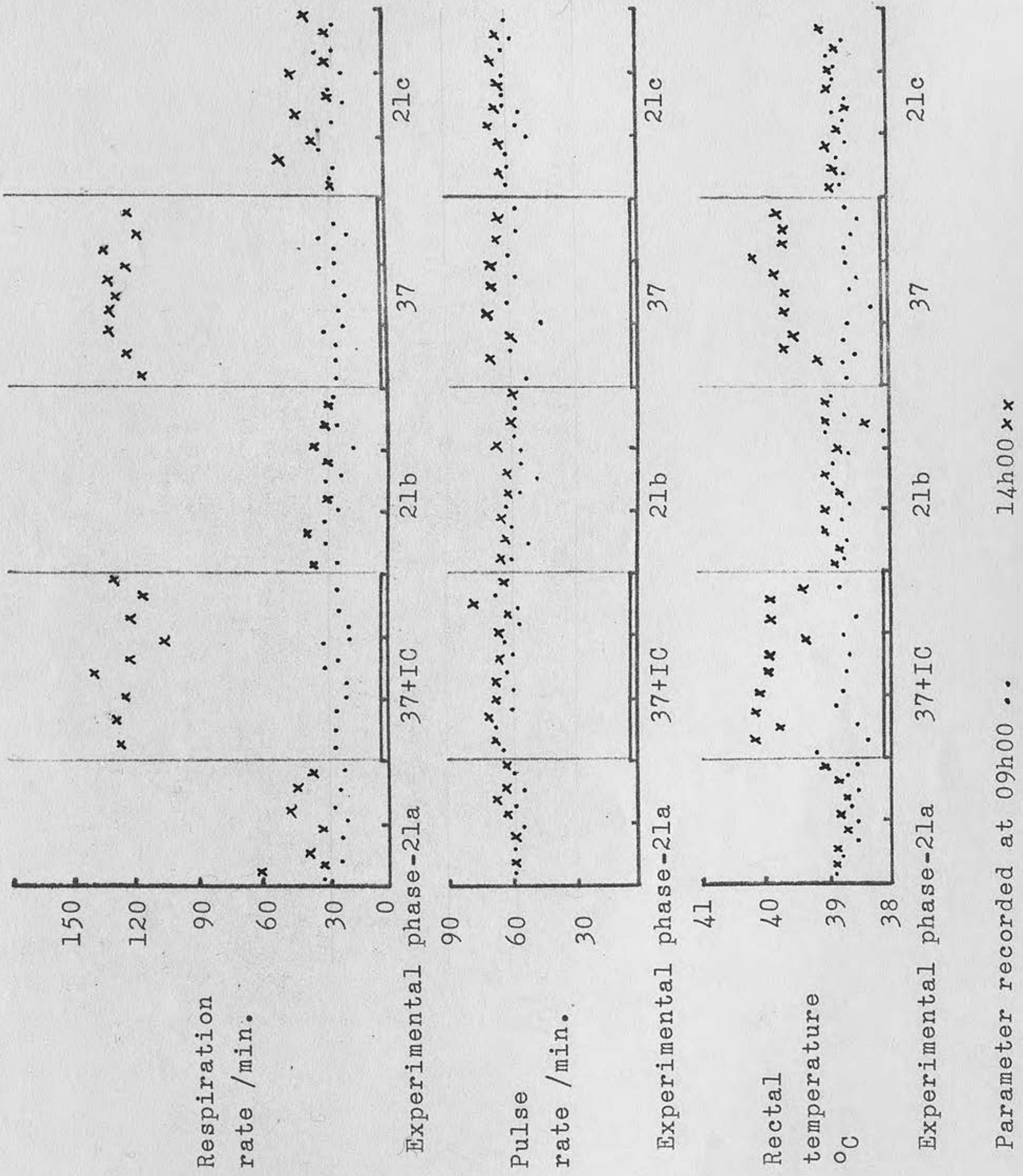


Figure 12 (c)

Clinical parameters of Cow 4 during the experimental period

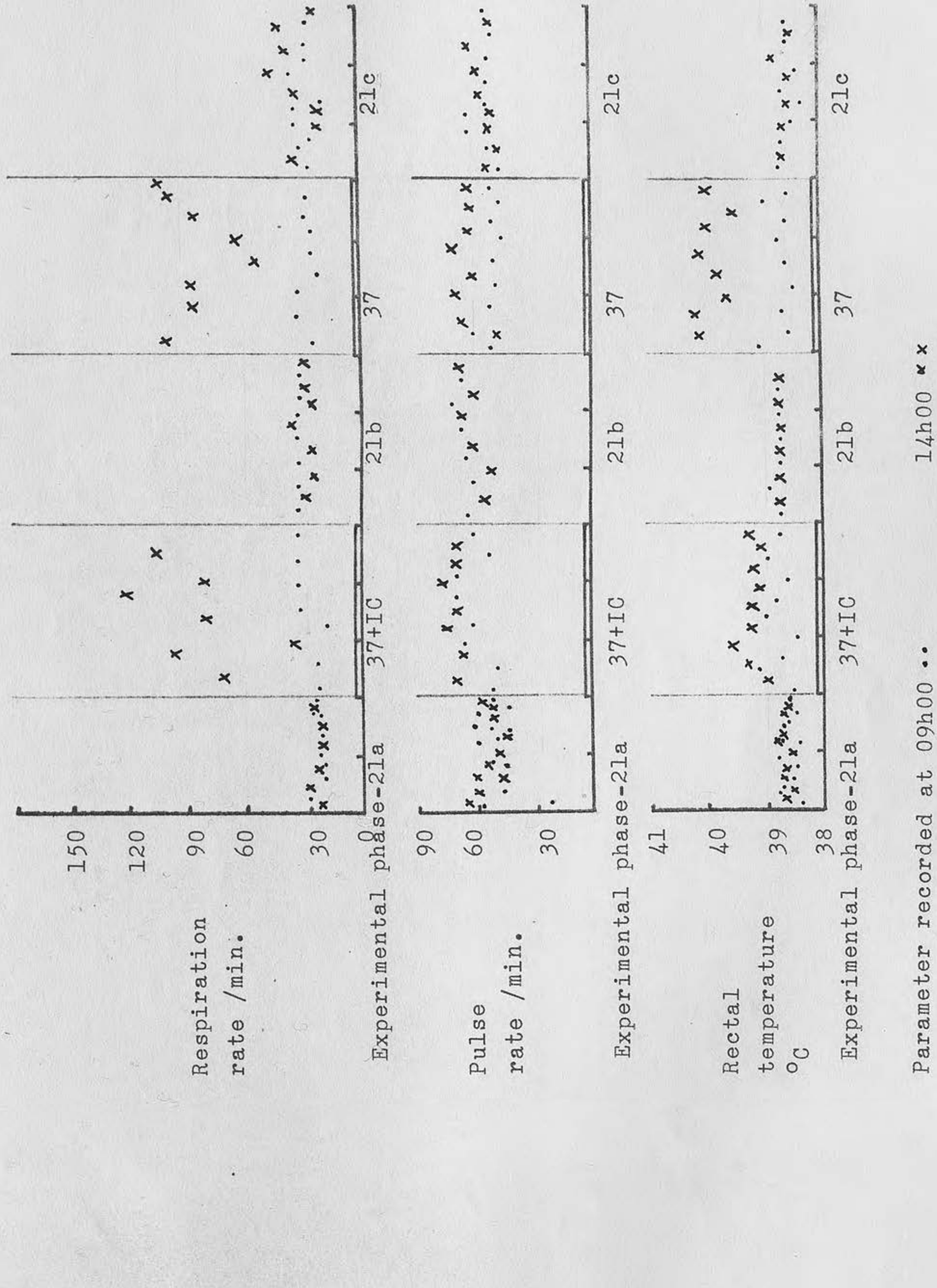


Figure 12 (d)

Clinical parameters of Cow 6 during the experimental period

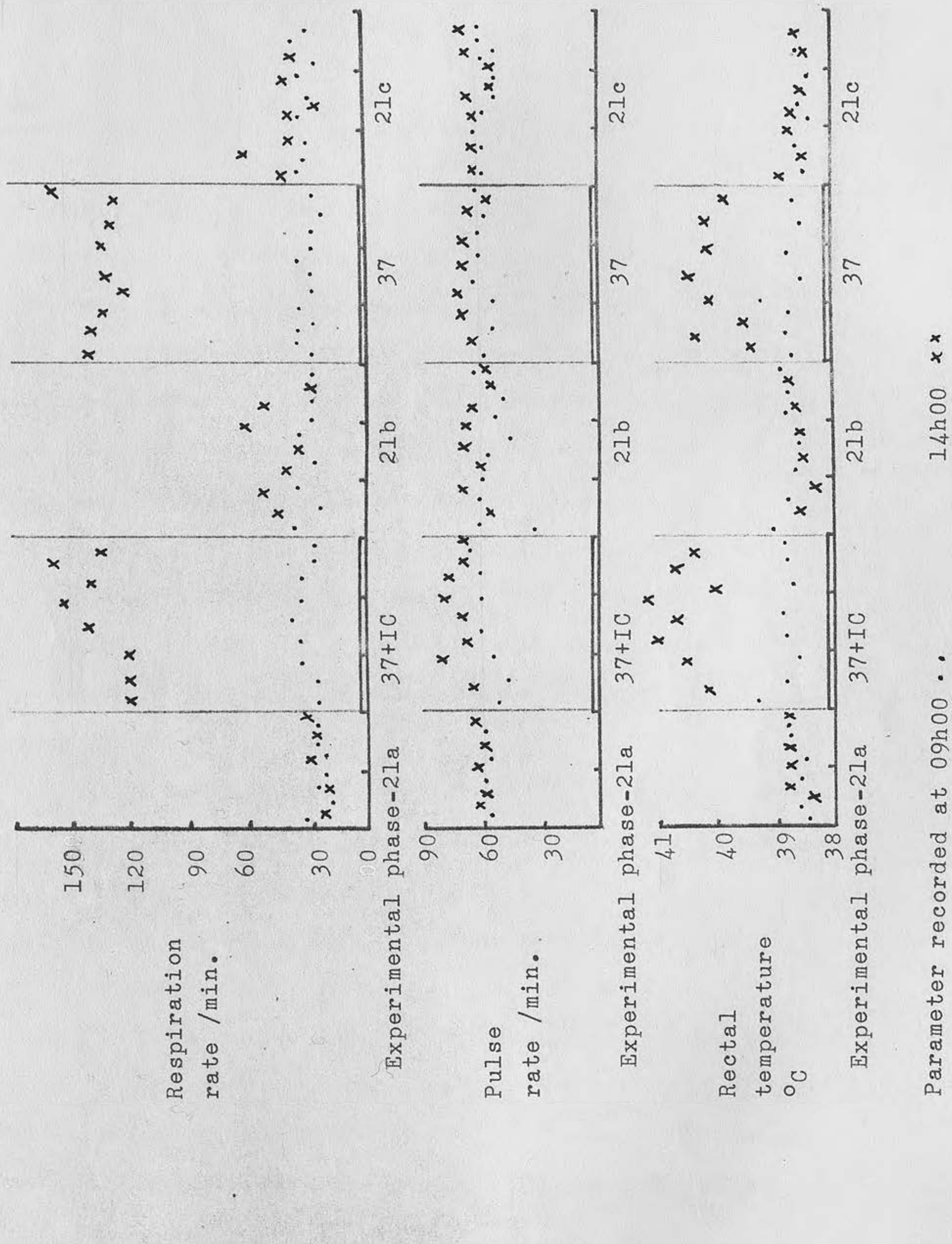


Table 10

Mean respiration rates(/min)

Treatment	Respiratory rate/min.	
	AM	PM
37 + IC	28.0	117.5
21	27.1	36.2
37	27.3	112.3
Mean	27.5	88.7

Obviously the morning and afternoon results are quite different from each other, which an analysis of variance confirmed ($p < 0.001$)(Appendix 4f). Since it was feared that the consistency of the morning respiratory rates would mask any treatment effects, the afternoon results alone were also statistically analysed (Appendix 4g). The resultant conclusions, which may be visualized in Figures 12a-d, were that iodinated casein had not significantly exacerbated heat stress; that respiratory rates throughout Treatment 21 were significantly lower than at other times ($p < 0.01$); and that the cows differed markedly from each other ($p < 0.01$).

There was a hint of acclimation to heat, reflected in Figs. 12a-d by the increasing variation between morning and afternoon respiration rates in Treatments 21b and 21c, as opposed to the consistent levels seen in Treatment 21a. This is most noticeable in cow 6 (Fig. 12d).

The respiration rates recorded hourly during one day late in each phase of the experiment are shown in Figure 8, and statistically analysed in Appendix 4h. Changes in respiration rate closely followed changes in ambient temperature; when T_A rose to 37°C, respiratory rate was significantly higher than at $T_A = 21°C$ ($p < 0.01$), but feeding iodinated casein did not exacerbate this effect ($p > 0.05$). There was a great variation between the cows, with high yielders breathing faster than low yielders ($p < 0.05$). Cow 6 could again be singled out as the most distressed by the heat, reaching 160/minute at 14h30 (T_A=38°C, RH=57%) during Treatment 37 + IC and 140/minute without the thyroprotein (T_A=36.5, RH=60%).

Respiration rate correlated well to various heat stress indices (Appendix 3). THI, Θ, HAC, wet bulb, and Bianca's db:wb formula were all well correlated to respiratory rate, usually within 99.9% confidence limits; the best correlation was to dry bulb temperature per se, where $r = 0.786$. Respiration rate may therefore be accepted as a sensitive indicator of heat stress in cattle.

VIII(b) 2 Rectal temperatures. Taken over the whole period of the experiment, an analysis of variance of the mean rectal temperatures of the four cows indicate that high ambient temperature caused an increase in rectal temperature ($p < 0.05$) but that feeding iodinated casein did not significantly aggravate this effect (Appendix 4i). However, when the results were represented graphically (Figs. 12a - d), only cow 3 (Fig. 12b) exactly fitted this postulate. In cows 1 and 6 T_R during Treatment 37 + IC was higher than in Treatment 37, while cow 4 showed the opposite trend and in so doing balanced (or possibly disrupted?) the statistical analysis. The acclimation noted in respiration rate is difficult to detect in rectal temperature; the consistency of cow 4's rectal temperature (Fig. 12c) during Treatment 21b is suspiciously unrealistic.

Table 11

Mean rectal temperatures, °C.

Treatment	T_R (°C) AM	PM
37+IC	38.7	39.8
21	38.7	38.6
37	38.5	39.5
Mean	38.6	39.3

Rectal temperatures recorded at hourly intervals on "full clinical" days are illustrated in Figure 9. During the first four hours of Treatments 37 + IC and 37, while ambient temperatures increased gradually to approximately 37°C (see Appendix 3 for details) iodinated casein did not markedly affect the cows' thermoregulatory functions, but thereafter their rectal temperatures increased to 39.8 ± 0.8°C which is above the normal range for cattle. The 39.2 ± 0.5°C recorded at 14h30 during Treatment 37, when T_A = 36.0° and RH = 60%, is the upper limit of normal, and although the difference between 39.8°C and 39.2°C was not statistically significant (Appendix 4j), it is clinically very important. The highest T_R recorded was in cow 6, during Treatment 37 + IC. When T_A = 38°C, RH = 57%, cow 6's rectal temperature was 40.9°C.

Rectal temperature did not correlate well to the various heat stress indices (Appendix 3); T_R: Dry bulb temperature, r = 0.429 within 99% confidence limits, was the best correlation calculated. When an allowance of one hour was made for the possible lag period between change in T_A and resultant change in T_R, the correlation factors were not improved (Appendix 3).

VIII(b) 3 Pulse Rate. Although pulse rate is not considered a reliable indicator of heat stress, the results summarised in Table 12 and illustrated in Figures 12a - d show that the cows' pulse rates did increase when ambient temperature increased, a trend which was significant at $p < 0.05$ (Appendix 4k).

Table 12

Mean pulse rates for the four cows during various phases of the experiment.

Treatment	Pulse rate/min (±SD)
21	56.3 ± 3.3
37	67.1 ± 7.1
37+IC	65.9 ± 2.8
Mean	63.1 ± 6.6

Iodinated casein did not have a statistically significant effect on pulse rate, but careful examination of Figures 12a - d reveal that the effect of the thyroprotein may have been overshadowed by the effect of the hot environment. In cow 1 (Fig 12a) the afternoon pulse rates increased rapidly when Treatment 37 + IC was instituted, due to the heat, while morning pulse rates increased gradually, possibly because there was no heat exposure in the early morning, and thyroprotein is known to have a gradual onset of effect. This response can also be seen in cows 4 and 6 (Figs 12c and d), although it must be pointed out that cow 6 responded in a similar manner during Treatment 37. Cow 3 (Fig. 12b) illustrates that exposure to high ambient temperature does not always cause a marked increase in pulse rate.

Figure 10 represents the pulse rates recorded at hourly intervals during one day late in each phase of the experiment. Exposing the cows to heat loads does not appear to have increased their pulse rates during the day, and feeding iodinated casein had a minimal effect.

VIII(b) 4 Haematology. The cardinal results are shown in Table 13. For further details and statistical analyses, see Appendix 41.

Table 13

Haematology

	RBC	WBC	Hb	Ht
Normal	5-10	6 000 - 10 000	8-15	25-45
Mean for:				
Cow 1	6.57	5247	12.68	41.9
Cow 3	7.35	9123	11.07	34.9
Cow 4	7.07	8421	11.17	34.1
Cow 6	6.19	6812	9.83	32.7
Treatment 37+IC	6.64	7020	11.24	35.5
Treatment 21	7.05	7913	11.33	37.3
Treatment 37	6.70	7269	11.03	34.9
Overall mean	6.80	7401	11.20	35.89

RBC = Red blood cells, x 1 million/µl
WBC = White blood cells, cells/µl
Hb = Haemoglobin, g/dl
Ht = Haematocrit, %
Normal values from Anon (1979) and Kelly (1976).

VIII(b) 4.1 <u>RBC</u>. Red blood cell counts for all cows at normal temperatures (Treatment 21) was 7.05 ± 0.47 million cells/μl. This was within the range considered normal for such cattle. Exposure to heat stress (Treatment 37) resulted in a significant depression in RBC ($p < 0.05$) to 6.70 ± 0.56 million erythrocytes/μl. Feeding iodinated casein under similar conditions (Treatment 37 + IC) was also accompanied by a decrease in RBC, to 6.64 ± 0.50 million cells/μl, which was not statistically significantly different to 6.70 ± 0.56 million cells/μl. This implies that the thyroprotein <u>per se</u> did not have a significant effect on RBC. There was a tremendous variation between cows ($p < 0.001$) but not specifically between high yielders and low yielders (Appendix 41(i)).

VIII(b) 4.2 <u>WBC</u>. The white blood cell counts are shown in Table 13. There was no statistically significant treatment effect, but it is notable that WBC in both Treatments 37 and 37 + IC were lower than in Treatment 21. There was a statistically significant difference between the cows ($p < 0.01$)(Appendix 41(ii)). Cow 1 had a constant leucocyte count of 5 247 ± 252 WBC/μl which is below the minimum "normal" level (6 000 WBC/μl) while cow 3 had an excessively high WBC count during Treatment 21, reaching 14 200 WBC/μl. Comparing cow 3's WBC count from blood samples taken in the afternoon to that of the same morning, there was an increase of 5 000 WBC/μl within 5 hours (Appendix 41(ii)). When cow 3's results during Treatment 21 are excluded, the general trend was for the cows to increase WBC by about 700 WBC/μl (ie. 10%) during the day, which may have been due to the daily increases in ambient temperature, since this environmental factor was the prime diurnal variable. However, nychthemeral, hormonal and other cycles should not be overlooked.

Apparently, iodinated casein did not affect WBC counts (Table 13) but in view of the fact that two of the values for Treatment 37 + IC had to be estimated (missing plots - Appendix 41(ii)) no definite conclusions can be reached in respect of the effect of thyroprotein on WBC.

VIII(b) 4.3 Hb. Refer to Table 13 for the mean haemoglobin values recorded and Appendix 41(iii) for the statistical analysis. There was a marked difference between cows ($p < 0.001$) which was accounted for almost completely by the difference between cow 1 (12.7 ± 1.6 g/dl) and cow 6 (9.8 ± 0.8 g/dl). This possibly created an artificial difference between high yielders and low yielders ($p < 0.001$), the former returning Hb levels of 10.4 ± 0.7 g/dl and the latter 11.9 ± 1.3 g/dl. Morning Hb levels (11.5 ± 1.2 g/dl) were consistently higher than afternoon levels (10.9 ± 1.0 g/dl)($p < 0.01$) which possibly indicated that increased ambient temperature may have been responsible for this trend.

VIII(b) 4.4 Ht. The mean haematocrit values are shown in Table 13. From the analysis of variance (Appendix 41(iv)) it is evident that Ht is a very sensitive haematological parameter, with every factor examined, except iodinated casein, having a very significant effect ($p < 0.001$).

The most pertinent fact to emerge was that the morning levels (39.3 ± 3.5%) were higher than the afternoon values (31.6 ± 3.9%) implying that the blood was more diluted later in the day when it was warmer. Feeding iodinated casein did not have a statistically significant effect. The high yielding cows (33.8 ± 3.5%) had very significantly lower ($p < 0.001$) Ht levels than the low yielders (38.0 ± 5.8%).

VIII(b) 5 <u>Thyroid hormone tests</u>. The results of the plasma thyroid hormone tests are tabulated and statistically analysed in Appendix 4m.

<u>Table 14</u>

<u>Mean plasma thyroid hormone test results recorded in various phases of the experiment.</u>

<u>Treatment</u>	<u>T_3 n mol/l (±SD)</u>
21	3.10 ± 0.60
37	2.81 ± 0.30
37 + IC	4.08 ± 0.81
Mean	3.33 ± 0.80
<u>Treatment</u>	<u>T_4 n mol/l (±SD)</u>
21	81.06 ± 19.93
37	77.67 ± 11.99
37 + IC	99.07 ± 15.28
Mean	85.94 ± 18.10
<u>Treatment</u>	<u>Thyopac-3 values (±SD)</u>
21	115.01 ± 3.44
37	116.78 ± 2.89
37 + IC	111.06 ± 6.38
Mean	114.28 ± 4.97
<u>Treatment</u>	<u>FTI (Thyopac-3;T_4 in n mol/l)</u>
21	70.73 ± 17.18
37	66.64 ± 11.15
37 + IC	90.19 ± 19.59
Mean	75.85 ± 18.83

All the values shown in Table 14 are comparable to the "normal" values for cattle shown in Appendix 8, excepting for Thyopac-3 values for which no reliable "normal" bovine value could be found.

The apparent effect of high ambient temperature (Treatment 37) was to decrease plasma T_3 and T_4, Thyopac-3, and FTI levels, but none of these depressions was found to be statistically significant when compared to levels recorded during Treatment 21. However, when thyroprotein was fed to the cows in a hot environment (Treatment 37 + IC), significant increases in plasma T_3 ($p < 0.01$), plasma T_4 ($p < 0.05$), Thyopac-3 values ($p < 0.01$) and FTI's ($p < 0.01$) were recorded. It made no difference whether blood for plasma thyroid hormone tests was drawn in the mornings or afternoons ($p > 0.05$); the high yielding cows did not differ significantly from the how yielders in respect of individual tests ($p > 0.05$), but the FTI's of the high yielders were significantly lower than the low yielders ($p < 0.01$)(Appendix 4m(iv)).

VIII(b) 6 <u>Sweat rates</u>. The average sweat rate of the cows was 12.1 ± 6.2 mg/10cm^2/5min, which is the equivalent of a medium sized cow (4m^2 surface area) sweating 13.9 litres in 24 hours. These results are comparable to those of Thompson <u>et al</u> (1953) and Kibler & Brody (1953). A table of results is presented in Appendix 4n, with an analysis of variance; Figure 11 shows the effect of the treatments. Only Treatment 37 was significantly different to Treatment 21 ($p < 0.05$). The tremendous effect of time of day on sweat rate ($p < 0.001$) was almost certainly due to the increase in ambient temperature which occurred through the day, and even in Treatment 21 ambient temperature went up to 24°C by 14h30. The highest sweat rate recorded was from cow 3 during Treatment 37, when $T_A = 36^{\circ}C$ and RH = 66%. Her sweat rate of $27mg/10cm^2/5min$ does not, however, compare to the $43mg/10cm^2/5min$ at $T_A = 38^{\circ}C$ reported by McDowell (1972). The fact that the sweat rates shown in Figure 11 indicate that the cows sweated less when fed thyroprotein at high ambient temperatures should not be credited with much importance - the difference between Treatment 37 and Treatment 37 + IC was not statistically significant, the coefficient of variation was 41.8%, and there were limitations to the accuracy of the techniques employed, which will be discussed in section IX.

VIII(b) 7 <u>Metabolic heat production</u>. The mean metabolic heat production of the cows was $41.14 \pm 6.42kJ/hr/LW^{0.75}$ and when corrected for milk production $27.14 \pm 4.69kJ/hr/LW^{0.75}$. These results are comparable to the 600k cal/hr/cow (= $23.9kJ/hr/LW^{0.75}$, assuming the cow weighed 500kg) recorded by Kibler & Brody (1953), and the 8 000 k cal/24hr for a fasting steer (= $13.3kJ/hr/LW^{0.75}$, assuming the steer weighed 500kg) reported by Blaxter (1965). The oxygen consumption, carbon dioxide and methane production figures are tabulated in Appendix 10, but for convenience sake the derived heat production data is given in Table 15. The difference between the heat production of the high yielding cows (cows 3 and 6, Table 15a) and low yielders, was significant at $p < 0.001$ (Appendix 4 o(i)). However, when the heat production data was corrected for milk production, it was found that the high yielders (cows 3 and 6, Table 15b) produced less heat than the low yielders ($p < 0.05$) (Appendix 4 o(ii)). Note that cow 6 produced 25kJ/hr/LW$^{0.75}$ in the process of milk secretion, which is more than half her total heat production, whereas in cow 1, the lowest yielder, the figure was 5kJ/hr/LW$^{0.75}$, which is 15% of her total heat production.

Exposure to high ambient temperatures depressed heat production by 4.3%, which was not statistically significant ($p > 0.05$). Feeding thyroprotein markedly increased the cows' heat output by 5.6% (when compared to Treatment 21) which was statistically significant ($p < 0.05$), and by 10.3% when compared to Treatment 37.

Table 15a

Heat production (kJ/hr/LW$^{0.75}$)

Treatment	37 + IC	21	37	Mean of cow
Cow 1	37.2	35.6	35.2	36.00
3	48.3	48.5	42.5	46.43
4	35.9	34.5	34.1	34.83
6	50.7	44.4	44.1	46.40
Mean of Treatment	43.03	40.75	38.98	41.14

Table 15b

Heat production (kJ/hr/$LW^{0.75}$) corrected for milk production.

Treatment	37 + IC	21	37	Mean of cow
Cow 1	30.9	29.9	30.8	30.53
3	31.7	32.5	26.4	30.20
4	26.8	26.1	26.7	26.53
6	23.9	19.4	20.9	21.40
Mean of Treatment	28.30	26.97	26.20	27.14

Correction for milk production: Subtract 62% of

$$\frac{4.94 \text{ (MJ) x milk produced (l/hr)}}{LW^{0.75}} \text{ from}$$

the total heat production calculated for the animal.

According to M.A.F.F. (1975):

62% is the efficiency of ME utilisation for lactation.

4.94 MJ is the ME required to produce 1kg of milk.

$LW^{0.75}$ is the animal's metabolic liveweight.

Cow 1 and 6 were again individually responsible for the difference between cows, and between high and low yielders. Their Ht values were 41.9 ± 4.7% and 32.7 ± 2.8% respectively.

VIII(c) Other results

VIII(c) 1 Feed refusal. At no time did cow 1 or 4 refuse any feed offered. Cows 3 and 6, the high yielders, left some feed on several occasions. On most occassions loss of appetite could be related to some management factor.

Table 16

Feed refusal

Cow	Amount of feed left (kg)	Treatment at that time	Related factor
6	2.9	37 + IC	In "tent"
6	4.2	21	Drinking water off
6	1.3	21	Day after water off
6	3.7	21	In "tent"
6	2.4	21	Digestibility trial
6	1.5	37	Digestibility trial
6	0.5	37	-
6	4.4	37	In "tent"
6	4.0	37	Feed water-logged
6	2.0	37	-
6	3.5	37	-
6	2.8	37	-
3	3.2	21	In "tent"
3	1.2	21	Day after tent
3	2.0	21	-

It is not particularly surprising to find that spending 24 hours in the "tent" put cows off their feed, nor that water deprivation affected food intake. What is possibly unusual, is the fact that cow 6 did not finish her feed when digestibility trials were conducted - she should hardly have been disturbed by the simple experimental procedures associated with conducting a digestibility trial. It is notable that only once while iodinated casein was being fed did one cow leave some feed, and for a "good reason" (Table 16). However, when ambient temperatures rose to 37°C, without thyroprotein supplementation (Treatment 37) cow 6 refused feed for no apparent reason on four occassions.

These results were not considered suitable for statistical analysis.

VIII(c) 2 Water intake. This experiment was plagued by technical malfunctions in the water supply system, which rendered the water intake data unreliable.

Table 17

Water intake (l/day)

Cow	Normal requirement*	Treatment 21	Treatment 37	Treatment 37 + IC
1	57.2	45	50	49
3	90.8	81	84	95
4	58.1	48	49	55
6	97.0	87	87	85
Mean		62	68	71

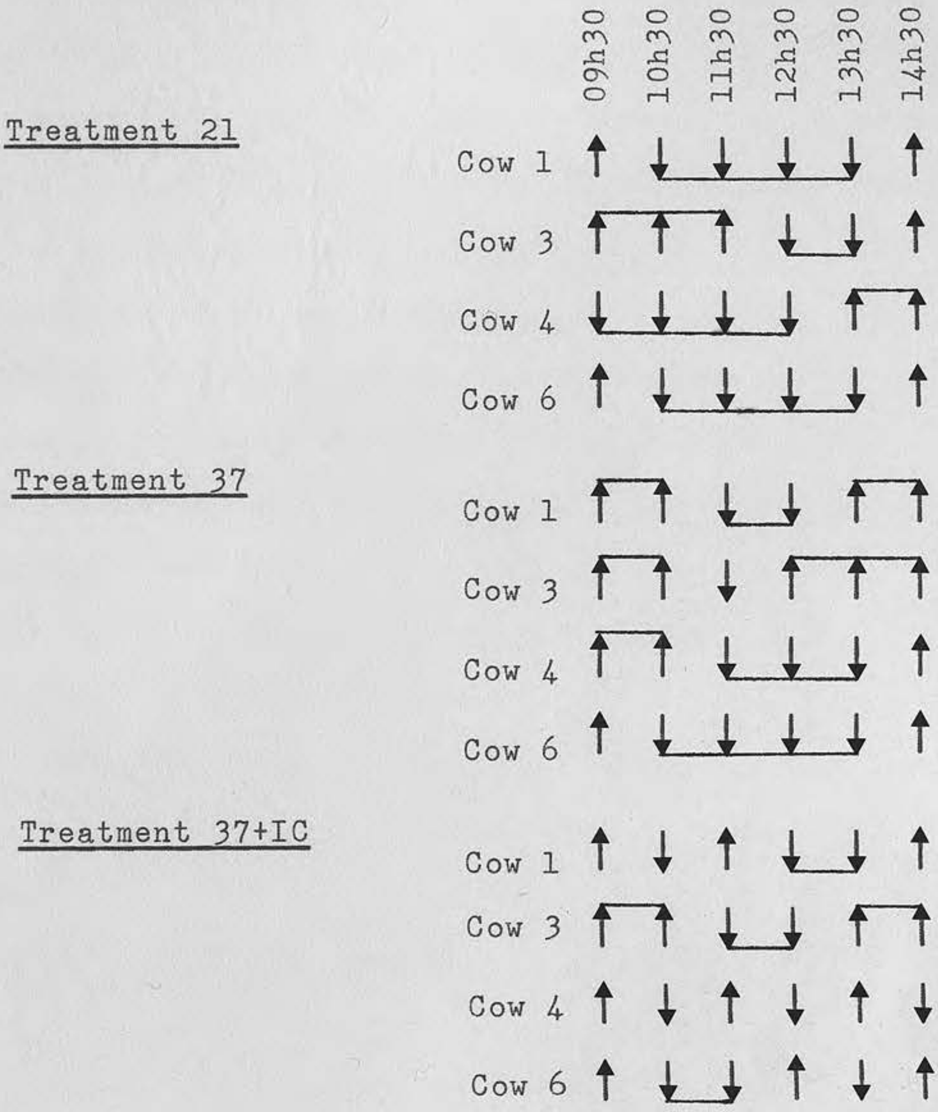
* ARC (1965)

According to the analysis of variance (Appendix 4p(i)) there was no significant treatment effect. From Table 17 it appears that high ambient temperatures promoted water intake, which is quite likely since feed intake remained fairly constant. The very significant difference between the high yielders (87 ± 51) and low yielders (49 ± 31) was largely due to the water required for milk secretion. Taken as a percentage of Treatment 21, the high yielding cows did not exhibit a significantly higher relative water requirement than low yielders when ambient temperatures increased (Appendix 4p(ii)), and it is thus concluded that in respect of water intake the high yielding cows were not more affected by high ambient temperatures than low yielders. Iodinated casein supplementation did not appear to have an effect on water intake.

VIII(c) 3 Behaviour. Chi squared tests were carried out to see if cows preferred lying or standing during the various phases of the experiment, but there were no significant differences. However, the number of changes in posture increased during Treatment 37 + IC (Fig 13) which was significant at $p < 0.05$(Appendix 4q). These results hint at a degree of restlessness when cows were fed thyroprotein, but overt excitement or irritability was not reported.

Figure 13

A Diagram Showing the Posture Adopted by the Animals During the "Full Clinical" Days



Postures were recorded on entering the climate chambers.

↓ = lying ↑ = standing

IX. DISCUSSION

IX(a) The Experiment.

When interpreting the results of this experiment, constraints such as the small number of animals involved and the short time period should be taken into consideration. Trends which were found to be statistically significant cannot be accepted without circumspection, and statistically insignificant trends may deserve some attention. These disadvantages are balanced by the care which could be exercised in carrying out the experiment, the depth of the investigation, and the comparisons which could be drawn between the cows.

The experimental design may have been improved on had Treatment 37 preceded Treatment 37 + IC in the case of two cows, as shown in Figure 14.

Figure 14

The Experimental Design Used.

Cow 1 & 6	21a	37 + IC	21b	37	21c	-
Cow 3 & 4	-	21a	37 + IC	21b	37	21c

A Redesign of this Experiment

Cow 1 & 6	21a	37 + IC	21b	37	21c
Cow 3 & 4	21a	37	21b	37 + IC	21c

Factors like stage of lactation, acclimation, after-effects of treatments, and cows becoming accustomed to experimental procedures would have been obviated.

Housing the animals in pairs was advantageous because it permitted a degree of social interaction between the cows, and treatments could be carried out simultaneously. A major disadvantage was that the humidistats were not able to cope with the high vapour pressures generated by the cows. (See Appendix 3 for details). Consequently, RH was very high, especially during Treatment 21. The degree to which cows were upset by being isolated and incarcerated in the "tent" could not be gauged.

Other problems, such as leaking water supply lines and cow 6 suffering mild dysphagia at strategic times, were to be expected in experiments of this nature.

Throughout the study it was noted that cows 1 & 6 generally responded to treatments differently to cows 3 & 4. One of the reasons for this can be found in Table 18: The climate chamber in which cows 3 & 4 were housed took three to four hours to reach maximum temperature during Treatments 37 and 37 + IC, while the room containing cows 1 & 6 took two hours. Cows 1 & 6 were also exposed to maximum temperatures 1-2°C higher than cows 3 & 4.

Constant reference is made to the cows being high yielders or low yielders. It must be pointed out that the difference in their milk yields was almost entirely a function of stage of lactation. Their previous records show that all four cows were capable of producing 3 000 - 4 000 kg/lactation.

IX(b) Production Parameters

IX(b) 1 Milk Production. Since the milk production results were suitable for comparison to each other in the

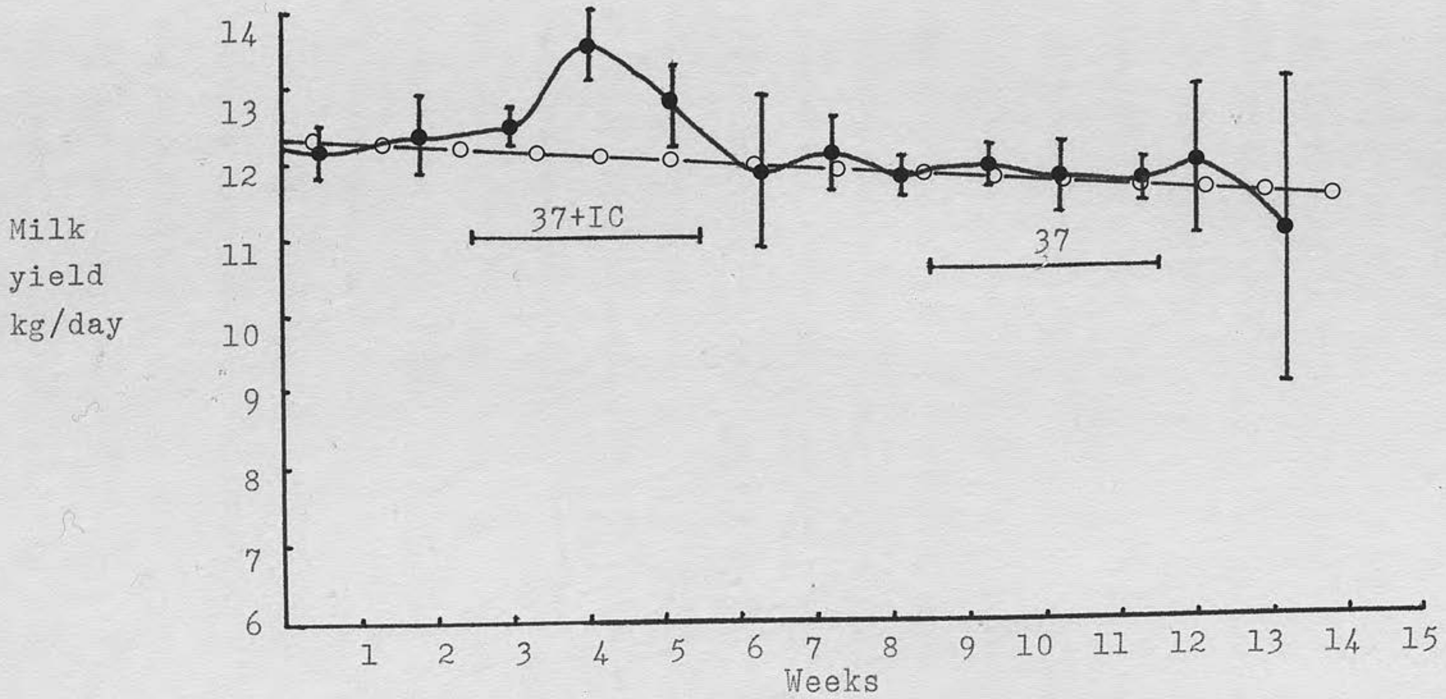


Figure 15. The Effects of the Treatments on Milk Production.

●—● The mean of the four experimental cows' milk yields.

○—○ "Normal" lactation curve.

statistical analyses, it was considered acceptable to compile a composite graph (Fig. 15) to illustrate the general trends observed. (Strictly speaking it is not correct to combine the results like this because the cows were at different stages of lactation, the treatments were not executed at the same times, and there were very significant differences between the cows in respect of milk yield ($p < 0.001$, Appendix 4a)).

The "normal" lactation curve shown in Figure 15 is similar in slope to the "normal" lactation curves published by Wood (1969) after examining the milk production records of 859 Friesian lactations. The approximately 10% increase in milk production due to feeding iodinated casein (Treatment 37 + IC) is slightly less than reported by others (Thomas _et al_, 1954), but is quite in keeping with the expected response when cows are offered limited amounts of feed and low doses of thyroprotein (Turner, 1970). The response to thyroprotein was not as persistent as previously reported (Thomas, 1953), and illustrated in Figure 2. A possible reason for this becomes evident when thyroid function is discussed later in this section. On cessation of thyroprotein feeding, milk yield did drop slightly below "normal", but not as much as described by Blaxter (1945), Thomas _et al_ (1954) and Moore (1958). This was ascribed to the fact that the earlier workers administered higher doses of thyroprotein than used in this experiment. Secondly, Swan (1976) clearly showed that providing extra feed to dairy cows markedly increased their milk production. If the cows in this experiment had been fed levels in excess of their calculated requirements, as happened in the trials of Blaxter (1945) and the others, it is reasonable to expect that their "normal" milk yields would have been higher, and their response to thyroprotein magnified. The thought then arises whether the post-thyroprotein decline in milk production may not have been more severe? However, providing extra feed is the very method recommended by Blaxter (1945), Thomas _et al_ (1954), Moore (1958) and Turner (1970) for preventing the post-thyroprotein decline in milk production from dropping to levels below "normal".

There was a purpose in feeding the cows to requirement. Since they increased milk production and lost body weight when thyroprotein was fed, and nutrient intake was constant, it may be concluded that iodinated casein promotes milk secretion at the expense of body tissue. This concurs with current theories on the role of thyroxine in the partition of energy between milk production and body tissues (Bines & Hart, 1978; Carroll, 1975; Turner, 1970). The physiological principles involved are complicated. There seem to be three theories:

i) Iodinated casein improves the efficiency of energy utilisation for lactation, modifies rumen VFA's, and stimulates general metabolism.

ii) Iodinated casein promotes lactogenesis by a direct effect on mammary tissue, alters hormonal balances, and promotes milk secretion at the expense of body tissues.

iii) A combination of (i) and (ii).

A review of the literature (section V) indicates that (iii) is the most plausible.

There was little or no milk yield depression during heat exposure without thyroprotein (Treatment 37) (Fig. 15). Since the clinical parameters show that the cows did suffer from heat stress during Treatment 37, the non-depression of milk yield is at odds with the literature (Bianca, 1965; Mount, 1979; Webster, 1976). A possible explanation may be that the cows were not producing milk to maximum capacity because feed intake was limited to calculated requirements, and milk yield was therefore less sensitive to unfavourable environmental conditions. A further consideration may be that the cows were exposed to a short period (three weeks) of diurnal heat loads (4-6 hours) and were able to recover at night (18 hours). Such a phenomenon has been reported by Ansell (1976) and is in line with the thinking of Berman (1968), Holder (1960) and Schmidt-Nielsen (1979).

The steep decline in milk yield at the end of the experiment (Fig 15) is attributed to the terminal decline in lactation experienced by cow 1, and mastitis in cow 6. The sharp drop in milk yield when cows were deprived of drinking water (Fig 6) further emphasizes the important role of management in dairy farming.

IX(b) 2 Liveweight Changes. The loss of weight by cows while being fed thyroprotein and the subsequent rapid regain thereof after thyroprotein withdrawal is in keeping with the literature (Thomas *et al*, 1954). Since nutrient intake was constant and there was no meaningful change in dry matter digestibility, the leveweight gain recorded on cessation of thyroprotein administration can be likened to the efficient liveweight gain of hypothyroid animals reported by Gardner & Millen (1950). The possible use of thyroid suppressants such as thiouracil, or the induction of mild goitre by limiting iodine intake in fattening steers may warrant further investigation.

The fact that cows regain their body weight after thyroprotein withdrawal, without being offered extra feed, is important when evaluating the economic pros and cons of feeding iodinated casein.

IX(b) 3 Dry matter digestibility. It is not clear from the literature whether DMD% increases or decreases due to high ambient temperatures and/or thyroprotein feeding (see Literature Review, section V), but it does seem as though the changes observed are small. The finding that, in this experiment, there was no significant change in dry matter digestibility, was therefore not surprising. The extent to which the digestibility data was invalidated by cow 6 not finishing her feed at times, the mild diarrhoea observed in cow 3 at one stage, and the inexplicably varied DMD% recorded for cow 1 (Table 9), can only be surmised.

IX(c) Health and Heat Stress.

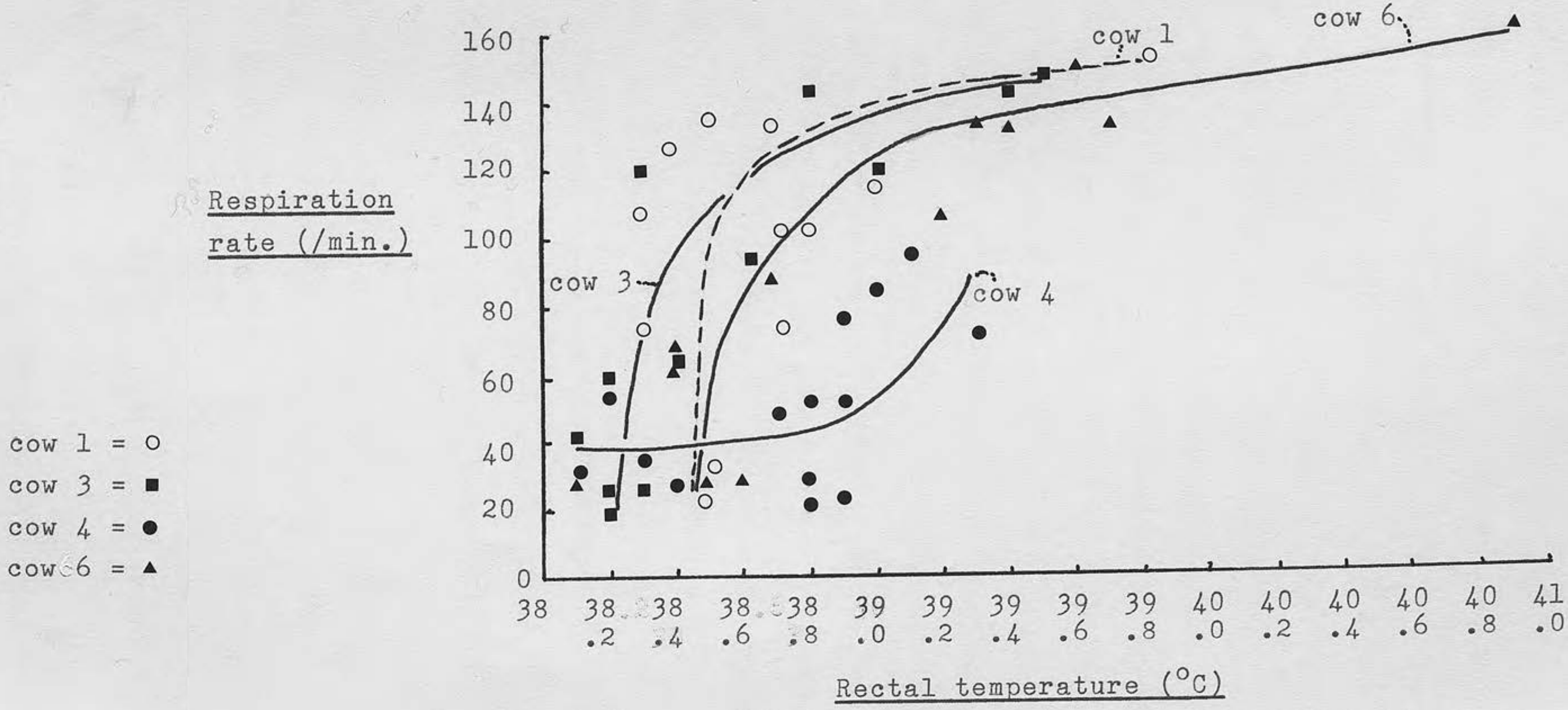
A pertinent point which needed clarifying was whether feeding iodinated casein to heat stressed dairy cows exacerbated or alleviated the effects of the environment. This experiment indicated that, clinically, cows were only slightly more distressed by high ambient temperatures when thyroprotein was administered. The lower sweat rates recorded while feeding thyroprotein at $T_A = 37^oC$ may imply that the cows were quite able to cope with the additional heat produced. Alternatively, thyroprotein may directly inhibit sweating; reference to such a mechanism was not found in the literature. In spite of the unfavourable environment, feeding iodinated casein did stimulate milk production.

IX(c) 1 <u>Clinical parameters</u>. As was expected, the increase in respiration rate closely followed increases in ambient temperature. Referring to Figures 9 and 16, it can be seen that normal rectal temperature was maintained until a certain stage. As ambient temperature approached 37°C, and respiration rate 70-80/min, T_R was "released" from its normal level. Apparently respiratory and other heat dissipating mechanisms were unable to wholly counteract the heat of the environment and heat storage was initiated. This could be construed as a disruption of thermoregulation (Bianca, 1963), but Ansell (1976) and Schmidt-Nielsen (1979) may support a suggestion that such lability of rectal temperature is a normal thermoregulatory response.

The individual responses of the cows as shown in Figure 16 deserves attention. Cow 1, the lowest yielder, was able to maintain $T_R = 38.4$ by increasing her respiration rate until quite a late stage of heat stress, when her respiration rate reached 100/min ($T_A = 35\text{-}37^oC$). Cows 3 and 6, the high yielders, showed a remarkably similar

Figure 16

The Relationship Between Respiration Rate and Rectal Temperature: Results recorded at various ambient temperatures and humidities.



response to heat stress. Both maintained normal rectal temperatures until their respiratory rates reached 60/min (T_A = 34-35°C) and then a gradual T_R increase occurred. The line of best fit drawn for cow 4 may well be a misrepresentation. Although a straight line or some other shape curve may be proposed, the fact remains that she did not respond to heat loads as the other cows did. When ambient temperature increased, cow 4's rectal temperature increased, while her respiration rate remained fairly constant until T_R = 38.8°C (T_A = 35°C). It was thought that it may be possible to predict a cow's heat tolerance capacity by testing the degree of heat stress she could endure without increases in T_R occurring, but this theory is somewhat confounded by cow 4. According to the above mentioned hypothesis, cow 1 would be the most heat tolerant, but during Treatment 37 her milk production decreased by 20%. (This may have been an anomaly induced by the very late stage of lactation.) Cows 3 & 6, the high yielders, showed a decrease in milk production of 5% and 1% respectively, during Treatment 37, while cow 4 increased milk production on exposure to heat, albeit by less than 1%.

Since the requisites of the Iberia Heat Tolerance test (Rhoad, 1944), the Rainsby test (Dowling, 1956), and other heat tolerance tests had not been complied with, the results of this experiment could not, in good faith, be used in the equations developed for those tests.

Clinically, the effect of feeding iodinated casein to the cows when exposed to heat loads was shown in Figures

12a-d to be almost imperceptible. Respiration rate was marginally affected by thyroprotein supplementation (Fig. 8), but it will be noted from Figure 9 that by 14h30, when ambient temperature had been 35-38°C for two to three hours, the rectal temperatures of the cows in Treatment 37 + IC were clearly higher than those recorded in Treatment 37. Thereafter, ambient temperatures dropped rapidly because the doors of the climate chambers had to be opened to facilitate milking. As a result, there may be speculation as to whether T_R would have risen higher than Figure 9 shows, if ambient temperature had declined slowly after about 16h00, as would be the case under natural conditions in the tropics. If an additional two to three hours of exposure to heat loads caused the animals to suffer from hyperthermia as a result of the thyroprotein in the diet, the conclusions drawn from this experiment would be seriously challenged. The available data, however, indicates that the cows were not more stressed whether they were fed thyroprotein or not during periods of exposure to high ambient temperatures.

Various heat stress indices (Appendix 3) correlated about equally well to respiration rate and rectal temperature. Clearly, respiration rate was the most sensitive indicator of heat stress. It is interesting to note that using rectal temperatures taken one hour after the environmental factors did not improve the correlation between T_R and heat stress index. This could be because the increase in T_R when T_A increased, was not linear (Fig 9).

Of all the heat stress indices, dry bulb temperature per se gave the best correlation factor to respiration rate and to rectal temperature (Appendix 3). This is contrary to current thinking (Bianca, 1962; Cargill et al, 1962; McDowell, 1972; Mount, 1979; Lawrence, 1978). The most plausible explanation is that RH was consistently high and so, effectively, the only variable environmental factor was temperature.

IX(c) 2 Haematology. The haematology results were, with one exception, all within the normal range for cattle (Anon, 1979; Kelly, 1976). The exception was the WBC count of 14 200 leucocytes/ml recorded for cow 3 during Treatment 21. This was an increase of 5 000 WBC/μl within five hours, and not inconsistent with changes usually associated with pathological processes (Coles, 1974). A differential leucocyte count was not done, nor were follow-up tests executed since the cow's habitus and rectal temperatures were not indicative of illness at that time. A week later a vulvar discharge was observed and cow 3 suffered an otherwise uneventful abortion. Another consideration is the flushing effect that increased blood circulation (due to exercise, fear, hyperthermia, or any other cause) has on white blood cells. Neutrophils, especially, are mobilised from recesses in the body where blood flows slowly, and circulating WBC counts quickly rise (Coles, 1974; Ganong, 1975). This would explain why afternoon WBC levels were consistently higher than morning levels. It could be postulated that feeding iodinated casein increases blood circulation and would therefore increase WBC; in this experiment the thyroprotein did not significantly increase the cows' pulse rates, nor could any effect on WBC be detected.

The expansion of extra-cellular fluid volume when ambient temperature rises, with a resultant dilution of blood cells (McDowell et al, 1969) explains the decrease in RBC, Hb, and Ht recorded in the afternoons. Note that even during Treatment 21 the afternoon temperatures sometimes reached 24°C (Table 18) while night time temperatures were below 21°C. At no stage did iodinated casein have a statistically significant effect on haematology, but erythrocyte parameters were consistently lower during Treatment 37 + IC as compared to Treatments 37 and 21. Large amounts of iron are not usually lost from the body during normal red blood cell catabolism (Brander & Pugh, 1971; Ganong, 1975). Unless haemorrhage or erythrolysis occurs, the iron is recycled. However, it may be desirable to add haematinics like iron, copper, cobalt, etc., to diets when iodinated casein is used so that raw materials would be available for erythropoiesis, should there be an increased demand for RBC production when the animal's metabolic rate increases. This purpose would probably be served if additional feed was supplied, as is recommended by Turner (1970) and others.

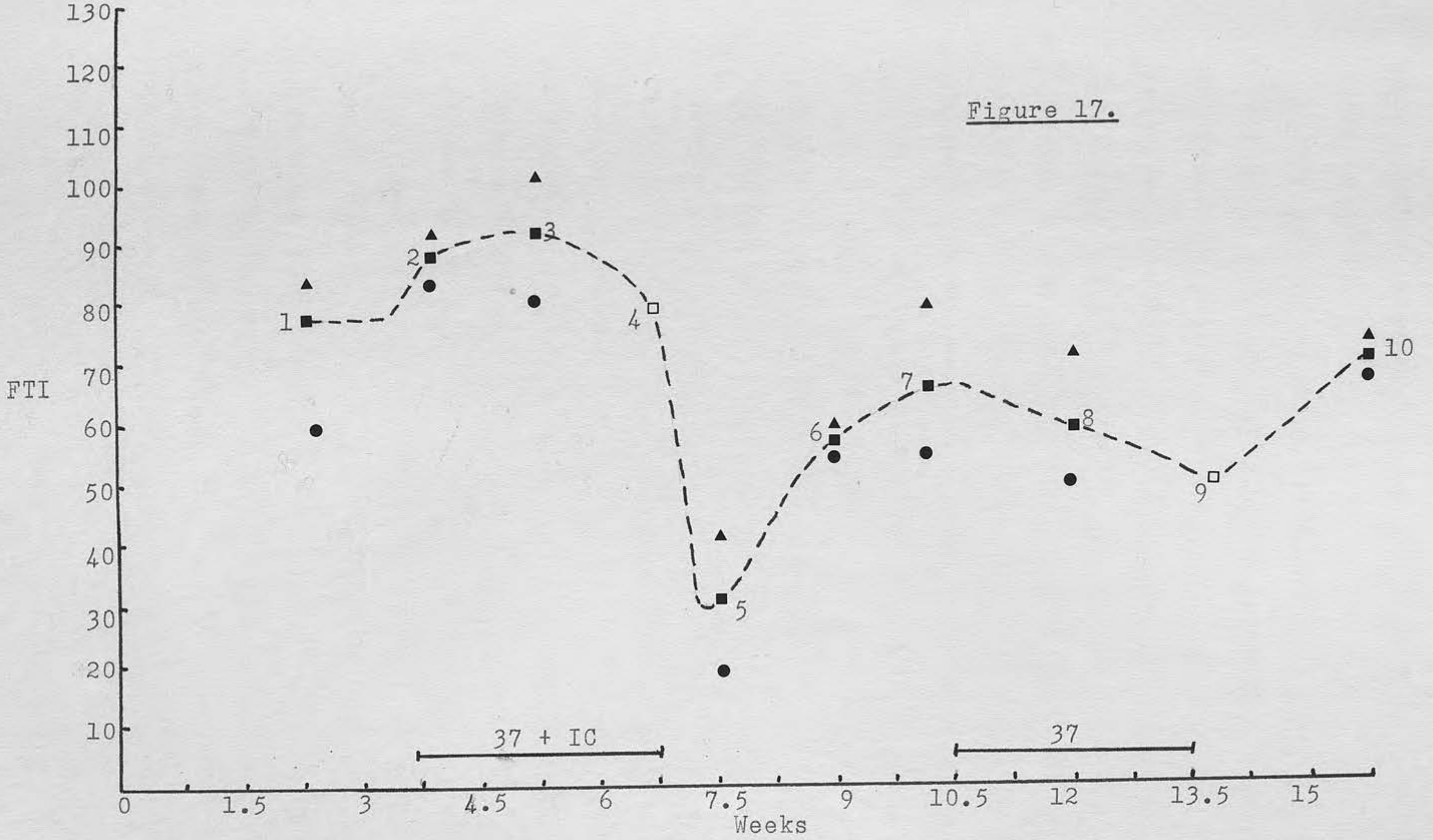
IX(c) 3 Thyroid function. The results of the thyroid hormone tests recorded during Treatment 21a are comparable to the published normal values for cattle (Appendix 8).

The Free Thyroxine Index is reported to be the best general test of thyroid function in humans (Anon, 1978); Kallfelz & Erali (1973) concluded that it was not particularly suitable for use in the dog; no reports on the merits or demerits of the FTI in cattle could be found. Since Kallfelz & Erali (1973) proceded by including a "normal" FTI for cattle in their authoritative publication, it was decided to use the FTI as the prime indicator of plasma thyroid hormone status in this study.

Figure 17 was compiled by pooling the results from the four cows. Their "normal" FTI seems to have been in the region of 70-75 (T_4 in n mol/l; Thyopac-3). When the cows were fed thyroprotein the FTI understandably rose. On cessation of thyroprotein administration it dropped down to 30-35 (T_4 in n mol/l; Thyopac-3). The thyroid gland then resumed secretion and "normal" plasma thyroid hormone levels were recorded approximately three weeks later, as predicted by Turner (1970). However, the cows appeared clinically normal directly after the withdrawal of iodinated casein.

In Figure 17, point 4 was postulated because a sharp decline in FTI prior to cessation of thyroprotein feeding could not be reasonably justified. In response to thyroprotein feeding, the half-life of plasma thyroxine declines from 2.47 days to 1.05 days (Premachandra & Turner, 1962). Thus, as was shown by Shaw et al (1975), plasma T_4 increases sharply when iodinated casein is fed, but soon peaks and then settles to a level well below the expected, but still above the cow's normal endogenous

Figure 17.



FTI derived from T_4 in n mol/l,and Thyopac-3 values.

▲ Values actually recorded for low yielding cows.

● Values actually recorded for high yielding cows.

■ Mean values.

□ Postulated values.

level (assuming enough iodinated casein is offered). The decline in FTI from point 7 to 8, and presumably 9, is interpreted as the well documented thyroid suppression when cows are exposed to high ambient temperatures (Bianca, 1965).

The poor persistence of response to thyroprotein referred to earlier, when discussing milk production, is explained by the FTI levels shown in Figure 17. The low rate of supplementation with iodinated casein (7.5g/cow) was barely enough to push plasma T_4 levels above normal (Turner, 1970), and with the increased rate of T_4 excretion (Premachandra & Turner, 1962) it is possible that plasma thyroid hormone concentrations declined to a level (point 4?) so close to, or even within, the cows' normal range that late in Treatment 37 + IC stimulation of milk production was not achieved. This would also have contributed to the slightness of the milk depression after withdrawal of thyroprotein. It is therefore concluded that the levels of 7.5g iodinated casein/cow (0.6g/45kg) used in this experiment were the minimum which would elicit a response. This response may not be sustained, but feeding 7.5g iodinated casein per cow would be ideal for maintaining plasma thyroxine levels in heat stressed dairy cows, and in so doing would prevent any decline in milk production due to thyroid suppression. It is thus envisaged that a low level of thyroprotein (7.5g/cow/day) may be fed to dairy cows in the tropics throughout the declining phase of lactation, not to stimulate milk production, but to prevent its suppression.

Relevant field trials have been conducted, by Stanley & Morita (1968). They concluded that 1g per 100lb body weight (1g/45kg) would be required to stimulate production. Their publication does suggest that Hawaiian conditions were hot enough to cause thyroid suppression, but the Met. Office (1966) reveals that in August the average daily temperatures range from 68-82°F (20-28°C) with 88°F (31°C) being the maximum. The climate is therefore not as harsh as elsewhere in the tropics, and it is not unreasonable to suspect that the control cows used by Stanley & Morita may not have suffered from heat stress; neither clinical parameters nor thyroid function tests are cited.

IX(c) 4 Sweat rates. The criticism of the capsule technique hinted at earlier is all that remains to be discussed here. It has been found that holding the cup in position for 10 minutes rather than 5 minutes gives a more accurate result (Richards, 1980); as pointed out before, the 5 minute technique was considered adequate for the comparative purposes of this experiment.

IX(c) 5 Heat production. The increase in metabolic heat production associated with the feeding of iodinated casein to dairy cattle was the reason why various authors (Blaxter, 1945; Thomas, 1953; Moore, 1958; McDonald, 1977; and others) thought that thyroprotein use in hot environments was contra-indicated. They did, however, base their opinions on (rational) extrapolations of their findings under temperate conditions, and supported them by quoting each other. This trial seems to be one of the few which specifically examined the heat production - heat stress relationship while feeding thyroprotein under controlled environmental conditions. The above mentioned authors are partly vindicated and partly challenged: Feeding iodinated casein to heat stressed cows did increase their metabolic heat production, but the clinical parameters indicated that the cows were able to cope with the additional heat load, and were not more distressed thereby.

IX(c) 6 Other. The aetiology of the vulvar discharge from cow 1 in the 3rd week of the experiment was not ascertained. However, it was similar to episodes in other experiments where cows were exposed to high ambient temperatures (Richards, 1980). There was no evidence to suggest that it had been induced by the iodinated casein, and the literature does not recognise iodinated casein as an abortifacient.

IX(d) Conclusion.

In conclusion, a few generalisations are risked:

i) Cows respond to thyroprotein administration in a hot environment much as they would in a cool climate.

ii) Low levels of thyroprotein supplementation, fed over a short period, do not exacerbate heat stress in lactating dairy cows, if diurnal variations in ambient temperatures allow the cows to recover at night.

It is envisaged that low levels of thyroprotein supplementation (7.5g/cow) may be of use in well managed dairy herds to prevent milk yield depression due to hot environmental conditions. Feeding 8-12g/cow, plus extra feed, may be used to temporarily boost milk production so that maximum advantage can be taken of market fluctuations, or at times when difficulty is experienced in fulfilling milk supply quotas which are legally binding. Factors like the disquieting loss of body weight, post-thyroprotein depression of milk yield, and the great variation between cows in their response to iodinated casein should be kept in mind.

There may be some benefit in feeding thyroprotein to male and/or female farm animals where subfertility is associated with heat stress and hypothyroidism.

Where acute heat stress is anticipated, for example when temperate breeds of cattle are exported to tropical countries, maintenance of milk production by feeding thyroprotein may be contemplated, provided the degree of heat stress is not so severe as to cause concern for the well-being of the animal.

Before instituting the above mentioned suggestions, they will have to be tested in field trials, and the economic advantages and disadvantages taken into consideration.

The logical follow up to this study would be to perform a similar experiment, but to feed the cows ad libitum.

X. BIBLIOGRAPHY

ABILAY, T.A., MITRA, R. & JOHNSON, H.D. (1975) Plasma cortisol levels and total progestin levels in Holstein steers during acute exposure to high environment temperature (42°C) conditions. J.Anim.Sci. 41(1) 113 - 117

AGRICULTURAL RESEARCH COUNCIL (1965) Ruminants Technical Review No.2

AITKEN, J.N., BOYNE, A.W. & CRICHTON, J.A.J (1953) The effect of feeding iodinated casein and L-thyroxine upon the health, reproduction and yield of a dual-purpose breed of cattle and a dairy breed. J.Dairy Sci. 20 291 - 300

ALEXANDER, F. (1969) Veterinary Pharmacology : An introduction to. 2nd ed. E.S.Livingstone Ltd., London.

ALVAREZ, M.B. & JOHNSON, H.D. (1973) Environmental heat exposure on cattle plasma catecholamines and glucocorticoids. J.Dairy Sci. 56(2) 189 - 194

ALVAREZ, M., ROBERTSON, W.D., HAHN, L., YOUSEF, M.K. & JOHNSON, H.D. (1967) Pyysiological responses of the bovine to catecholamine. J.Anim.Sci. 26 940

ANDERSON, R.R. (1978) Personal communication. (Prof., Dept.Dairy Husbandry, Univ.Missouri-Columbia)

ANNISON, C.F. (1976) Energy utilisation in the body. In Principles of Cattle Production (ed. Swan & Broster) Butterworths, London.

ANON. (1962) Scientific Tables 6th ed. Documenta Geigy. (ed. Konrad Diem) Geigy Pharmaceutical Co.

ANON. (1966) <u>Handbook of Chemistry and Physics</u> 46th ed. The Chemical Rubber Co., Ohio.

ANON. (1972) Revocation of iodinated casein for sows. <u>Dairy Sci.Abs.</u> <u>34</u> 2567 (Abstract)

ANON. (1976a) Thyopac-3, Kit for T_3uptake test. The Radiochemical Centre, Amersham, England.

ANON. (1976b) RIA kit for the immunoassay of serum T_3 (liothyronine). The Radiochemical Centre, Amersham, England.

ANON. (1978) New T_3 uptake (MAA) kit. The Radiochemical Centre, Amersham, England.

ANON. (1979) <u>The Merck Veterinary Manual</u> 5th ed. (ed. Siegmund,O.H.) Merck & Co., Rahway, New Jersey.

ANSELL,R.H. (1976) Maintaining dairy cattle in the Near East. <u>Wld.Anim.Rev.</u> <u>20</u> 1 - 7

ATTEBERY,J.T. & JOHNSON,H.D. (1969) Effects of environmental temperature, controlled feeding and fasting on rumen motility. <u>J.Anim.Sci.</u> <u>29</u> 734 - 737

BAILEY,G.L., BARTLETT,S. & FOLLEY,S.J. (1949) Use of L-thyroxine by mouth for stimulating milk secretion in lactating cows. <u>Nature</u> <u>163</u> 800

BARCROFT,J. (1944) The preparation and biological effects of iodinated proteins: Introduction. <u>J.Endocrinol.</u> <u>4</u> 219 - 220

BARRETT,M.A. & LARKIN,P.J. (1974) <u>Milk and Beef Production in the Tropics</u>. Oxford Univ. Press.

BAUMAN,T.R., HINDERY,G.A. & TURNER,C.W. (1965) Resumption of thyroid stimulating hormone secretion as shown by I^{131} uptake in cattle after graded withdrawal of thyroxine. <u>J.Dairy Sci.</u> <u>48</u> 484

BELDING,H.S. (1970) The search for a universal heat stress index. In Physiological and Behavioural Temperature Regulation. (ed. Hardy,J.H. et al) Thomas Springfield.

BERMAN,A. (1968) Nychthemeral and seasonal patterns of thermoregulation in cattle. Aust.J.Agric.Res. 19 181 - 189

BERMAN,A., AMIR,A. & VOLCANI,R. (1963) The relationship between the rate of heat production and the level of milk production in a subtropical climate. Aust.J.Agric.Res. 14 874 - 881

BIANCA,W. (1962) Relative importance of dry- and wet-bulb temperature in causing heat stress in cattle. Nature 195 251 - 252

BIANCA,W. (1963) Rectal temperature and respiration rate as indicators of heat tolerance in cattle. J.Agric.Sci. 60 113 -120

BIANCA,W. (1965) Reviews of the progress of dairy science. Section A: Physiology. Cattle in a hot environment. J.Dairy Res. 32 291 - 345

BIANCA,W. & FINDLAY,J.D. (1962) The effect of thermally induced hyperpnoea on the acid-base status of the blood of calves. Res.Vet.Sci. 3 38 - 49

BINES,J.A. (1976) Factors influencing the voluntary food intake of cattle. In Principles of Cattle Production (ed. Swan & Broster) Butterworths, London.

BINES,J.A. & HART,I.C. (1978) Hormonal regulation of the partition of energy between milk and body tissue in adult cattle. Proc.Nutr.Soc. 37 281 - 287

BLAGDEN, C. (1774) Experiments and observations in a heated room. <u>Phil. Trans. Roy. Soc</u>. <u>65</u> 111 - 123

BLAXTER, K. L. (1945) The preparation and biological effects of iodinated proteins: The effect of iodinated protein feeding on the lactating cow. <u>J. Endocrinol</u>. <u>4</u> 266 - 299

BLAXTER, K. L. (1946) Experiments with iodinated casein on farms in England and Wales. <u>J. Agric. Sci</u>. <u>36</u> 117 - 150

BLAXTER, K. L. (1965) <u>The Energy Metabolism of Ruminants</u> Academic Press, London.

BLAXTER, K. L. & WAINMAN, F. W. (1961) Environmental temperature and energy metabolism and heat emission of steers. <u>J. Agric. Sci</u>. <u>56</u> 81 - 90

BLIGH, J. & LAMPKIN, G. H. (1965) A comparison of the deep-body temperature of Hereford and Zebu cows recorded continuously by radio-telemetry under similar field conditions. <u>J. Agric. Sci</u>. <u>64</u> 221 - 227

BLOOD, D. C., HENDERSON, J. A. & RADOSTITS, O. M. (1979) <u>Veterinary Medicine</u> 5th ed. Bailliere Tindall, London.

BOGDONOVE, E. M. (1980) Trypsin-dispersed pituitary cells certainly can release prolactin in response to TRH. <u>Dairy Sci. Abs</u>. <u>42(2)</u> 862 (Abstract)

BONSMA, J. C. (1949) Breeding cattle for increased adaptability to tropical and subtropical environments. <u>J. Agric. Sci</u>. <u>39</u> 204 - 221

BONSMA, J. C., SCHOLTZ, G. D. J. & BADENHORST, F. J. G. (1940) Die invloed van klimaat op beeste: Vrugbaarheid en gehardheid van sekere rasse. <u>Boerdery in Suid-Afrika</u> Jan. 1940.

BOOTH, A.N., ELVEHJEM, C.A. & HART, E.B. (1947) Some effects of feeding iodinated casein to dairy cows. J.Dairy Sci. 30(7) 443 - 455

BOOTS, L.R., LUDWICK, T.M. & RADER, E.R. (1970) Plasma glutamic-oxaloacetic and glutamic-pyruvic transaminase activities in lactating Holstein dairy cattle. J.Dairy Sci. 53(11) 1587 - 1591

BRANDER, G.C. & PUGH, D.M. (1971) Veterinary Applied Pharmacology and Therapeutics 2nd ed. Bailliere Tindall, London.

BROUWER, E. (1965) In Energy Metabolism of Ruminants (ed. Blaxter, K.L.) p 441-443 Academic Press, London.

BROWN, G.R. (1978) Research indicates implant may cut heat stress. Ralgro Reprint, IMC Vet.Prod.Division Terre Haute, Indiana.

BRYSON, R.A. & HARE, F.K. (1974) Climates of North America. In World Survey of Climatology (ed. Landsberg) Elsevier Scientific Publishing Co., New York.

CARGILL, B.F., STEWART, R.E. & JOHNSON, H.D. (1962) Effect of humidity on total room heat and vapour dissipation of Holstein cows at 65, 80 and 90°F. Univ.Mo.Agr.Exp.Sta.Res.Bull. 794

CARROLL, E.J. (1975) Thyroid. In Veterinary Endocrinology and Reproduction 2nd ed. (ed. McDonald, L.E.) Lea & Febiger, Philadelphia.

CARSTAIRS, J.A. (1980) Postpartum reproduction and lactation performance of cows relative to energy, phosphorus and hormonal status. Dairy Sci.Abs. 42(2) 513 (Abstract)

CLARK,J.H. (1975) Lactational responses to post-ruminal administration of proteins and amino acids. J.Dairy Sci. 58 1178 - 1197

COLGHALIS,S. (1969) Use of I supplements in the feeding of dairy cattle. Dairy Sci.Abs. 31 3239 (Abstract)

COLES,E.H. (1974) Veterinary Clinical Pathology 2nd ed. W.B.Saunders Co., Philadelphia.

COLLOCOTT,T.C. (1971) Dictionary of Science and Technology. W&R Chambers, London.

CONVEY,E.M., THOMAS,J.W., TUCKER,H.A. & GILL,J.L. (1973) Effect of thyrotropin releasing hormone on yield and composition of bovine milk. J.Dairy Sci. 56 484 - 487

COWIE,A.T. & SWINBURNE,JOAN K. (1977) Hormones, drugs, metals and pesticides in milk: A guide to the literature. Dairy Sci.Abs. 39 391 - 399 (abstract)

CRAVEN,J.A. & KILKENNY,J.B. (1976) The structure of the British cattle industry. In Principles of Cattle Production (ed. Swan & Broster) Butterworths, London.

DENCKLA,W.D. (1975) Pituitary inhibitor of thyroxine. Fed.Proc. 34(1) 96

DE VLEESCHAWER,A. & HENDRICKX,H. (1949) Preparation et analyse chimique de la caseine iodee. Proc. XII Int. Dairy Congress, Stockholm 2 907 - 911 (English summary)

DICKSON,W.M. (1970) Endocrine glands. In Dukes' Physiology of Domestic Animals 8th ed. (ed. Swenson,M.J) Cornell University Press.

DJURDEVIC,D., JOVANOVIC,M.,PANTIO,V., VELICKOVIC,G., SINADINOVIC,J. & GEMBACEV,O. (1974) Some effects of iodinated protein "Protamone" on the endocrine organs and lactation. Dairy Sci.Abs. 36 1048 (Abstract)

DJURDEVIC,D., MILICIVIC,Z. & KRDZALIT,P. (1979) Level of thyroid hormones in the serum of cows in relation to milk yield. Vet.Bull. 50 990 (Abstract)

DOWLING,D.F. (1956) An experimental study of heat tolerance of cattle. Aust.J.Agric.Res. 7(5) 469-481

DUDYZEV,Y. (1980) Gas and energy exchange in Kholmogor cows in relation to milk production and feeding level. Dairy Sci.Abs. 42(3) 1567 (Abstract)

DUKES,H.H. (1970) The cardiovascular system. In Bovine Medicine and Surgery; and herd health management 1st ed. (ed. Gibbons, Catcott & Smithcors) American Veterinary Publications, Inc., Illinois.

DYRENDAHL,S. (1949) Some effects of feeding iodinated casein for a long time to cattle, swine and rats. Nutr.Abs.&Rev. 19 478 (Abstract)

EDWARDS,C.R.W. (1976) The hypothalamic-pituitary-adrenal axis. Med. Monograph 10, The Radiochemical Centre, Amersham, England.

ELEY,R.M., COLLIER,R.J., BRUSS,M.L., VAN HORN,H.H. & WILCOX,C.J. (1978) Interrelationship between heat stress parameters and milk composition and yield in dairy cows. J.Dairy Sci. 61(Suppl.1) 147 (Abstract)

ENAMI,J. (1980) Hormonal control of milk protein synthesis in mouse mammary epithelium cells *in vitro*. *Dairy Sci.Abs.* *42*(2) 866 (Abstract)

EVANS,P.R. (1975) The concentration of volatile fatty acids in the rumen of dairy dairy cows kept at high ambient temperatures. *M.Sc. thesis,* Univ. Edinburgh.

EVERED,D., VICE,P.A. & CLARK,F. (1976) The investigation of thyroid disease. *Med. Monograph 9* The Radiochemical Centre, Amersham, England.

FOLMAN,Y., BERMAN,A., HERZ,Z., KAIM,M., ROSENBERG,M., MAMEN,M. & GORDIN,S. (1980) Milk yield and fertility of high yielding dairy cows in a sub-tropical climate during summer and winter. Nutr.Abs.& Rev. *50* 2890 (Abstract)

FRANCOIS,A., DE BALSAC,H.H., LEROY,A.M. & PAREZ,M. (1953) Detection in cows of lactation fraudulently disturbed by ingestion of iodised protein. *Dairy Sci.Abs.* *15* 234 (Abstract)

GANONG,W.F. (1975) *A Review of Medical Physiology* 7th ed. Lange Medical Publications, California.

GARDENER,K.E. & MILLEN,T.W. (1950) Thyroprotein for lactating cows in mid-summer. *J.Dairy Sci*. *33* 531-538

GATENBY, RUTH (1980) Personal communication. Dept. Trop. Anim. Prod. & Health, C.T.V.M., University of Edinburgh.

GILETTE,D.D. (1977) Growth response of Muscovy ducklings to thyroxine (iodinated casein). *Nutr.Abs.& Rev.* *47*(Ser.B) 2765 (Abstract)

GIRAUD,P. & COIGNET,J. (1954) Stimulation of milk secretion in women. *Dairy Sci.Abs.* *16*(12) 991 (Abstract)

GORET,E.H., JOHNSON,H.D. & HAHN,L. (1973) Plasma TSH in lactating cattle at 10°C and 30°C. J.Anim.Sci. 37 313

GREIG,W.R., BOYLE,I.T. & BOYLE,J.A. (1967) Diagnosis of thyroid disorders using radioactive iodine. Med. Monograph 5 The Radiochemical Centre, Amersham, England.

HANCOCK,J. (1954) The direct influence of climate on milk production. Dairy Sci.Abs. 16(2) 89-102

HARRIS,D.L., SHRODE,R.R., RUPEL,I.W. & LEIGHTON,R.E. (1960) A study of solar radiation as related to physiological and production responses of lactating Holstein and Jersey cows. J.Dairy Sci. 43 1255-1262

HART,I.C., BINES,J.A. & MORANT,S.V. (1979) Endocrine control of energy metabolism in the cow: Correlations of hormones and metabolites in high yieldimg and low yielding cows for stages of lactation. J.Dairy Sci. 62(2) 270-277

HART,I.C., BINES,J.A., ROY,J.H.B. & MORANT,S.V. (1979) Plasma thyroxine and free thyroxine in high- and low-yielding cattle and calves of different breeds. J.Endocrinol. 80(2) 52-53

HEITZMAN,R.J. & MALLISON,C.B. (1972) A comparison of the thyroxine levels in the plasma of healthy, starved and acetonaemic dairy cows. Res.Vet.Sci. `13 591-593

HEMKEN,R.W., VANDERSALL,J.H., SASS,B.A. & HIBBS,J.W. (1971) Goitrogenic effects of a corn silage - soybean meal supplemented ration. J.Dairy Sci. 54 85-88

HENDERSON, NANCY (1979) Personal communication. Edinburgh School of Agriculture.

HOLDER,J.M. (1960) Observations on the grazing behaviour of lactating dairy cattle in a sub-tropical environment. J.Agric.Sci. 55(2) 261-267

INGRAM,D.L. (1965) The effect of humidity on temperature regulation and cutaneous water loss in the young pig. Res.Vet.Sci. 6 9-17

JOHNSON,H.D., KIBLER,H.H., RAGSDALE,A.C. & SHANKLIN,M.D. (1960) Effects of various combinations of temperatures and humidities on milk production. J.Dairy Sci. 43 871 (Abstract)

JOHNSON,H.D., WAYMAN,O., KIBLER,H.H., RAGSDALE,A.C., BERRY,I.L. & MERILAN,C.P. (1961) Effects of temperature and controlled feeding on milk production and related physiological reactions in cattle. J.Anim.Sci. 20 974

JOHNSTON,J.E. (1958) Effect of environmental temperature on milk production. J.Dairy Sci. 41 349-350

JOHNSTON,J.E., HINDERY,G.A., SCHRABER,G.T. & HAMBLIN,F.B. (1958) Effectof thyroprotein on metabolic and productive function of lactating Jersey cattle exposed to hot and cool weather. J.Dairy Sci. 41 725 (Abstract)

KALLFELZ,F.A. & ERALI,R.P. (1973) Thyroid function tests in domesticated animals: Free thyroxine index. Am.J.Vet.Res. 34 1449-1451

KASSAB,S.A., EL-BARBARY,A.S.A., MAHMOUD,S. & EL-SANTIEL,G. (1980) Effect of thyroxine injection on milk constituents and yield in Friesian cows. Dairy Sci.Abs. 42(3) 1558 (Abstract)

KELLOG,D.W., BALOK,C.J. & MILLER,D.D. (1971) Method of experimental induction of ketosis utilising the interaction of low energy intake and thyroxine. J.Dairy Sci. 54 1499-1503

KELLY,W.R. (1976) Veterinary Clinical Diagnosis 2nd ed. Bailliere Tindall, London.

KIBLER,H.H. & BRODY, SAMUEL (1953) Influence of humidity on heat exchange and body temperature regulation in Jersey, Holstein, Brahman and Brown Swiss cattle. Univ.Mo.Agr.Exp.Sta.Res.Bull. 522

LAWRENCE,P. (1978) Unpublished data. Dept. Trop. Anim. Prod. & Health, C.T.V.M., University of Edinburgh.

LEE,J.A., ROUSSEL,J.D. & BEATTY,J.F. (1976) Effect of temperature - season on bovine adrenal cortical function, blood cell profile and milk production. J.Dairy Sci. 59 104-108

LOGINOV,V.V. (1980) Effect of thyroxine on milk fat biosynthesis of cows. Dairy Sci.Abs. 42(3) 1540 (Abstract)

LONGIMORE,D.B. & SWANSON,E.W. (1971) Effects of dietary iodine on estimated thyroxine secretion rates of cows during lactation. J.Dairy Sci. 54 453 (Abstract)

MABON,R.M. & HUTCHINSON,H.G. (1954) Studies on the environmental physiology of cattle in Tanganyika. I. Preliminary observations on the seasonal diurnal vasiation in rectal temperature of local Zebu cattle. J.Agric.Sci. 44 121-128

MACHLIN,L.J. (1973) Effect of growth hormone on milk production and feed utilisation in dairy cows. *J.Dairy Sci.* *56* 575-580

M.A.F.F. (1975) *Energy Allowances and Feeding Systems for Ruminants*. Tech.Bull. 33, H.M.S.O., London.

MAGDUB,A.B., EL-NOUTY,F.D. & JOHNSON,H.D. (1979) Effects of milking and milk level on thyroxine in plasma and milk. *J.Dairy Sci.* *62*(Suppl.1) 114-115 (Abstract)

MAGDUB,A., KHOJA,N., GANABA,S. & JOHNSON,H.D. (1980) Plasma, milk and urinary thyroid hormones as indicators of heat stress in dairy cows. *J.Dairy Sci.* *63*(Suppl.1) 147 (Abstract)

MAGEMBE,S.R. (1977) The relative effect of thyroxine, glucose and water administration on the physiology and milk production of dairy Friesian cattle subjected to acute heat stress. *M.Sc. thesis* Univ. Edinburgh.

MANSON,W. (1978) Aspects of the value and the limitations of milk protein as a food material. *Proc.Nutr.Soc.* 37 217-223

MASON,T.L. (1975) Maintaining crossbred populations of dairy cattle in the tropics. *Wld.Anim.Rev.* *11* 36-43

MAYMONE,B. & REGENSBURGER,G.R. (1960) Economic return from stimulating milk secretion with iodinated casein. *Nutr.Abs.& Rev.* *30* 6847 (Abstract)

MCDONALD,L.E. (1975) *Veterinary Endocrinology and Reproduction* 2nd ed. Lea & Febiger, Philadelphia.

MCDONALD,L.E. (1977) Hormones influencing metabolism. In *Veterinary Pharmacology and Therapeutics* 4th ed. (ed. Jones, Booth and McDonald) AMES The Iowa State Press.

MCDOWELL,R.E. (1972) Improvement of Livestock Production in Warm Climates W.H.Freeman & Co. San Francisco.

MCDOWELL,R.E., CAMOENS,J.K., VAN VLECK,L.D., CHRISTENSEN,E. & CABELLO FRIAS,E. (1976) Factors affecting performance of Holsteins in subtropical regions of Mexico. J.Dairy Sci. 59 722-729

MCDOWELL,R.E., MOODY,E.G., VAN SOEST,P.J., LEHMANN,R.P. & FORD,G.L. (1969) Effect of heat stress on energy and water utilisation of lactating cows. J.Dairy Sci. 52 188

MCLEAN,J.A. & CALVERT,D.T. (1972) Influence of air humidity on the partition of heat exchanges of cattle. J.Agric.Sci. 78 303-307

MEPHAM,B. (1976a) The Secretion of Milk. The Institute of Biology's Studies in Biology, no.60. Edward Arnold, London.

MEPHAM,T.B. (1976b) Amino acid supply as a limiting factor in milk and muscle synthesis. In Principles of Cattle Production. (ed. Swan & Broster) Butterworths, London.

METEOROLOGICAL OFFICE (1966) Tables of Temperature, Relative Humidity and Precipitation for the World Part V. H.M.S.O., London.

MISCHLER,T.W. & REINEKE,E.P. (1970) Thyroid hormone analysis of thyroactive iodinated casein. J.Dairy Sci. 53(2) 233-238

MITRA,R., CHRISTISON,G.I. & JOHNSON,H.D. (1972) Effect of prolonged thermal exposure on growth hormone (G.H.) secretion in cattle. J.Anim.Sci. 34(5) 776-779

MOORE,L.A. (1958) Thyroprotein for dairy cattle. J.Dairy Sci. 41 452-455

MOUNT,L.E. (1979) Adaptation to Thermal Environment Contemporary Biology Series, Edward Arnold, London.

NADALIYAK,E.A. & OVCHARENKO,E.V. (1976) Effect of thyroid-active and thyroid depressing preparations and insulin on the total energy metabolism and energy metabolism in mammary gland and liver of lactating cows. In Energy Metabolism of Farm Animals (ed. M.Vermorel) Proc.7th Symp. Euro. Assos. Anim. Prod.

NEWCOMER,W.S. (1977) Thyroxine and triiodothyronine in blood after ingestion of iodinated casein by chicks. Nutr.Abs.& Rev. 47(ser.B) 218 (Abstract)

O'KELLY,J. (1977) Plasma protein-bound iodine and lipids in genetically different types of cattle grazing in a tropical environment. Brit.Vet.J. 133 579-584,

OLDHAM,J.D., HART,I.C. & BINES,J.A. (1978) Effect of abomasal infusions of casein, methionine, or phenylalanine on growth hormone, insulin, prolactin, thyroxine and some metabolites in blood from lactating goats. Proc.Nutr.Soc. 37 p 9A (Abstract)

OSBOURN,D.F. (1976) The utilisation of natural grasslands in the tropics. In Beef Cattle Production in Developing Countries. (ed. A.J.Smith) Univ. Edinburgh.

PAAPE,M.J., SCHULTZE,W.D., MILLER,R.H. & SMITH,J.W. (1973) Thermal stress and circulating erythrocytes, leucocytes and milk somatic cells. J.Dairy Sci. 56 84-91

PITT RIVERS,ROSALIND, & RANDALL,S.S. (1945) Preparation and biological effects of iodinated proteins: Preparation and properties of physiologically active iodinated proteins. J.Endocrinol. 4 221-236

PLANT,J.A. (1968) The Climate of Edinburgh. Climatological memorandum no.54A, Met. Office, Edinburgh.

PREMACHANDRA,B.N. & TURNER,C.W. (1962) Increased lactation response in cattle with thyroxine 50% above thyroxine secretion rate. J.Dairy Sci. 45 1098-1101

PRESCOTT,J.H.D. (1976) Growth and development of beef cattle. In Beef Cattle Production in Developing Countries. (ed. A.J.Smith) Univ. Edinburgh.

REINEKE,E.P. & TURNER,C.W. (1943) The recovery of l-thyroxine from iodinated casein by direct hydrolysis with acid. J.Biol.Chem. 149 555-570

RHOAD,A.O. (1944) The Iberia heat tolerance test for cattle. Trop.Agric. 21 162-164

RICHARDS,J.I. (1979) The role of iodinated casein in alleviating the effects of high temperature on the milk production of dairy cattle in the tropics. Anim.Prod. 28 414 (Abstract)

RICHARDS,J.I. (1980) Personal communication. Dept.Trop.Anim.Prod.& Health, C.T.V.M., Univ. Edinburgh.

RICHARDS,J.I. & GATENBY,RUTH (1980) Unpublished data. Dept.Trop.Anim.Prod.& Health, C.T.V.M., Univ. Edinburgh.

ROBERTSON,J.D. (1945) The preparation and biological effects of iodinated protein: The effect on basal metabolism of milk from cows fed with iodinated protein. J.Endocrinol. 4 300-303

SCHALM,O.W., JAIN,N.C. & CARROLL,E.J. (1975) Veterinary Hematology 3rd ed. Lea & Febiger, Philadelphia.

SCHMIDT,G.H., DEVERNA,J.D. & KILMER,L.H. (1973) Effect of periodic feeding of thyroprotein on milk yield and fat test of Holstein cows. J.Dairy Sci. 56(8) 1047-1051

SCHMIDT,G.H., WARNER,R.G., TYRRELL,H.F. & HANSEL,W. (1971) Effect of thyroprotein feeding on dairy cows. J.Dairy Sci. 54(4) 481-492

SCHMIDT-NIELSEN,K. (1979) Desert Animals Physiological Problems of Heat and Water. Dover Publ., Inc. New York.

SCHMIDT-NIELSEN,K., SCHMIDT-NIELSEN,B., JARNUM,S.A. & HOUPT,J.R. (1957) Body temperature of the camel and its relation to water economy. Amer.J.Physiol. 188 103-112

SCOTT,I.M., JOHNSON,H.D. & HAHN,G.L. (1976) Response of Holstein cows to temperature cycles. J.Anim.Sci. 43 303 (Abstract)

SHAW,G.H., CONVEY,E.M., TUCKER,H.A., REINEKE,E.P., THOMAS,J.W. & BYRNE,J.J. (1975) Bovine serum thyroxine, prolactin, growth hormone, glucocorticoids and thyroid binding globulin responses to thyroprotein. J.Dairy Sci. 58(5) 703-708

STANLEY,R.W. & MORITA,K. (1967) Effect of feeding thyroprotein to dairy cattle in a subtropical environment on milk composition and production, rumen metabolism, and fatty acid composition of milk fat. J.Dairy Sci. 50(2) 1097-1100

STANLEY,R.W. & MORITA,K. (1968) The effect of short- and long-term feeding of thyroprotein on the performance of lactating dairy cattle in Hawaii. Hawaii Agr.Exp.Sta.Tech.Bull. 75

STEINBACH,K. & FOSTIERIS,N. (1977) Process for making hormone-free iodine-casein (iodinated milk protein) with full thyroid gland effect. Dairy Sci.Abs. 39 3628 (Abstract)

STEPANOV,D.D., KUCHENEV,P.V. & RAZMAKHNIN,YU.E. (1976) Milk production of cows on rations with added thyroprotein and glucavamorin PIOX. Dairy Sci.Abs. 38 2017 (Abstract)

SWAN,H. (1976) The physiological interrelationship of reproduction, lactation and nutrition in the cow. In Principles of Cattle Production. (ed. Swan & Broster) Butterworths, London.

SWANSON,E.W. (1949) Effects and economy under Tennessee conditions of thyroprotein feeding during lactation decline. J.Dairy Sci. 32 708 (Abstract)

SWANSON,E.W. & BEARDEN,B.J. (1963) Effect of prepartum thyroprotein feeding upon the next lactation. J.Dairy Sci. 46 423-425

SWANSON,R.G. & KNODT,C.B. (1949) A study of feeding low levels of thyroprotein to dairy cows for a period of fifty-two weeks. J.Dairy Sci. 32 257-264

SWENSON, M.J. (1970) Dukes' Physiology of Domestic Animals 8th ed. Cornell Univ. Press.

SYKES, J.F., THOMAS, J.W. & MOORE, L.A. (1952) Observations on the electrocardiograms of cattle fed thyroproteins. J.Anim.Sci. 11 693-699

TENNEBAUM, J., EZRA, S., ADAR, R. & GILAT, T. (1961) The physiological significance of the cumulative discomfort index. Harefuah 60 315-319 (Abstract)

THOMAS, J.W. (1953) The use of thyroprotein for milk production. National Research Council, publ. 266 p 47-54.

THOMAS, J.W., COPLAND, D.V., KEYES, E.A., VAN HORN, A.G. & MOORE, L.A. (1954) Effects on economy and efficiency of milk production when thyroprotein is fed for a short period of time to milking cows. J.Dairy Sci. 37 877-888

THOMAS, J.W. & MOORE, L.A. (1951) Effects of feeding thyroprotein to dairy cows for successive lactations - a report of progress. J.Dairy Sci. 34 507 (Abstract)

THOMAS, J.W., MOORE, L.A. & SYKES, J.F. (1949) Some effects of feeding thyroprotein to dairy cows during their first lactation. J.Dairy Sci. 32 278-291 (Abstract)

THOMPSON, G.E. (1976) Principles of climate physiology. In Beef Cattle Production inDeveloping Countries. (ed. A.J.Smith) Univ. Edinburgh.

THOMPSON, H.J., WORSTELL, D.M. & BRODY, SAMUEL (1953) The effect of humidity on insensible weight loss, total vaporized moisture and surface temperature in cattle. Univ.Mo.Agr.Exp.Sta.Res.Bull. 531

THOMPSON,R.D., JOHNSTON,J.E., BREIDENSTEIN,C.P., GUIDRY,A.J., BANERJEE,M.R. & BURNETT,W.T. (1963) Effect of hot conditions on adrenocortical, thyroidal and other metabolic responses of dairy heifers. J.Dairy Sci. 46 227-231

TOPPS,J.H. (1976) Effect of energy and protein deprivation on the performance of beef cattle. In Beef Cattle Production in Developing Countries. (ed. A.J.Smith) Univ. Edinburgh.

TRENKLE,A. (1978) Relation of hormonal variations to nutritional studies and metabolism of ruminants. J.Dairy Sci. 61 281-293

TUCKER,H.A. & REECE,R.P. (1961) Thyroid supplementation at peak of lactation. J.Dairy Sci. 44(2) 1751-1753

TURNER,C.W. (1949) Effect of mild hyperthyroidism on milk production in dairy cattle. J.Dairy Sci. 32 702

TURNER,C.W. (1970) What causes high production? Story of the role of the thyroid glands in milk secretion. Univ.Mo.Agr.Exp.Sta.Bull. 871

TURTON,J.D. (1980) Lecture notes, Trop.Anim.Prod. & Health, C.T.V.M., Univ. Edinburgh.

VANJONACK,W,J. & JOHNSON,H.D. (1975) Effects of moderate heat and milk yield on plasma thyroxine in cattle. J.Dairy Sci. 58(4) 507-511

VOHNHOUT,K. & BATEMAN,J.V. (1972) Effects of crude fibre upon feeding efficiency of cattle in "warm" environments. J.Agric.Sci. 78 413-416

VOLCANI,R. (1973) High milk production under unfavourable natural conditions. Wld.Anim.Rev. 8 28-33

VONDERHAAR,B.K. (1980) Lactose synthetase activity in mouse mammary gland is controlled by thyroid hormones. Dairy Sci.Abs. 42(3) 1534 (Abstract)

WARD,P. (1978) The effects of exposure of dairy cattle to heat loads. M.Sc. thesis, Univ. Edinburgh.

WAYMAN,O., JOHNSON,H.D., MERILAN,C.P. & BERRY,I.L. (1962) Effect of *ad libitum* or force feeding of two rations on lactating dairy cows subjected to temperature stress. J.Dairy Sci. 45(2) 1472-1478

WEBSTER,A.J.F. (1976) The influence of the climatic environment on metabolism of cattle. In Principles of Cattle Production. (ed. Swan & Broster) Butterworths, London.

WEGNER,T.N., SCHUH,J.D., NELSON,F.E. & STOTT,G.H. (1976) Effect of stress on blood leucocyte and milk somatic cell counts in dairy cows. J.Dairy Sci. 59 946-956

WEITZ,J., HOUTMAN,A.G. & ROBORGH,J.R. (1953) The effect of iodinated casein fraction on the milk yield of goats. Netherlands J.Agric.Sci. 1 39-43 (Abstract)

WELDY,J.R., MCDOWELL,R.E., VAN SOEST,P.J. & BOND,J. (1964) Influence of heat stress on rumen acid levels and some blood constituents of cattle. J.Anim.Sci. 23 147

WHITE,A., HANDLER,P. & SMITH,E.L. (1964) Principles of Biochemistry. 3rd ed. McGraw-Hill Book Co.

WILLIAMSON,G. & PAYNE,W.J.A. (1978) Animal Husbandry in the Tropics; An introduction to. 3rd ed. Longmans, London.

WOOD,P.D.P. (1968) Factors affecting the lactation curve. Anim.Prod. 11(3) 307-316

YECK,R.G. & STEWART,R.E. (1959) A ten-year summary of the psychroenergetic laboratory dairy cattle research at the University of Missouri. Trans.Am.Soc.Agric.Engrs. 2 71-77

YOUSEF,M.K. & JOHNSON,H.D. (1966) Calorigenesis of dairy cattle as influenced by thyroxine and environmental temperature. J.Anim.Sci. 25 150-156

YOUSEF,M.K., KIBLER,H.H. & JOHNSON,H.D. (1967) Thyroid activity and heat production in cattle following sudden ambient temperature changes. J.Anim.Sci. 26 142-148

YOUSRI,R.M. (1976) Effect of environmental temperature on some physiological and nutritional aspects of animals. Wld.Anim.Rev. 12(4) 75-81

ZWOLINSKI,J., LIPINSKA,H. & SINDZINSKI,S. (1971) Effect of iodinated casein on milk yield of nursing mares. Dairy Sci.Abs. 33 2193 (Abstract)

APPENDIX 1

An Example of the ME Requirements of a 500kg Cow Producing 20kg Average Milk

(M.A.F.F., 1975)

Average milk contains 36g/kg butterfat and 86g/kg solids-not-fat.

Maintenance requirements:

$8.3 + 0.091 \times 500 = 53.8$ MJ/day

Lactation requirements:

$1.694 \times 4.88 = 8.3$ MJ/kg milk

$8.3 \times 20 = 166.0$ MJ/day

Total Daily ME Required = 53.8
166.0
219.8

$\frac{166.0}{219.8} = .75$, thus 75% of this cow's energy intake is required for milk production.

Efficiency of ME utilisation for maintenance is 72%, which means 100 - 72 = 28% is "lost" as heat.

Efficiency of ME utilisation for lactation is 62%, which means 100 - 62 = 32% is "lost" as heat.

$(53.8 \times 0.28) + (166 \times 0.38) = 78.1$ MJ/day "lost" as heat.

This is the Heat Increment.

$\frac{78.1}{219.8} = 0.3598$, or about 36% of this cow's ME intake is lost as heat.

APPENDIX 2

Specification of Climate Chambers

Volume	71m^3
Brick Shell	3.45 x 3.15m
Internal Dimensions	3.2 x 2.9m x 2.5m high
False ceiling gives internal height	2.1m
Insulation	10.2cm Expanded polystyrene
Internal Lining	18mm plywood finish with GRP Plastic
Doors	1 x single rebated type with 1.88m x 1.2m clear opening
	1 x single rebated type with 1.8m x 0.68m clear opening
	Hung on galvanised hinges fitted with galvanised fastener and closing on rubber gaskets to ensure airtight seal.
Floor	5cm thick reinforced Granolithic coved to walls.

The machinery used allows maintenance of a variable temperature range 5°C to 38°C ± 1.5°C and relative humidity 65 - 90%.

Condensing Unit	Prestcold AS-150-3H air-cooled.
Cooler Heater	Searle Bush UCL-120 forced draught and ventilation unit.
Control	Ronald Trust Dual Temperature mid-off mercury switches in series with magnetic values high and low temperature safety switches.
Humidity	Defensor humidifier complete with automatic water feed and humidity control.

APPENDIX 3

Table of Rectal Temperature, Respiratory Rate, Pulse, Dry Bulb Temperature, Wet Bulb Temperature and Relative Humidity during the experimental period.

T_R = Rectal temperature in °C.

Resp = Respiratory rate, per minute.

Pulse = Pulse rate, per minute.

RH = Relative humidity in %.

Db:Wb = Bianca's (1962) formula = (Db x 0.35) + (Wb x 0.65)

HAC = Heat Absorption Capacity from Appendix 3a after Lawrence (1978)

Θ = Equivalent Temperature = $T + Pv/y$
where T = Db temperature in °C
Pv = Vapour pressure
y = Constant 0.66 mbar/°C
(Mount, 1979).

THI = Temperature Humidity Index calculated from
0.72 (Db + Wb) + 40.6
(McDowell, 1972).

Cows Exposed to 21°C

measurements taken hourly 9.30 to 14.30

T_R	Resp	Pulse	Db	Wb	Db:Wb	HAC	Θ	THI	RH%
Cow 1									
38.5	24	60	21.5	20.5	20.85	82.6	57.0	70.5	91
38.5	32	54	21.5	21.0	21.18	79.7	58.6	71.2	95
38.6	24	48	22.5	21.5	21.85	76.5	60.3	72.3	91
38.8	28	48	23.0	21.5	22.03	75.5	60.3	72.6	87
38.5	24	56	23.5	21.5	22.20	76.4	60.3	73.0	83
38.5	28	52	24.5	23.0	23.53	69.8	65.5	74.4	87
Cow 3									
38.7	28	56	22.0	20.0	20.70	79.6	55.4	70.9	82
38.5	26	56	22.5	20.5	21.20	80.2	57.0	71.6	82
38.3	56	60	22.5	20.5	21.20	80.2	57.0	71.6	82
38.2	40	60	22.5	21.5	21.85	76.5	60.3	72.3	91
38.4	64	56	23.5	21.5	22.85	73.1	63.7	73.7	91
39.1	60	63	23.5	23.0	22.85	73.1	63.7	73.7	91
Cow 4									
38.3	16	48	22.0	20.0	20.70	79.6	55.4	70.9	82
38.6	20	46	22.5	20.5	21.20	80.2	57.0	71.6	82
38.4	18	66	22.5	20.5	21.20	80.2	57.0	71.6	82
38.5	24	48	22.5	21.5	21.85	76.5	60.3	72.3	91
38.6	36	60	23.5	22.5	22.85	73.1	63.7	73.7	91
39.5	36	56	23.5	22.5	22.85	73.1	63.7	73.7	91
Cow 6									
38.5	24	64	21.5	20.5	20.85	82.6	57.0	70.5	91
37.7	32	57	21.5	21.0	21.18	79.7	58.6	71.2	95
38.1	32	60	22.5	21.5	21.85	76.5	60.3	72.3	91
38.3	36	44	23.0	21.5	22.03	75.5	60.3	72.6	87
38.2	56	66	23.5	21.5	22.20	76.4	60.3	73.0	83
38.4	52	68	24.5	23.0	23.53	69.8	65.5	74.4	87

Cows Exposed to 37°C

measurements taken hourly 9.30 to 14.30

T_R	Resp	Pulse	Db	Wb	Db:Wb	HAC	Θ	THI	RH%
Cow 1									
37.9	32	72	21.5	21.0	21.18	76.6	58.6	71.2	95
38.3	72	80	34.0	33.5	33.68	27.1	111.8	89.2	96
38.7	72	76	36.5	36.0	36.18	10.2	125.9	92.8	96
38.7	96	70	36.5	30.1*	32.34	39.6*	96.9*	86.1*	68*
38.5	136	66	37.0	29.5	32.13	47.5	91.9	88.5	55
38.7	132	72	36.5	30.5	32.60	51.5	96.6	88.8	63
Cow 3									
38.3	26	64	20.0	19.5	19.68	85.0	53.8	69.0	86
38.2	24	64	26.5	24.5	25.20	61.9	71.0	76.6	84
38.4	66	64	34.5	27.0	29.63	58.3	81.0	84.9	54
38.3	120	64	35.5	29.5	31.60	46.3	92.0	87.4	63
39.0	120	64	36.0	30.5	32.43	40.4	96.6	88.5	66
39.5	148	60	36.0	31.0	32.75	46.4	99.0	88.8	60
Cow 4									
38.4	26	64	20.0	19.5	19.68	85.0	53.8	69.0	86
38.9	24	60	26.5	24.5	25.20	61.9	71.0	76.6	84
38.0	24	56	34.5	27.0	29.63	58.3	81.0	84.9	54
38.7	48	54	35.5	29.5	31.60	46.3	92.0	87.4	63
38.8	52	60	36.0	30.5	32.43	40.4	96.6	88.5	66
38.9	52	60	36.0	31.0	32.75	46.4	99.0	88.8	60
Cow 6									
38.6	28	78	21.5	21.0	21.18	76.6	58.6	71.2	95
38.4	60	68	34.0	33.5	33.68	27.1	111.8	89.2	96
38.6	92	72	36.5	36.0	36.18	10.2	125.9	92.8	96
39.3	136	70	36.5	30.1*	32.34	39.6*	96.9*	86.1*	68*
39.6	148	72	37.0	29.5	32.13	47.5	91.9	88.5	55
39.7	132	80	36.5	30.5	32.60	51.5	96.6	88.8	63

* Missing plots, calculated.

Cows Exposed to 37°C while being fed Iodinated Casein,

measurements taken hourly 9.30 to 14.30

T_R	Resp	Pulse	Db	Wb	Db:Wb	HAC	θ	THI	RH%
Cow 1									
38.2	24	64	22.0	20.0	20.70	80.45	55.4	70.8	82
38.4	126	60	35.5	25.5	29.00	65.16	74.9	84.5	43
38.3	108	62	37.5	29.0	31.98	47.55	89.6	88.5	53
38.7	104	64	37.0	29.5	32.13	46.38	91.9	88.5	56
38.9	116	60	37.0	29.0	31.80	48.50	89.6	88.1	54
39.8	153	62	38.0	30.5	33.13	40.99	96.6	89.9	57
Cow 3									
38.2	20	60	19.5	19.0	19.18	81.00	52.2	68.3	95
38.1	42	66	32.5	27.5	29.25	54.33	83.1	83.8	67
38.2	60	72	34.0	28.5	30.43	50.00	86.4	85.6	65
38.6	96	72	35.0	29.5	31.43	45.85	90.9	87.0	65
38.8	144	66	36.0	31.0	32.75	35.40	99.0	88.8	69
39.4	144	72	36.5	31.0	32.96	41.80	99.1	89.3	66
Cow 4									
38.8	20	60	19.5	19.0	19.18	81.00	52.2	68.3	95
38.8	28	60	32.5	27.5	29.25	54.33	83.1	83.8	67
38.6	60	68	34.0	28.5	30.43	50.00	86.4	85.6	65
38.9	76	60	35.0	29.5	31.43	45.85	90.9	87.0	65
39.1	96	72	36.0	31.0	32.75	35.40	99.0	88.8	69
39.0	84	76	36.6	31.0	32.96	41.80	99.1	89.3	66
Cow 6									
38.1	28	64	22.0	20.0	20.70	80.45	55.4	70.8	82
38.4	66	66	35.5	25.5	29.00	65.16	74.9	84.5	43
38.7	86	60	37.5	29.0	31.98	47.55	89.6	88.5	53
39.2	108	72	37.0	29.5	32.13	46.38	91.9	88.5	56
39.4	132	72	37.0	29.0	31.80	48.50	89.6	88.1	54
40.9	160	72	38.0	30.5	33.13	40.99	96.6	89.9	57

Correlations between Heat Stress Indices and Clinical Findings

	Cows during treatment 37	Cows during treatments 21 and 37
	r	r
T_R - Db:Wb	0.406	0.243
T_R - Db	0.458*	0.429**
T_R - Wb	0.352	0.383**
T_R - HAC	-0.247	-0.233
T_R - θ	0.327	0.361*
T_R - TH%	0.407	0.405**
Resp - Db:Wb	0.629**	0.755***
Resp - Db	0.694***	0.786***
Resp - Wb	0.555**	0.588***
Resp - HAC	-0.439*	-0.649***
Resp - θ	0.524**	0.698***
Resp - TH%	0.639**	0.761***

* p less than 0.05
** p less than 0.01
*** p less than 0.001

To allow for a delay in T_R response when environmental changes occurred, the Heat Stress Indices were also compared to T_R one hour later. This did not provide better correlation factors as the following three examples show:-

T_R - HAC, r = -0.268
T_R - θ, r = 0.039
T_R - THI, r = 0.491*

APPENDIX 4

Statistical Analysis

Abbreviations

df	Degrees of freedom
SS	Sum of the squares
V	Variance
VR	Variance ratio
*	$p \leqslant 0.05$
**	$p \leqslant 0.01$
***	$p \leqslant 0.001$
n.s.	not significant
SE	Standard error
SD	Standard deviation
CV	Coefficient of variation
LSR	Least significant range
HY:LY	High yielders vs. low yielders
AM:PM	Morning vs. afternoon

Appendix 4a

Mean milk yields (kg)

Cow	21a	37+IC	21b	37	21c	Sum
1	5.79	5.95	5.48	4.50	3.57	25.29
3	15.69	16.47	15.34	14.68	14.69	76.87
4	7.06	8.24	6.81	7.00	5.06	34.17
6	20.40	20.75	20.39	20.14	20.13	101.81
Sum	48.94	51.41	48.02	46.32	43.45	238.14
Mean	12.23	12.85	12.00	11.58	10.86	11.91

	df	SS	V	VR	Significance
Total	19	792.51			
Cows	3	780.76	260.25	1073.20	***
HY:LY	1	710.67	710.67	2930.60	***
Residual	2	70.09	35.05	144.54	***
Treatments	4	8.84	2.21	9.11	**
Error	12	2.91	0.24		

SE_{mean} 1.44

CV 4.1%

LSR 1.13

Treatment	Mean				
37+IC	12.85	1.99*	1.27*	0.84	0.61
21a	12.24	1.38*	0.66	0.23	
21b	12.01	1.15*	0.43		
37	11.58	0.72			
21c	10.86				

Appendix 4b

Mean milk yields (kg)

Treatment 21 = $\frac{21a + 21b}{2}$, treatment 21c ignored.

Cow	37+IC	21	37	Sum
1	5.95	5.64	4.50	16.09
3	16.47	15.52	14.68	46.67
4	8.24	6.94	7.00	22.18
6	20.75	20.40	20.14	61.29
Sum	51.41	48.50	46.32	146.23
Mean	12.85	12.13	11.58	12.19

	df	SS	V	VR	Significance
Total	11	450.57			
Cows	3	446.53	148.84	1167.38	***
Treatments	2	3.27	1.64	12.86	**
Error	6	0.765	0.128		

SE_{mean} = 1.848

CV = 2.9%

LSR = 0.78

Treatment	Mean		
37+IC	12.85	1.27*	0.72
21	12.13	0.55	
37	11.58		

Appendix 4c

Mean liveweights (kg)

Cow	21a	37+IC	21b	37	Sum
1	593	583	613	626	2415
3	561	560	571	574	2266
4	567	572	580	586	2305
6	482	449	472	471	1874
Sum	2203	2164	2236	2257	8860
Mean	551	541	559	564	554

	df	SS	V	VR	Significance
Total	15	43815.0			
Treatments	3	1237.5	412.5	4.46	*
Cows	3	41745.5	13915.2	150.53	***
HY:LY	1	21025.0	21025.0	227.44	***
Residual	2	20720.5	10360.3	112.08	***
Error	9	832.0	92.4		

SE_{mean} = 13.5

CV = 1.7%

LSR = 21.25

Treatment	Mean			
37	564.25	23.25*	13.50	5.25
21b	559.00	18.00	8.25	
21a	550.75	9.75		
37+IC	541.00			

Appendix 4d (i)

Liveweight changes.

The differences between liveweight recorded on the 3rd or 4th day of each part of the experiment and those found at the end of each phase, in kg.

Cow	21a	37+IC	21b	37	Sum
1	10	-22	37	10	35
3	7	2	0	13	22
4	-13	3	10	10	10
6	10	-30	32	0	12
Sum	14	-47	79	33	79
Mean	4	-12	20	8	5

	df	SS	V	VR	Significance
Total	15	4286.94			
Treatments	3	2043.68	681.23	2.86	n.s.
Cows	3	98.19	32.73	0.14	n.s.
HY:LY	1	7.56	7.56	0.03	n.s.
Residual	2	90.63	45.32	0.19	n.s.
Error	9	2145.07	238.34		

$SE_{mean} = 4.2$

CV = 312%

Appendix 4d(ii)

Liveweight changes

Add 40kg to all values in Appendix 4d(i)

Cow	21a	37+IC	21b	37	Sum
1	50	18	77	50	195
3	47	42	40	53	182
4	27	43	50	50	170
6	50	10	72	40	172
Sum	174	113	239	193	719
Mean	44	28	60	48	45

	df	SS	V	VR	Significance
Total	15	4286.94			
Cows	3	2043.68	681.23	2.86	n.s.
HY:LY	1	98.19	32.73	0.14	n.s.
Residual	2	7.56	7.56	0.03	n.s.
Treatment	3	90.63	45.32	0.19	n.s.
Error	9	2145.07	238.34		

$SE_{mean} = 4.2$

CV = 34.4%

Appendix 4e

Dry matter digestibility (%)

Cow	37+IC	21	37	Sum
1	50.0	55.6	68.9	174.5
3	73.8	69.7	62.2	205.7
4	65.7	62.7	66.0	194.5
6	78.4	68.6	64.1	211.2
Sum	268.0	256.5	261.4	785.8
Mean	67.0	64.1	65.3	65.5

	df	SS	V	VR	Significance
Total	11	616.97			
Treatments	2	17.15	8.58	0.153	n.s.
Cows	3	263.09	87.69	1.562	n.s.
HY:LY	1	191.72	191.72	3.416	n.s.
Residual	2	71.37	35.69	0.636	n.s.
Error	6	336.73	56.12		

SE_{mean} = 2.16
CV = 11.4%

Results used in the analysis of variance shown in appendix 4e.

Cow	Treatment	DMI	kg Wet faeces	DM%	Dry faeces	DMD%
1	37+IC	11.14	33.5	16.58	5.56	50.0
3	21	16.80	30.4	14.30	4.36	74.1
4	21	11.49	32.9	15.30	4.91	57.3
6	37+IC	17.68	27.8	13.17	3.82	78.4
1	21	11.14	28.3	17.44	4.94	55.6
3	37+IC	16.80	32.0	13.79	4.41	73.8^{xx}
4	37+IC	11.49	24.7	15.98	3.95	65.7
6	21	17.68	36.9	15.04	5.55	68.6
1	21	11.14				
3	37	16.80	44.8	14.16	6.35	62.2
4	37	14.49^{x}	25.0	15.59	3.90	66.0
6	21	15.48^{x}				
1	37	11.14	19.1	18.75	3.46	68.9
3	21	16.80	36.6	14.05	5.87	65.4
4	21	11.49	22.5	17.20	3.66	68.2
6	37	16.18^{x}	39.6	13.65	5.81	64.1

DMI = Dry matter intake
DM% = Faecal dry matter %
DMD% = Dry matter digestibility, %
x = some feed refused
xx = mild diarrhoea observed

Appendix 4f.

Respiration rates (/min.)

	Cow	37+IC	21	37	Sum
AM	1	25.1	26.0	27.3	78.4
	3	27.4	27.4	25.9	80.7
	4	28.3	26.7	26.0	81.0
	6	31.3	28.5	29.8	89.6
	Sum				329.7
PM	1	112.5	29.5	106.4	248.4
	3	97.0	28.2	81.8	207.0
	4	129.0	37.4	128.7	295.1
	6	131.4	49.7	132.4	313.6
	Sum	582.0	253.4	558.3	1064.0
	Mean	72.8	31.7	69.8	44.3

	df	SS	V	VR	Significance
Total	23	41772.27			
Cows	7	24788.69	3541.24	5.77	**
AM:PM	1	22466.52	22466.52	36.63	***
HY:LY	1	1122.03	1122.03	1.83	n.s.
Residual	5	1200.14	240.03	0.39	n.s.
Treatments	2	8395.99	4197.99	6.84	**
Error	14	8587.59	613.40		

$SE_{mean} = 8.70$

CV = 42.65%

LSR = 32.40

Treatment	Mean		
37+IC	72.75	41.07*	2.97
37	69.79	38.10*	
21	31.68		

Appendix 4g.

Respiration rate; afternoon values only.

Cow	37+IC	21	37	Sum
1	112.5	29.5	106.4	248.4
3	129.0	37.4	128.7	295.1
4	97.0	28.2	81.8	207.0
6	131.4	49.7	132.4	313.5
Sum	469.9	144.8	449.3	1064.0
Mean	117.5	36.2	112.3	88.7

	df	SS	V	VR	Significance
Total	11	19297.87			
Cows	3	2324.94	774.98	2.00	n.s.
HY:LY	1	1982.85	1982.85	5.12	n.s.
Residual	2	342.09	171.05	0.44	n.s.
Treatments	2	16596.55	8289.28	21.43	**
Error	6	2323.38	387.23		

$SE_{mean} = 12.09$

CV = 22%

LSR = 42.7

Treatment	Mean		
37+IC	117.48	81.28*	5.15
37	112.33	76.13*	
21	36.20		

Appendix 4h

Respiratory rates taken at hourly intervals on "full clinical" days. (mean values for the day)

Cow	37+IC	21	37	Sum
1	38.71	38.57	38.47	115.75
3	38.55	38.53	38.63	115.70
4	38.87	38.65	38.62	116.14
6	39.12	38.20	39.07	116.39
Sum	155.25	153.95	154.78	463.98
Mean	38.81	38.48	38.69	38.66

	SS	df	V	VR	Significance
Total	0.7143	11			
Cows	0.1077	3	0.359	5.52	*
HY:LY	0.0030	1	0.003	0.04	n.s.
Residual	0.1050	2	0.053	0.81	n.s.
Treatments	0.2160	2	0.108	1.66	n.s.
Error	0.3900	6	0.065		

$SE_{mean} = 0.073$

CV = 0.66%

Appendix 4i (i)

Rectal temperature(^{o}C)

	Cow	37+IC	21	37	Sum
AM	1	38.54	38.59	38.61	115.74
	3	38.69	38.57	38.49	115.75
	4	38.74	38.63	38.48	115.85
	6	38.82	38.84	38.59	116.25
	Sum				463.59
PM	1	39.29	38.63	39.08	117.00
	3	39.87	38.65	39.64	118.16
	4	39.27	38.60	38.98	116.85
	6	40.64	38.63	40.15	119.42
	Sum	313.86	309.14	312.02	935.02
	Mean	39.24	38.64	39.00	38.96

	df	SS	V	VR	Significance
Total	23	7.633			
Cows	7	4.047	0.578	3.73	n.s.
AM:PM	1	2.560	2.560	16.52	**
HY:LY	1	0.714	0.714	4.61	*
Residual	5	0.772	0.154	0.99	n.s.
Treatments	2	1.415	0.708	4.56	*
Error	14	2.171	0.155		

SE_{mean} = 0.118

CV = 1.0%

LSR = 0.516

Treatment	Mean		
37+IC	39.23	0.59*	0.23
37	39.00	0.36	
21	38.64		

Appendix 4i (ii)

Rectal temperatures; afternoon values only.

	df	SS	V	VR	Significance
Total	11	4.919			
Cows	3	1.428	0.476	4.07	n.s.
HY:LY	1	1.159	1.159	9.91	*
Residual	2	0.269	0.635	5.43	*
Treatments	2	2.787	1.394	11.91	**
Error	6	0.704	0.117		

SE_{mean} = 0.193
CV = 2.5%

LSR = 0.742

Treatment	Mean		
37+IC	39.77	1.143*	0.31
37	39.46	0.830*	
21	38.63		

Appendix 4j

Rectal temperatures (°C) taken at 14h30 on "full clinical" days.

Cow	37+IC	37	21	Sum
1	39.8	39.5	39.5	118.8
3	39.4	38.9	39.1	117.4
4	39.0	38.7	38.5	116.2
6	40.9	39.7	38.4	119.0
Sum	159.1	156.8	155.5	471.4
Mean	39.78	39.2	38.9	39.3

	df	SS	V	VR	Significance
Total	11	5.157			
Treatments	2	1.662	0.831	2.804	n.s.
Cows	3	1.717	0.572	1.930	n.s.
Error	6	1.778	0.296		

SE_{mean} = 0.197
CV = 1.4%

Rectal temperature (°C); the differences between rectal temperature at 09h30 and 14h30 on "full clinical" days.

Cow	37+IC	37	21
1	1.6	0.8	0.0
3	1.2	1.2	0.4
4	0.2	0.5	1.2
6	2.8	1.1	-0.1
Sum	5.8	3.6	1.5
Mean	1.5	0.9	0.4

	df	SS	V	VR	Significance
Total	11	7.13			
Cows	3	0.65	0.22	0.32	n.s.
Treatments	2	2.31	1.16	1.67	n.s.
Error	6	4.17	0.70		

SE_{mean} = 0.232
CV = 220%

Appendix 4k
Pulse rate; mean values for the whole duration of each phase of the experiment.

Cow	21	37	37+IC	Sum
1	53.00	72.67	62.00	187.67
3	58.50	63.33	68.00	189.83
4	54.00	59.00	66.00	179.00
6	59.83	73.33	67.67	200.83
Sum	225.33	268.33	263.67	757.33
Mean	56.33	67.08	65.92	63.11

	df	SS	V	VR	Significance
Total	11	484.29			
Treatments	2	278.39	139.19	6.670	*
Cows	3	80.65	26.88	1.287	n.s.
HY:LY	1	47.96	47.96	2.297	n.s.
Residual	2	32.69	16.35	0.783	n.s.
Error	6	125.25	20.88		

SE_{mean} = 1.915
CV = 7.24%
LSR = 9.91

Treatment	Mean		
37	67.08	10.75*	1.17
37+IC	65.91	9.58	
21	56.33		

Appendix 41 (i)

RBC (x 1 million cells/ul)

Cow	21		37		37+IC		Sum
	AM	PM	AM	PM	AM	PM	
1	7.16	6.99	6.68	6.44	5.98	6.19	39.44
3	7.80	7.41	7.42	7.17	7.42^{x}	6.91	44.13
4	7.38	7.10	7.14	6.90	7.14^{x}	6.76	42.42
6	6.30	6.28	5.91	5.97	6.44	6.25	37.15
Sum	28.64	27.78	27.15	26.48	26.98	26.11	163.14
Mean	7.16	6.95	6.79	6.62	6.75	6.53	6.80

	df	SS	V	VR	Significance
Total	21	6.747			
Cows	3	4.814	1.605	23.390	***
HY:LY	1	0.014	0.014	0.204	n.s.
Residual	2	4.800	2.400	34.978	***
Treatments	5	1.041	0.208	3.031	*
AM:PM	1	0.240	0.240	3.489	n.s.
Residual	4	0.801	0.200	2.915	n.s.
Error	13	0.892	0.068		

SE_{mean} = 0.111

CV = 3.8%

LSR = 0.499

Treatment	Mean					
21 AM	7.160	0.632*	0.540*	0.415	0.372	0.215
21 PM	6.945	0.417	0.325	0.200	0.157	
37 AM	6.788	0.260	0.168	0.043		
37+IC AM	6.745	0.217	0.125			
37 PM	6.620	0.092				
37+IC PM	6.528					

x = missing plots, estimated values.

Appendix 41 (ii)

WBC (cells/ul)

	21		37		37+IC		
Cows	AM	PM	AM	PM	AM	PM	Sum
1	4938	5200	5185	5409	5657	5093	31483
3	9319	14200	7669	7970	7669^{x}	7912	54739
4	7846	7887	8446	9002	8446^{x}	8900	50527
6	7294	6621	7263	7213	5179	7302	40872
Sum	29397	33908	28563	29594	26951	29208	177621
Mean	7349	8477	7141	7398	6738	7302	7401

	df	SS	V	VR	Significance
Total	21	91836725			
Cows	3	53955102	17985034	7.501	**
HY:LY	1	7707800	7707800	3.215	n.s.
Residual	2	46247302	23123651	9.644	**
Treatments	5	6711567	1342313	0.560	n.s.
AM:PM	1	2535340	2534350	1.057	n.s.
Residual	4	4177217	1044304	0.436	n.s.
Error	13	31170056	2397697		

$SE_{mean} = 408$

CV = 20.9%

x = missing plots, estimated.

Appendix 41 (iii)

Hb (g/dl)

	21		37		37+IC		
Cow	AM	PM	AM	PM	AM	PM	Sum
1	13.1	12.7	12.8	12.5	13.3	11.7	76.1
3	11.3	10.8	11.4	10.9	11.4^{x}	10.6	66.4
4	11.6	11.3	11.4	10.4	11.4^{x}	11.1	67.2
6	10.1	9.7	9.4	9.4	10.4	10.0	59.0
Sum	46.1	44.5	45.0	43.2	46.5	43.4	268.7
Mean	11.53	11.13	11.25	10.80	11.63	10.85	11.20

	df	SS	V	VR	Significance
Total	21	28.39			
Cows	3	24.52	8.14	67.83	***
HY:LY	1	13.35	13.35	111.25	***
Residual	2	11.17	5.59	46.58	***
Treatment	5	2.31	0.46	3.83	*
AM:PM	1	1.76	1.76	14.67	**
Residual	4	0.55	1.56	0.12	
Error	13	1.56	0.12		

SE_{mean} = 0.226

CV = 3.1%

LSR = 0.663

Treatment		Mean					
37+IC	AM	11.63	0.83*	0.78*	0.50	0.66	0.10
21	AM	11.53	0.73*	0.68*	0.40	0.56	
37	AM	11.25	0.45	0.40	0.12		
21	PM	11.13	0.33	0.28			
37+IC	PM	10.85	0.05				
37	PM	10.80					

Appendix 4 1 (iv)

Ht (%)

	21		37		37+IC		
Cow	AM	PM	AM	PM	AM	PM	Sum
1	46.8	41.2	46.4	34.9	44.1	38.0	251.4
3	41.4	30.9	37.9	30.7	37.9*	30.3	209.1
4	38.7	32.6	37.2	29.5	37.2*	29.6	204.8
6	34.0	32.7	34.5	27.7	35.4	31.8	196.1
Sum	160.9	137.4	156.0	122.8	154.6	129.7	861.4
Mean	40.23	34.35	39.00	30.70	38.65	32.43	35.89

	df	SS	V	VR	Significance
Total	21	654.318			
Cows	3	303.421	101.140	31.825	***
HY:LY	1	108.375	108.375	34.102	***
Residual	2	195.046	97.523	30.68	***
Treatment	5	309.583	61.917	19.483	***
AM:PM	1	277.440	277.440	87.300	***
Residual	4	32.143	8.036	2.529	n.s.
Error	13	41.314	3.178		

$SE_{mean} = 1.089$

CV = 5.0%

LSR = 2.414

Treatment	Mean					
21 AM	40.23	9.53*	7.80*	5.88*	1.58	1.23
37 AM	39.00	8.30*	6.57*	4.65*	0.35	
37+IC AM	38.65	7.95*	6.22*	4.30*		
21 PM	34.35	3.65*	1.92			
37+IC PM	32.43	1.73				
37 PM	30.70					

Appendix 4m (i)

Plasma T_3 (n mol/l)

	Cow	37+IC	21	37	Sum
AM	1	5.92	2.86	3.26	12.03
	3	3.59	4.37	3.08	11.02
	4	4.13	3.33	2.85	10.31
	6	3.79	2.80	2.68	9.27
	Sum				42.63
PM	1	4.36	3.22	2.43	10.01
	3	3.47	3.14	2.96	9.57
	4	3.65	2.36	2.37	8.38
	6	3.76	2.72	2.87	9.35
	Sum	32.65	24.79	22.50	79.94
	Mean	4.081	3.009	2.813	3.331

	df	SS	V	VR	Significance
Total	23	14.7394			
Cows	7	3.0070	0.4296	1.29	n.s.
AM:PM	1	1.1790	1.1790	3.55	n.s.
HY:LY	1	0.0961	0.0961	0.29	n.s.
Treatments	2	7.0850	3.5425	10.67	**
Error	14	4.6463	0.3319		

$SE_{mean} = 0.163$

CV = 17.3%

LSR = 0.754

Treatment	Mean		
37+IC	4.081	1.269*	0.982*
21	3.099	0.287	
37	2.831		

Appendix 4m (ii)

Plasma T_4 (n mol/l)

	Cow	37+IC	21	37	Sum
AM	1	128.80	86.60	78.80	294.10
	3	84.40	120.40	84.60	289.40
	4	92.55	78.14	83.72	254.41
	6	91.45	56.48	57.79	205.72
	Sum				1043.63
PM	1	115.90	89.52	91.45	296.87
	3	95.30	85.70	86.30	267.30
	4	96.60	61.82	77.30	325.72
	6	87.58	69.85	61.50	218.93
	Sum	792.58	648.51	621.36	2062.45
	Mean	99.073	81.064	77.670	85.935

	df	SS	V	VR	Significance
Total	23	7539.15			
Cows	7	2885.06	412.15	2.27	n.s.
AM:PM	1	25.65	25.65	0.14	n.s.
HY:LY	1	414.58	414.58	2.29	n.s.
Residual	5	2444.82	488.96	2.69	n.s.
Treatments	2	2117.07	1058.53	5.85	*
Error	14	2537.02	181.22		

SE_{mean} = 3.696

CV = 15.7%

LSR = 17.610

Treatment	Mean		
37+IC	99.073	21.43*	18.01*
21	81.064	3.39	
37	77.670		

Appendix 4m (iii)

Thyopac-3 values

	Cow	37+IC	21	37	Sum
AM	1	102.7	110.9	115.1	328.69
	3	113.3	118.3	115.7	347.30
	4	114.3	119.0	119.1	352.39
	6	115.1	115.3	118.4	348.80
	Sum				1377.18
PM	1	99.06	109.1	111.5	319.65
	3	112.9	116.4	116.6	345.70
	4	115.2	116.4	121.1	352.72
	6	115.9	114.7	116.7	347.30
	Sum	888.48	920.1	934.2	2742.75
	Mean	111.06	115.01	116.78	114.281

	df	SS	V	VR	Significance
Total	23	568.073			
Cows	7	291.050	41.579	4.16	*
AM:PM	1	35.697	35.698	3.57	n.s.
HY:LY	1	7.243	7.243	0.72	n.s.
Residual	5	248.109	49.622	4.96	**
Treatments	2	136.990	68.495	6.85	**
Error	14	140.033	10.002		

$SE_{mean} = 1.014$

CV = 2.8%

LSR = 5.532

Treatment	Mean		
37	116.78	1.77	5.72*
21	115.01	3.94	
37+IC	111.06		

Appendix 4m (iv).

FTI (T_4 n mol/l, Thyopac-3 values)

	Cow	37+IC	21	37	Sum
AM	1	125.4	79.6	68.4	273.4
	3	74.5	101.8	73.1	249.4
	4	81.3	64.8	70.3	206.5
	6	79.5	49.0	48.8	177.2
	Sum				916.4
PM	1	117.0	82.1	82.1	281.2
	3	84.4	73.6	74.0	232.0
	4	83.8	54.0	63.8	201.6
	6	75.6	61.0	52.7	189.3
	Sum	721.5	565.8	533.1	1820.4

	df	SS	V	VR	Significance
Total	23	8156.25			
Cows	7	3422.61	488.94	3.11	*
HY:LY	1	1495.48	1495.48	9.52	**
AM:PM	1	6.48	6.48	0.04	n.s.
Residual	5	1920.65	348.13	2.44	n.s.
Treatments	2	2533.27	1266.63	8.06	**
Error	14	2200.37	157.17		

$SE_{mean} = 3.844$

CV = 16.5%

LSR = 16.40

Treatment	Mean		
37+IC	90.186	23.551*	19.456*
21	70.730	4.095	
37	66.635		

Appendix 4n

Sweat rate (mg/10cm^2/5min.)

	df	SS	V	VR	Significance
Total	43	2032.24			
Cow-time	15	1096.79	73.119	2.86	*
Cows	3	106.94	35.647	1.39	n.s.
Time	3	913.86	304.619	11.92	***
HY:LY	1	0.22	0.22	0.01	n.s.
Residual	8	75.77	9.43	0.37	n.s.
Error	26	664.75	25.567		

Cow	Time	37+IC	21	37	Sum
1	09h30	6.54*	6.0	3.9	16.46
	11h00	4.4	13.0	7.6	25.00
	12h15	14.8	9.7	22.7	47.22
	14h15	17.8	10.5	23.2	51.50
3	09h30	6.6	6.54*	5.8	18.98
	11h00	9.7	7.7	19.2	36.64
	12h15	14.4	14.4	27.6	56.36
	14h15	19.8	18.6	18.7	57.08
4	09h30	7.3	6.54*	7.0	20.80
	11h00	10.7	6.3	16.0	33.00
	12h15	18.7	4.0	23.3	46.02
	14h15	21.4	6.7	24.0	52.14
6	09h30	6.54*	11.1	4.6	22.24
	11h00	6.7	5.9	3.8	16.44
	12h15	9.2	8.9	17.0	35.14
	14h15	10.6	16.1	19.3	46.02
Sum		185.2	152.0	243.9	581.04
Mean		11.57	9.50	15.24	12.11

* = missing plots, estimated values.

SE_{mean} = 0.949

CV = 41.8%

LSR = 4.917

Treatment	Mean		
37	15.24	5.74*	3.67
37+IC	11.57	2.07	
21	9.50		

Appendix 4o (i).

Heat production (kJ/hr./LW$^{0.75}$)

	Cow	37+IC	21	37	Sum
Day	1	37.4	36.2	35.7	109.3
	3	52.3	49.6	44.2	146.1
	4	34.7	34.5	37.2	106.4
	6	53.2	45.9	45.7	144.8
	Sum				506.6
Night	1	36.9	35.0	34.9	106.8
	3	47.9	47.3	40.7	135.9
	4	39.1	34.4	31.0	104.5
	6	48.2	42.8	42.5	133.5
	Sum	349.7	325.7	311.9	987.3
	Mean	43.71	40.71	38.99	41.14

	df	SS	V	VR	Significance
Total	23	948.756			
Cows	7	784.029	112.00	21.403	***
HY:LY	1	740.370	740.37	141.489	***
Day:Night	1	27.950	27.950	5.341	*
Residual	2	15.799	7.90	1.509	n.s.
Treatments	2	91.469	45.74	8.74	*
Error	14	73.258	5.23		

SE_{mean} = 0.04

CV = 5.6%

LSR = 2.992

Treatment	Mean		
37+IC	43.71	4.73*	3.00*
21	40.71	1.73	
37	38.99		

Appendix 4o (ii)

Heat production (kJ/hr./LW$^{0.75}$), corrected for milk yield.

	Cow	37+IC	21	37	Sum
Day	1	30.9	30.6	29.8	91.3
	3	30.9	33.9	27.8	92.6
	4	24.8	25.3	29.9	80.0
	6	26.6	20.8^{x}	23.4^{x}	70.8
	Sum	113.2	110.6	110.9	334.7
Night	1	30.9	29.1	31.8	91.8
	3	32.4	31.0	24.9	88.3
	4	28.8	26.8	23.4	79.0
	6	21.1	18.0	18.4	57.5
	Sum	226.4	215.5	209.4	651.3
	Mean	28.3	26.9	26.2	27.14

	df	SS	V	VR	Significance
Total	23	464.956			
Cows	7	356.836	50.976	7.967	***
HY:LY	1	45.10	45.10	7.05	*
Day:Night	1	13.65	13.65	2.13	n.s.
Residual	2	298.086	149.04	23.295	***
Treatments	2	18.54	9.27	1.449	n.s.
Error	14	89.59	6.398		

SE_{mean} = 0.92
CV = 9.3%

Appendix 4p (i)

Mean daily water consumption (l).

Cow	37+IC	21	37	Sum
1	49	45	50	144
3	95	81	84	260
4	55	48	49	152
6	85	87	87	259
Sum	284	261	270	815
Mean	71.0	62.3	67.5	67.9

	df	SS	V	VR	Significance
Total	11	4308.92			
Cows	3	4154.92	1384.97	95.70	***
HY:LY	1	4144.08	4144.08	286.35	***
Residual	2	10.80	5.40	0.37	n.s.
Treatment	2	62.19	31.08	2.15	n.s.
Error	6	86.83	14.47		

$SE_{mean} = 5.7$
CV = 5.6%

Appendix 4p (ii)

Percentage increase in water intake, treatment 21 taken as "normal".

Cow	37+IC	37	Sum
1	9%	11%	20
3	17%	4%	21
4	15%	2%	17
6	-2%	0%	-2
Sum	39	17	56
Mean	9.8%	4.3%	7%

	df	SS	V	VR	Significance
Total	7	348.0			
Cows	3	175.0	58.33	1.55	n.s.
HY:LY	1	40.5	40.5	1.08	n.s.
Residual	2	134.5	67.25	1.79	n.s.
Treatment	1	60.5	60.5	1.61	n.s.
Error	3	112.5	37.50		

$SE_{mean} = 2.49$
CV = 231%

Appendix 4q

Number of changes in posture, lying vs. standing.

Cow	21	37	37+IC	Sum
1	2	2	4	8
3	2	2	2	6
4	1	2	5	8
6	2	2	4	8
Sum	7	8	15	30
Mean	1.8	2.0	3.8	2.5

	df	SS	V	VR	Significance
Total	11	15.000			
Cows	3	1.000	0.333	0.444	n.s.
HY:LY	1	0.333	0.333	0.444	n.s.
Residual	2	0.667	0.333	0.444	n.s.
Treatment	2	9.500	4.750	6.333	*
Error	6	4.500	0.750		

SE_{mean} = 0.30

CV = 34.6%

LSR = 1.88

Treatment	Mean		
37+IC	3.8	2.0*	1.8
37	2.0	0.2	
21	1.8		

APPENDIX 5(a)

Milk Yields in kg/day during Treatment 21a

Cow 1	Cow 3	Cow 4	Cow 6
5.8	15.6	6.9	20.5
7.0	16.3	6.7	19.2
6.0	16.3	7.0	20.4
5.5	18.1	7.3	21.4
5.8	15.8	7.1	21.2
5.4	15.8*	7.0*	21.2
5.6	16.8	6.9	18.3
6.1	16.7	6.8	21.0
5.8	15.9	6.8	20.4
5.5	15.2	7.5	20.6
6.5	14.5	7.3	21.5
5.3	15.1	6.7	20.7
5.4	15.5	6.7	19.5
5.5*	15.9	6.9	19.8*
5.6	15.0	7.1	20.5
	15.5	7.7	
	14.5	7.5	
	15.1	7.0	
	15.2	7.2	
	16.4	6.7	
	15.9	7.2	
	16.4	7.4	
	16.7	7.2	
	16.4	7.4	
	16.5	6.6	
	15.4	6.8	
	16.0	7.2	

* Injected Vit A 2million iu, Vit D 30 000 iu, Vit E 200 iu.

APPENDIX 5(b)

Milk Yields in kg/day during Treatment 37 + IC

Cow 1	Cow 3	Cow 4	Cow 6
5.6	16.8***	7.2***	20.7
5.4	16.0	8.0	20.9
5.5	15.0*	7.4	20.7
6.0	14.8	8.1	21.9
6.0	15.4	7.5	21.4
6.2	16.8	7.9	22.2
6.0	17.0	8.5	22.3
5.8	16.5	8.5	21.6
5.6*	16.5	8.8	21.8
4.7*	17.9	8.8	20.6
5.6	17.5	8.8	20.8
6.1	17.3	8.7	20.7
6.6	16.8	8.6	19.5
6.4	16.2	8.6	20.0
6.5	17.3	8.4	21.3
6.9	16.6	8.1	18.6
6.2**	15.7	8.2	17.8**

* Vulvar discharge (possible abortion in cow 1).

** Drinking water switched off.

*** Room on all night at 30°C.

APPENDIX 5(c)

Milk Yields kg/day during Treatment 21b

Cow 1	Cow 3	Cow 4	Cow 6
5.2**	16.4	7.9	15.1**
6.4	16.2	7.5	19.1
5.9	16.3	7.7	19.1
5.6	16.7	7.8	19.8
5.6	15.6	6.7	20.1
4.9	15.1	6.7	20.5
5.5	15.5	6.2	21.6
5.5	15.4	5.9	19.5
5.9	15.0	6.2	20.3
5.5	15.8	6.3	21.1
6.1	15.1	6.9	20.3
5.4	15.7	7.1	20.7
5.5	15.1**	6.7**	19.2
5.6	9.5**	7.1**	19.3
5.0	15.1	7.0	19.5
5.4	15.7	6.9	20.2
5.5	12.7	6.2	20.7
5.5	14.6	7.1	20.5
5.1	14.6	6.8	20.8
4.9	15.0	7.1	20.2
5.1	14.9	5.9	20.7
4.7			19.9
5.9			20.7
5.8			22.0
5.1			21.3
5.3			20.4
5.1			21.4

** Water switched off.

APPENDIX 5(d)

Milk Yields kg/day during Treatment 37

Cow 1	Cow 3	Cow 4	Cow 6
4.8	15.2	6.2	21.2
4.9	14.3	6.7	20.2
4.7	15.1	7.2	19.6
4.9	14.9	6.4	20.9
4.9	15.2	7.0	21.6
4.6	14.3	7.4	20.4
4.8*	15.0	6.8	18.5*
4.8	13.5	7.2	19.8
5.0	14.2	6.7	19.6
3.8	15.3	6.8	19.3
4.5	15.0	6.4	20.3
4.4	14.3	7.3	20.3
4.4	12.7**	7.0**	20.1
3.9	12.8	7.4	19.8
4.2	16.0	7.8	20.1
4.3	15.2	7.4	19.7
4.0	14.4	7.4	19.5
4.3	12.4	7.9	19.8
4.2	17.4	6.1	20.9

* Food water-logged.

** Water switched off.

APPENDIX 5(e)

Milk Yields kg/day during Treatment 21c

Cow 1	Cow 3	Cow 4	Cow 6
4.0	15.0	4.5	20.3
3.8	14.9	3.6	20.1
3.8	14.8	3.6	21.2
3.5	15.5	6.4	20.1
3.6	13.3	3.9	21.0
4.0	14.2	5.6	19.9
3.3	15.8	6.3	19.7
4.8	14.2	5.7	20.2
3.2	14.5	5.9	19.5
3.4			20.5
3.4			20.0
3.2			19.8
3.4			20.6
3.2			17.1
3.0			9.9*
3.0			9.2*
3.1			7.6*
2.1			10.3*
2.6			10.1*

* Mastitis treatment.

APPENDIX 6

Theoretical Endogenous Urinary Nitrogen

From "The nutrient requirements of farm livestock" (Agricultural Research Council, 1965):

Endogenous urinary nitrogen (EUN) $= 0.12 \times W^{0.73}$ g/day

e.g. for 500 kg cow EUN $= 0.12 \times 93.3$ g/day

$= 11.2$ g/day

The heat output of such a cow $= 250 \times W^{0.73}$

$= 23\,325$ kJ/day

EUN correction (Brouwer, 1965) $= -4.5$ kJ/g EUN

$= -4.5 \times 11.2$ kJ/day

$= 50$ kJ/day

Thus the EUN correction is negligible.

APPENDIX 7

Liveweight (kg) Recorded During the Experiment.

Cow 1	Cow 3	Cow 4	Cow 6
Treatment 21(a)			
605	570	595	480
595	585	595	475
	565	595	
	570	560	
	570	560	
	550	560	
	557	582	
Treatment 37+IC			
610	558	572	485
580	585	565	460
585	572	580	455
585	561	565	455
583	552	573	441
	560	575	
Treatment 21 (b)			
588	558	570	443
603	575	568	460
603	555	578	475
630	580		485
625	565	570	475
	560	580	465
Treatment 37			
630	560	580	470
605	575	585	470
620	573	590	470
635			475
640			470
Treatment 21 (c)			
635			470
640			485
650			490

APPENDIX 8

Plasma Thyroid Hormone Levels

a) Conversion factors

1 ng = 10^{-9}g
1 ug = 10^{-6}g
1 mg = 10^{-3}g

1 ug/100ml = 10 ng/ml
T_3 ng/ml x 1.538 = T_3 n mol/l
T_4 ug/100ml x 12.87 = T_4 n mol/l

Thyopac 3 = 207.9 - (T_3 uptake x 3.48)
FTI (Thyopac 3) = FTI(T_3 uptake) x 3.25 - 3.17

b) Some normal plasma levels in the cow

T_4 (ng/ml)	Reference
51 ± 13	Kallfelz & Erali (1973)
30 - 50	Hart *et al* (1979)
10 - 15	Heitzman & Mallison (1972)
75 - 87	Magdub *et al* (1979)
80 - 105	Magdub *et al* (1980)
54	Shaw *et al* (1975)
50 - 70	Vanjonack & Johnson (1975)
51 ± 13	Ward (1978)
T_3 (ng/ml)	
1.65	Magdub *et al* (1980)
1.95	Richards (1979)
2.23	Ward (1978)
FTI	
14.0 ± 4.4 (T_4 ng/ml x T_3 uptake)	Kallfelz & Erali (1973)
TSR	
1 - 10 mg	Turner (1970)

c) Discussion

5% of body weight is plasma (Turner, 1970), so a 500 kg cow has 25 kg plasma, or about 25 l. If she secretes 1 - 10 mg T_4 into this volume, plasma T_4 levels work out at 40 - 400 ng/ml. However, plasma T_4 concentration cannot be predicted from TSR alone.

It is necessary to include metabolisation and excretion rates in the calculation. This was illustrated by Shaw _et_ _al_ (1975), who fed iodinated casein to cows at a rate of 15g/cow/day. Theoretically, plasma T_4 levels could have been 600 ng/ml, but were in fact only 140 ng/ml. This implies that the rate of T_4 excretion exceded the rate of absorption. Subsequently, plasma T_4 levels dropped well below 140 ng/ml (but stayed about 20 ng/ml above the normal level for those cows). Apart from enzyme induction (Brander & Pugh, 1971), this could also have been due to the animals' high metabolic rate, as a result of the high plasma T_4 levels, promoting metabolisation and excretion of T_4 itself.

APPENDIX 9

Mean weekly water intake results (l/day)

Treatment	Cow 1	Cow 6
21a	40	90
37 + IC	45	90
37 + IC	47	82
37 + IC	52	81
37 + IC	52	87
21b	45	90
21b	53	89
21b	40	90
37	57	86
37	47	87
37	47	87
21c	47	84
21c	46	84
Mean	47.8	86.8

Treatment	Cow 3	Cow 4
21a	46	84
21a	47	68
21a	50	83
21a	44	85
37 + IC	50	90
37 + IC	57	107
37 + IC	59	87
21b	49	84
21b	49	79
37	45	84
37	49	84
37	54	85
21c	54	85
Mean	50.4	85.3

APPENDIX 10

Gaseous Exchange and Heat Production Data

Treatment	Cow No.	O_2 consumed 1/hr	CO_2 produced 1/hr	CH_4 produced 1/hr	Heat produced kJ/hr	Heat produced kJ/hr/$LW^{0.75}$	Heat (kJ)* from milk production	Heat produced kJ/hr/$LW^{0.75}$ minus(0.625 x *)
21	1	207.9	207.9	7.1	4392	36.2	9.0	30.6
21	1	200.0	203.9	7.1	4244	35.0	9.4	29.1
21	3	278.2	251.5	8.8	5744	49.6	25.1	33.9
21	3	263.0	243.9	8.8	5480	47.3	26.0	31.0
21	4	91.5	179.8	15.6	3967	34.5	14.6	25.3
21	4	187.6	191.5	15.6	39.63	34.4	12.2	26.8
21	6	215.8	235.8	17.2	4638	45.9	40.1	20.8
21	6	199.8	227.8	17.2	4326	42.8	39.6	18.0
37	1	215.1	207.3	15.6	4486	35.7	9.4	29.8
37	1	207.0	215.1	15.6	4396	34.9	7.5	31.8
37	3	236.3	250.2	14.5**	5047	44.2	26.2	27.8
37	3	218.2	236.3	14.5**	4685	40.7	25.3	24.9
37	4	204.8	216.0	14.5**	4366	37.2	11.7	29.9
37	4	175.0	167.6	14.5**	3641	31.0	12.1	23.4
37	6	233.2	260.4	18.3	5032	45.7	35.7	23.4
37	6	190.5	248.8	18.3	4291	42.5	38.6	18.4
37+IC	1	209.3	216.7	11.6	4449	37.4	10.4	30.9
37+IC	1	205.5	216.7	11.6	4387	36.9	9.6	30.9
37+IC	3	265.1	261.1	21.4	5976	48.6	34.6	30.9
37+IC	3	249.3	296.4	21.4	5476	47.9	24.8	32.4
37+IC	4	191.1	203.0	13.9	4080	34.7	15.8	24.8
37+IC	4	207.0	207.0	13.9	4357	37.1	13.3	28.8
37+IC	6	242.8	254.2	15.6	5170	53.2	42.6	26.6
37+IC	6	220.0	202.9	15.6	4746	48.2	43.4	21.1

$* \ \dfrac{4.94(\text{MJ}) \times \text{milk produced}(1/\text{hr})}{LW^{0.75}}$

** estimated.

APPENDIX 11

Equivalent Temperature

(Dry bulb + Vapour pressure/0.66)

Temp °C	Vapour Pressure									
	0	1	2	3	4	5	6	7	8	9
20	20.0	21.5	23.0	24.5	26.1	27.6	29.1	30.6	32.1	33.6
21	21.0	22.5	24.0	25.5	27.1	28.6	30.1	31.6	33.1	34.6
22	22.0	23.5	25.0	26.5	28.1	29.6	31.1	32.6	34.1	35.6
23	23.0	24.5	26.0	27.5	29.1	30.6	32.1	33.6	35.1	36.6
24	24.0	25.5	27.0	28.5	30.1	31.6	33.1	34.6	36.1	37.6
25	25.0	26.5	28.0	29.5	31.1	32.6	34.1	35.6	37.1	38.6
26	26.0	27.5	29.0	30.5	32.1	33.6	35.1	36.6	38.1	39.6
27	27.0	28.5	30.0	31.5	33.1	34.6	36.1	37.6	39.1	40.6
28	28.0	29.5	31.0	32.5	34.1	35.6	37.1	38.6	40.1	41.6
29	29.0	30.5	32.0	33.5	35.1	36.6	38.1	39.6	41.1	42.6
30	30.0	31.5	33.0	34.5	36.1	37.6	39.1	40.6	42.1	43.6
31	31.0	32.5	34.0	35.5	37.1	38.6	40.1	41.6	43.1	44.6
32	32.0	33.5	35.0	36.5	38.1	39.6	41.1	42.6	44.1	45.6
33	33.0	34.5	36.0	37.5	39.1	40.6	42.1	43.6	45.1	46.6
34	34.0	35.5	37.0	38.5	40.1	41.6	43.1	44.6	46.1	47.6
35	35.0	36.5	38.0	39.5	41.1	42.6	44.1	45.6	47.1	48.6
36	36.0	37.5	39.0	40.5	42.1	43.6	45.1	46.6	48.1	49.6
37	37.0	38.5	40.0	41.5	43.1	44.6	46.1	47.6	49.1	50.6
38	38.0	39.5	41.0	42.5	44.1	45.6	47.1	48.6	50.1	51.6
39	39.0	40.5	42.0	43.5	45.1	46.6	48.1	49.6	51.1	52.6
40	40.0	41.5	43.0	44.5	46.1	47.6	49.1	50.6	52.1	53.6
41	41.0	42.5	44.0	45.5	47.1	48.6	50.1	51.6	53.1	54.6
42	42.0	43.5	45.0	46.5	48.1	49.6	51.1	52.6	54.1	55.6
43	43.0	44.5	46.0	47.5	49.1	50.6	52.1	53.6	55.1	56.6
44	44.0	45.5	47.0	48.5	50.1	51.6	53.1	54.6	56.1	57.6
45	45.0	46.5	48.0	49.5	51.1	52.6	54.1	55.6	57.1	58.6

Equivalent Temperature

(Dry bulb + Vapour pressure/0.66)

Temp °C	Vapour Pressure									
	10	11	12	13	14	15	16	17	18	19
20	35.2	36.7	38.2	39.7	41.2	42.7	44.2	45.8	47.3	48.8
21	36.2	37.7	39.2	40.7	42.2	43.7	45.2	46.8	48.3	49.8
22	37.2	38.7	40.2	41.7	43.2	44.7	46.2	47.8	49.3	50.8
23	38.2	39.7	41.2	42.7	44.2	45.7	47.2	48.8	50.3	51.8
24	39.2	40.7	42.2	43.7	45.2	46.7	48.2	49.8	51.3	52.8
25	40.2	41.7	43.2	44.7	46.2	47.7	49.2	50.8	52.3	53.8
26	41.2	42.7	44.2	45.7	47.2	48.7	50.2	51.8	53.3	54.8
27	42.2	43.7	45.2	46.7	48.2	49.7	51.2	52.8	54.3	55.8
28	43.2	44.7	46.2	47.7	49.2	50.7	52.2	53.8	55.3	56.8
29	44.2	45.7	47.2	48.7	50.2	51.7	53.2	54.8	56.3	57.8
30	45.2	46.7	48.2	49.7	51.2	52.7	54.2	55.8	57.3	58.8
31	46.2	47.7	49.2	50.7	52.2	53.7	55.2	56.8	58.3	59.8
32	47.2	48.7	50.2	51.7	53.2	54.7	56.2	57.8	59.3	60.8
33	48.2	49.7	51.2	52.7	54.2	55.7	57.2	58.8	60.3	61.8
34	49.2	50.7	52.2	53.7	55.2	56.7	58.2	59.8	61.3	62.8
35	50.2	51.7	53.2	54.7	56.2	57.7	59.2	60.8	62.3	63.8
36	51.2	52.7	54.2	55.7	57.2	58.7	60.2	61.8	63.3	64.8
37	52.2	53.7	55.2	56.7	58.2	59.7	61.2	62.8	64.3	65.8
38	53.2	54.7	56.2	57.7	59.2	60.7	62.2	63.8	65.3	66.8
39	54.2	55.7	57.2	58.7	60.2	61.7	63.2	64.8	66.3	67.8
40	55.2	56.7	58.2	59.7	61.2	62.7	64.2	65.8	67.3	68.8
41	56.2	57.7	59.2	60.7	62.2	63.7	65.2	66.8	68.3	69.8
42	57.2	58.7	60.2	61.7	63.2	64.7	66.2	67.8	69.3	70.8
43	58.2	59.7	61.2	62.7	64.2	65.7	67.2	68.8	70.3	71.8
44	59.2	60.7	62.2	63.7	65.2	66.7	68.2	69.8	71.3	72.8
45	60.2	61.7	63.2	64.7	66.2	67.7	69.2	70.8	72.3	73.8

Equivalent Temperature

(Dry bulb + Vapour pressure/0.66)

Temp °C	Vapour Pressure									
	20	21	22	23	24	25	26	27	28	29
20	50.3	51.8	53.3	54.8	56.4	57.9	59.4	60.9	62.4	63.9
21	51.3	52.8	54.3	55.8	57.4	58.9	60.4	61.9	63.4	64.9
22	52.3	53.8	55.3	56.8	58.4	59.9	61.4	62.9	64.4	65.9
23	53.3	54.8	56.3	57.8	59.4	60.9	62.4	63.9	65.4	66.9
24	54.3	55.8	57.3	58.8	60.4	61.9	63.4	64.9	66.4	67.9
25	55.3	56.8	58.3	59.8	61.4	62.9	64.4	65.9	67.4	68.9
26	56.3	57.8	59.3	60.8	62.4	63.9	65.4	66.9	68.4	69.9
27	57.3	58.8	60.3	61.8	63.4	64.9	66.4	67.9	69.4	70.9
28	58.3	59.8	61.3	62.8	64.4	65.9	67.4	68.9	70.4	71.9
29	59.3	60.8	62.3	63.8	65.4	66.9	68.4	69.9	71.4	72.9
30	60.3	61.8	63.3	64.8	66.4	67.9	69.4	70.9	72.4	73.9
31	61.3	62.8	64.3	65.8	67.4	68.9	70.4	71.9	73.4	74.9
32	62.3	63.8	65.3	66.8	68.4	69.9	71.4	72.9	74.4	75.9
33	63.3	64.8	66.3	67.8	69.4	70.9	72.4	73.9	75.4	76.9
34	64.3	65.8	67.3	68.8	70.4	71.9	73.4	74.9	76.4	77.9
35	65.3	66.8	68.3	69.8	71.4	72.9	74.4	75.9	77.4	78.9
36	66.3	67.8	69.3	70.8	72.4	73.9	75.4	76.9	78.4	79.9
37	67.3	68.8	70.3	71.8	73.4	74.9	76.4	77.9	79.4	80.9
38	68.3	69.8	71.3	72.8	74.4	75.9	77.4	78.9	80.4	81.9
39	69.3	70.8	72.3	73.8	75.4	76.9	78.4	79.9	81.4	82.9
40	70.3	71.8	73.3	74.8	76.4	77.9	79.4	80.9	82.4	83.9
41	71.3	72.8	74.3	75.8	77.4	78.9	80.4	81.9	83.4	84.9
42	72.3	73.8	75.3	76.8	78.4	79.9	81.4	82.9	84.4	85.9
43	73.3	74.8	76.3	77.8	79.4	80.9	82.4	83.9	85.4	86.9
44	74.3	75.8	77.3	78.8	80.4	81.9	83.4	84.9	86.4	87.9
45	75.3	76.8	78.3	79.8	81.4	82.9	84.4	85.9	87.4	88.9

Equivalent Temperature

(Dry bulb + Vapour pressure/0.66)

Temp °C	Vapour Pressure									
	30	31	32	33	34	35	36	37	38	39
20	65.5	67.0	68.5	70.0	71.5	73.0	74.5	76.1	77.6	79.1
21	66.5	68.0	69.5	71.0	72.5	74.0	75.5	77.1	78.6	80.1
22	67.5	69.0	70.5	72.0	73.5	75.0	76.5	78.1	79.6	81.1
23	68.5	70.0	71.5	73.0	74.5	76.0	77.5	79.1	80.6	82.1
24	69.5	71.0	72.5	74.0	75.5	77.0	78.5	80.1	81.6	83.1
25	70.5	72.0	73.5	75.0	76.5	78.0	79.5	81.1	82.6	84.1
26	71.5	73.0	74.5	76.0	77.5	79.0	80.5	82.1	83.6	85.1
27	72.5	74.0	75.5	77.0	78.5	80.0	81.5	83.1	84.6	86.1
28	73.5	75.0	76.5	78.0	79.5	81.0	82.5	84.1	85.6	87.1
29	74.5	76.0	77.5	79.0	80.5	82.0	83.5	85.1	86.6	88.1
30	75.5	77.0	78.5	80.0	81.5	83.0	84.5	86.1	87.6	89.1
31	76.5	78.0	79.5	81.0	82.5	84.0	85.5	87.1	88.6	90.1
32	77.5	79.0	80.5	82.0	83.5	85.0	86.5	88.1	89.6	91.1
33	78.5	80.0	81.5	83.0	84.5	86.0	87.5	89.1	90.6	92.1
34	79.5	81.0	82.5	84.0	85.5	87.0	88.5	90.1	91.6	93.1
35	80.5	82.0	83.5	85.0	86.5	88.0	89.5	91.1	92.6	94.1
36	81.5	83.0	84.5	86.0	87.5	89.0	90.5	92.1	93.6	95.1
37	82.5	84.0	85.5	87.0	88.5	90.0	91.5	93.1	94.6	96.1
38	83.5	85.0	86.5	88.0	89.5	91.0	92.5	94.1	95.6	97.1
39	84.5	86.0	87.5	89.0	90.5	92.0	93.5	95.1	96.6	98.1
40	85.5	87.0	88.5	90.0	91.5	93.0	94.5	96.1	97.6	99.1
41	86.5	88.0	89.5	91.0	92.5	94.0	95.5	97.1	98.6	100.1
42	87.5	89.0	90.5	92.0	93.5	95.0	96.5	98.1	99.6	101.1
43	88.5	90.0	91.5	93.0	94.5	96.0	97.5	99.1	100.6	102.1
44	89.5	91.0	92.5	94.0	95.5	97.0	98.5	100.1	101.6	103.1
45	90.5	92.0	93.5	95.0	96.5	98.0	99.5	101.1	102.6	104.1

Equivalent Temperature

(Dry bulb + Vapour pressure/0.66)

Temp °C	Vapour Pressure									
	40	41	42	43	44	45	46	47	48	49
20	80.6	82.1	83.6	85.2	86.7	88.2	89.7	91.2	92.7	94.2
21	81.6	83.1	84.6	86.2	87.7	89.2	90.7	92.2	93.7	95.2
22	82.6	84.1	85.6	87.2	88.7	90.2	91.7	93.2	94.7	96.2
23	83.6	85.1	86.6	88.2	89.7	91.2	92.7	94.2	95.7	97.2
24	84.6	86.1	87.6	89.2	90.7	92.2	93.7	95.2	96.7	98.2
25	85.6	87.1	88.6	90.2	91.7	93.2	94.7	96.2	97.7	99.2
26	86.6	88.1	89.6	91.2	92.7	94.2	95.7	97.2	98.7	100.2
27	87.6	89.1	90.6	92.2	93.7	95.2	96.7	98.2	99.7	101.2
28	88.6	90.1	91.6	93.2	94.7	96.2	97.7	99.2	100.7	102.2
29	89.6	91.1	92.6	94.2	95.7	97.2	98.7	100.2	101.7	103.2
30	90.6	92.1	93.6	95.2	96.7	98.2	99.7	101.2	102.7	104.2
31	91.6	93.1	94.6	96.2	97.7	99.2	100.7	102.2	103.7	105.2
32	92.6	94.1	95.6	97.2	98.7	100.2	101.7	103.2	104.7	106.2
33	93.6	95.1	96.6	98.2	99.7	101.2	102.7	104.2	105.7	107.2
34	94.6	96.1	97.6	99.2	100.7	102.2	103.7	105.2	106.7	108.2
35	95.6	97.1	98.6	100.2	101.7	103.2	104.7	106.2	107.7	109.2
36	96.6	98.1	99.6	101.2	102.7	104.2	105.7	107.2	108.7	110.2
37	97.6	99.1	100.6	102.2	103.7	105.2	106.7	108.2	109.7	111.2
38	98.6	100.1	101.6	103.2	104.7	106.2	107.7	109.2	110.7	112.2
39	99.6	101.1	102.6	104.2	105.7	107.2	108.7	110.2	111.7	113.2
40	100.6	102.1	103.6	105.2	106.7	108.2	109.7	111.2	112.7	114.2
41	101.6	103.1	104.6	106.2	107.7	109.2	110.7	112.2	113.7	115.2
42	102.6	104.1	105.6	107.2	108.7	110.2	111.7	113.2	114.7	116.2
43	103.6	105.1	106.6	108.2	109.7	111.2	112.7	114.2	115.7	117.2
44	104.6	106.1	107.6	109.2	110.7	112.2	113.7	115.2	116.7	118.2
45	105.6	107.1	108.6	110.2	111.7	113.2	114.7	116.2	117.7	119.2

APPENDIX 12

Temperature Humidity Index

0.72 x (Dry bulb + Wet bulb) + 40.6

Dry Bulb °C	Wet Bulb °C									
	10	11	12	13	14	15	16	17	18	19
20	62.2	62.9	63.6	64.4	65.1	65.8	66.5	67.2	68.0	68.7
21	62.9	63.6	64.4	65.1	65.8	66.5	67.2	68.0	68.7	69.4
22	63.6	64.4	65.1	65.8	66.5	67.2	68.0	68.7	69.4	70.1
23	64.4	65.1	65.8	66.5	67.2	68.0	68.7	69.4	70.1	70.8
24	65.1	65.8	66.5	67.2	68.0	68.7	69.4	70.1	70.8	71.6
25	65.8	66.5	67.2	68.0	68.7	69.4	70.1	70.8	71.6	72.3
26	66.5	67.2	68.0	68.7	69.4	70.1	70.8	71.6	72.3	73.0
27	67.2	68.0	68.7	69.4	70.1	70.8	71.6	72.3	73.0	73.7
28	68.0	68.7	69.4	70.1	70.8	71.6	72.3	73.0	73.7	74.4
29	68.7	69.4	70.1	70.8	71.6	72.3	73.0	73.7	74.4	75.2
30	69.4	70.1	70.8	71.6	72.3	73.0	73.7	74.4	75.2	75.9
31	70.1	70.8	71.6	72.3	73.0	73.7	74.4	75.2	75.9	76.6
32	70.8	71.6	72.3	73.0	73.7	74.4	75.2	75.9	76.6	77.3
33	71.6	72.3	73.0	73.7	74.4	75.2	75.9	76.6	77.3	78.0
34	72.3	73.0	73.7	74.4	75.2	75.9	76.6	77.3	78.0	78.8
35	73.0	73.7	74.4	75.2	75.9	76.6	77.3	78.0	78.8	79.5
36	73.7	74.4	75.2	75.9	76.6	77.3	78.0	78.8	79.5	80.2
37	74.4	75.2	75.9	76.6	77.3	78.0	78.8	79.5	80.2	80.9
38	75.2	75.9	76.6	77.3	78.0	78.8	79.5	80.2	80.9	81.6
39	75.9	76.6	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4
40	76.6	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1
41	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8
42	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5
43	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2
44	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0
45	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0	86.7

Temperature Humidity Index

0.72 x (Dry bulb + Wet bulb) + 40.6

Dry Bulb °C	Wet Bulb °C									
	20	21	22	23	24	25	26	27	28	29
20	69.4	70.1	70.8	71.6	72.3	73.0	73.7	74.4	75.2	75.9
21	70.1	70.8	71.6	72.3	73.0	73.7	74.4	75.2	75.9	76.6
22	70.8	71.6	72.3	73.0	73.7	74.4	75.2	75.9	76.6	77.3
23	71.6	72.3	73.0	73.7	74.4	75.2	75.9	76.6	77.3	78.0
24	72.3	73.0	73.7	74.4	75.2	75.9	76.6	77.3	78.0	78.8
25	73.0	73.7	74.4	75.2	75.9	76.6	77.3	78.0	78.8	79.5
26	73.7	74.4	75.2	75.9	76.6	77.3	78.0	78.8	79.5	80.2
27	74.4	75.2	75.9	76.6	77.3	78.0	78.8	79.5	80.2	80.9
28	75.2	75.9	76.6	77.3	78.0	78.8	79.5	80.2	80.9	81.6
29	75.9	76.6	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4
30	76.6	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1
31	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8
32	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5
33	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2
34	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0
35	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0	86.7
36	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0	86.7	87.4
37	81.6	82.4	83.1	83.8	84.5	85.2	86.0	86.7	87.4	88.1
38	82.4	83.1	83.8	84.5	85.2	86.0	86.7	87.4	88.1	88.8
39	83.1	83.8	84.5	85.2	86.0	86.7	87.4	88.1	88.8	89.6
40	83.8	84.5	85.2	86.0	86.7	87.4	88.1	88.8	89.6	90.3
41	84.5	85.2	86.0	86.7	87.4	88.1	88.8	89.6	90.3	91.0
42	85.2	86.0	86.7	87.4	88.1	88.8	89.6	90.3	91.0	91.7
43	86.0	86.7	87.4	88.1	88.8	89.6	90.3	91.0	91.7	92.4
44	86.7	87.4	88.1	88.8	89.6	90.3	91.0	91.7	92.4	93.2
45	87.4	88.1	88.8	89.6	90.3	91.0	91.7	92.4	93.2	93.9

Temperature Humidity Index

0.72 x (Dry bulb + Wet bulb) + 40.6

Dry Bulb °C	Wet Bulb °C									
	30	31	32	33	34	35	36	37	38	39
20	76.6	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1
21	77.3	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8
22	78.0	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5
23	78.8	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2
24	79.5	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0
25	80.2	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0	86.7
26	80.9	81.6	82.4	83.1	83.8	84.5	85.2	86.0	86.7	87.4
27	81.6	82.4	83.1	83.8	84.5	85.2	86.0	86.7	87.4	88.1
28	82.4	83.1	83.8	84.5	85.2	86.0	86.7	87.4	88.1	88.8
29	83.1	83.8	84.5	85.2	86.0	86.7	87.4	88.1	88.8	89.6
30	83.8	84.5	85.2	86.0	86.7	87.4	88.1	88.8	89.6	90.3
31	84.5	85.2	86.0	86.7	87.4	88.1	88.8	89.6	90.3	91.0
32	85.2	86.0	86.7	87.4	88.1	88.8	89.6	90.3	91.0	91.7
33	86.0	86.7	87.4	88.1	88.8	89.6	90.3	91.0	91.7	92.4
34	86.7	87.4	88.1	88.8	89.6	90.3	91.0	91.7	92.4	93.2
35	87.4	88.1	88.8	89.6	90.3	91.0	91.7	92.4	93.2	93.9
36	88.1	88.8	89.6	90.3	91.0	91.7	92.4	93.2	93.9	94.6
37	88.8	89.6	90.3	91.0	91.7	92.4	93.2	93.9	94.6	95.3
38	89.6	90.3	91.0	91.7	92.4	93.2	93.9	94.6	95.3	96.0
39	90.3	91.0	91.7	92.4	93.2	93.9	94.6	95.3	96.0	96.8
40	91.0	91.7	92.4	93.2	93.9	94.6	95.3	96.0	96.8	97.5
41	91.7	92.4	93.2	93.9	94.6	95.3	96.0	96.8	97.5	98.2
42	92.4	93.2	93.9	94.6	95.3	96.0	96.8	97.5	98.2	98.9
43	93.2	93.9	94.6	95.3	96.0	96.8	97.5	98.2	98.9	99.6
44	93.9	94.6	95.3	96.0	96.8	97.5	98.2	98.9	99.6	100.4
45	94.6	95.3	96.0	96.8	97.5	98.2	98.9	99.6	100.4	101.1

APPENDIX 13

Heat Absorption Capacities

Temp °C	Relative Humidity RH%										
	0	10	20	30	40	50	60	70	80	90	100
20	120.2	116.1	112.0	107.9	103.8	99.7	95.6	91.5	87.4	83.3	79.2
21	119.4	115.0	110.7	106.4	102.0	97.7	93.4	89.0	84.7	80.3	76.0
22	118.5	113.9	109.3	104.8	100.2	95.6	91.0	86.4	81.8	77.3	72.7
23	117.7	112.8	108.0	103.1	98.3	93.4	88.6	83.7	78.9	74.0	69.2
24	116.8	111.7	106.6	101.5	96.3	91.2	86.1	80.9	75.8	70.7	65.5
25	116.0	110.6	105.1	99.7	94.3	88.9	83.4	78.0	72.6	67.2	61.7
26	115.2	109.4	103.7	97.9	92.2	86.5	80.7	75.0	69.3	63.5	57.8
27	114.3	108.3	102.2	96.1	90.0	84.0	77.9	71.8	65.8	59.7	53.6
28	113.5	107.1	100.6	94.2	87.8	81.4	75.0	68.5	62.1	55.7	49.3
29	112.6	105.9	99.1	92.3	85.5	78.7	71.9	65.1	58.8	51.5	44.7
30	111.8	104.6	97.4	90.3	83.1	75.9	68.7	61.5	54.4	47.2	40.0
31	111.0	103.4	95.8	88.2	80.6	73.0	65.4	57.8	50.2	42.6	35.0
32	110.1	102.1	94.1	86.0	78.0	70.0	61.9	53.9	45.9	37.8	29.8
33	109.3	100.8	92.3	83.8	75.3	66.8	58.3	49.8	41.3	32.8	24.3
34	108.4	99.5	90.5	81.5	72.5	63.5	54.5	45.5	36.6	27.6	18.6
35	107.6	98.1	88.6	79.1	69.6	60.1	50.6	41.1	31.6	22.1	12.6
36	106.8	96.7	86.7	76.6	66.6	56.5	46.4	36.4	26.3	16.3	6.2
37	105.9	95.3	84.7	74.0	63.4	52.8	42.1	31.5	20.9	10.2	-0.4
38	105.1	93.8	82.6	71.3	60.1	48.9	37.6	26.4	15.1	3.9	-7.4
39	104.2	92.3	80.5	68.6	56.7	44.8	32.9	21.0	9.1	-2.8	-14.7
40	103.4	90.8	78.2	65.7	53.1	40.5	27.9	15.4	2.8	-9.8	-22.4
41	102.6	89.3	76.0	62.7	49.3	36.0	22.7	9.4	-3.9	-17.2	-30.5
42	101.7	87.7	73.6	59.5	45.4	31.4	17.3	3.2	-10.8	-24.9	-39.0
43	100.9	86.0	71.1	56.2	41.4	26.5	11.6	-3.3	-18.2	-33.0	-47.9
44	100.0	84.3	68.6	52.8	37.1	21.4	5.6	-10.1	-25.9	-41.6	-57.3
45	99.2	82.6	65.9	49.3	32.6	16.0	-0.7	-17.3	-34.0	-50.6	-67.2