An Examination of the effect of Climatic Housing and Nutrition on the performance of Calves.

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A Thesis submitted for the Degree of Doctorae Philosiphae In the Faculty of Science, Department of Agriculture, of the University of Glasgow.

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Ayr.

August, 1977.

This Thesis is dedicated to my wife, Cynthia, for her love and understanding.

ACKNOWLEDGEMENTS

I am deeply indebted to the trustees of the Dr.William Stewart Scholarships who made the award which enabled this research to be undertaken.

I wish to extend my sincere thanks to Professor Hall and Dr. A.M.Raven, my supervisors throughout the duration of the research, to Dr.Raven in particular for his invaluable assistance and discussion at the outset and during the compilation of this thesis.

I am deeply indebted to Mr.Walker-Love, Head of the Animal Husbandry Department for his encouragement, guidance and support, together with the use of the facilities of his Department where the research was undertaken. I should like to thank Mr.N.Day, the project leader, for the immense amount of work undertaken by him at the inception of the project and for his assistance and expert management of the calf unit.

My thanks are extended to Dr.J.McLean and his staff at the Hannah Research Institute, Ayr, for designing and maintaining the environmental monitoring unit, also for his aid in interpreting the environmental data. I am grateful for the advice and support of Mr.C.L.Wright and his staff of the Veterinary Investigation Service, Auchincruive.

I am indebted to Professor Finney of the Agricultural Research Unit of Statistics and in particular to Mr.E.A.Hunter of that Department for his expert statistical analyses of the calf performance data. I am also indebted to Mr.D.P.Arnott, statistician at the West of Scotland Agricultural College who aided in my appreciation of the statistical data.

I am grateful to the staff of the Farm Buildings Department of the West of Scotland Agricultural College for designing the four calf houses.

I should like to thank the members of staff of the Experimental Unit, Brickrow, who looked after the calves and also the staff of the Animal Husbandry Advisory and Development Service at Auchincruive who were a

constant source of ideas and encouragement during my stay in the Department.

Finally, I am grateful to Mrs. Lloyd for her care and neatness in typing this thesis.

C O N T E N T S

SUMMARY

Research was undertaken to examine the feasibility of rearing bought-in calves in climatic calf houses in the West of Scotland. An examination was also undertaken of the individual effects and the interactions between different levels of nutrition and the degree of protection afforded by climatic calf housing on the performance of Friesian type calves from approximately 6 to 160 days of age.

Satisfactory levels of performance and daily live-weight gains on a par with those achieved by calves of similar type reared under similar management conditions in other areas of Great Britain were achieved by the climatically housed calves. Overall calf losses represented 12% of the total purchased. When certain of the experimental trial conditions, which would be unacceptable in practice, were taken into account calf mortality was 7.9% which whilst not ideal was close to the mean level of 5.8% achieved by specialist bought-in calf rearers. Climatic calf housing was thus considered feasible for rearing young bought-in calves in the West of Scotland area.

Differing designs of calf housing incorporating varying degrees of insulation raised the mean internal house temperature above ambient by a maximum of 3°C. Insulation raised the mean internal temperature and reduced the internal range of temperature compared with the external mean and temperature range. The internal temperature ranges of the two non-insulated houses as a percentage of the external range were 94 and 87 per cent compared with 73 and 40 per cent in the insulated houses. Air movement within the houses was directly related to the degree of enclosure of the house and the external wind speed. Only in the completely enclosed house and during one intake were levels of relative humidity recorded which were considered detrimental to calf

health. The instantaneous environmental conditions within the four houses were almost totally dependent on the external environmental conditions at that instant.

In no single house did calves consistently perform better, were healthier or was mortality lower between arrival and weaning or arrival and sale. Completely enclosing the house was detrimental to calf health. There was a suggestion that better calf health, lower mortality and better performance could be obtained by a degree of insulation in an open fronted building.

Levels of nutrition ranging from 1.46 to 2.09 x maintenance had a far greater affect on the daily live-weight gain, health and mortality of the calves than any of the recorded environments. Higher calf mortality was associated with low levels of feeding and by feeding 300 compared with 600g of milk replacer per day. Increased calf scour was positively correlated with feeding 600g of milk replacer per day. Benefit was accrued in terms of better performance by feeding 400g of milk replacer per day compared with feeding either 300 or 600g/ day. Climatically housed calves have a requirement for a higher level of milk replacer feeding on a once daily feeding system than do calves housed in controlled environment buildings. Calves receiving equivalent amounts of metabolisable energy had better daily live-weight gains and lower mortality when receiving 600 compared with 300g of milk replacer per day plus concentrates. The optimum level of feeding for climatically housed calves was estimated to be in the region of 1.7 x maintenance.

Restricting the level of milk replacer feeding increased the calves' appetite for concentrates. Restricting the levels of milk replacer and concentrate feeding both individually increased the calves' appetite for hay. There was no affect of cold on the appetite for concentrates of calves receiving 600g of milk replacer per day. Calves receiving 300g of milk replacer per day increased their concentrate consumption

in response to cold.

The metabolizable energy value of a high fat (18%) milk replacer was 19.2 MJ/kg DM and was unaffected by feeding in levels of 300 or 600g/day or by feeding in conjunction with up to 1 kg/day of concentrates. The metabolizable energy value of high digestibility concentrates was 9.37 MJ/kg DM. The metabolizable energy value of the concentrates was affected by the duration of time for which the concentrates had been fed. The metabolizable energy requirements of the metabolism trial calves for maintenance and gain were 0.46 $MJ/kg^{0.75}$ and 12.36-13.47 MJ/kg gain respectively.

The metabolizable energy content of the gain of calves gaining at 0.3 and 0.6 kg/day was approximately 10.5 and 18.0 MJ.ME/kg gain respectively. It was considered that the higher metabolizable energy content of the gain was due to increased fat deposition in calves gaining at 0.6 kg/day compared with those gaining at 0.3 kg/day. Climatically housed calves have a higher percentage of fat in the gain compared with calves gaining weight at the same rate but housed in controlled environment buildings.

Young calves severly undernourished were lacking in total body insulation and upon realimentation made a small amount of compensatory growth which contained a higher percentage of fat than the gain of the control animal.

GENERAL INTRODUCTION

In planning houses for calves it is particularly important to consider the productivity and health of the animal. In a recent study of the levels of mortality in calf and beef units in Great Britain the average calf mortality on specialist calf rearing units where calves were reared to three months of age was 5.8% (M.L.C. 1976). The 90% range was from 0 - 19.7%. The average mortality cost per head sold on these units was £2.39 and the average veterinary and medical costs per head sold £1.33. It can thus be seen that calf ill health and mortality may seriously erode the potential profits from a calf rearing enterprise.

A considerable amount of research has been carried out to establish those factors which reduce the ability of the calf to survive. It has been verified that the environment in which the calf is reared, the level and type of nutrition and the management of the animals are all factors which may affect calf viability. Whilst each of the three factors mentioned is capable of reducing the viability of the calf there is the possibility of interactions occurring between two or more which may be more detrimental in their effect than any one of the single components. There is also the possibility that an adverse effect of any one feature may be compensated by more favourable conditions in any of the other factors relating to calf rearing.

The environment in which the calf is reared should not be so cold, so hot or so uncomfortable as to reduce the animal's weight gain or food conversion efficiency. It should also supply sufficient fresh air to minimise the risk of infectious disease. Most traditional

concepts of what constitute the thermal requirements of livestock have been based upon anthropomorphic thinking, which is unfortunate because man is uniquely sensitive to cold for an animal so large.

On the evidence of calorimetric data Webster (1977) stated that the air temperature fluctuations in unheated airy buildings, likely to be encountered in the United Kingdom, are so small as to have a negligible effect on the productivity of calves. The directly harmful effects of low air temperatures on calves from one week of age onwards would be so small that the beneficial effects of fresh air in reducing the survival and spread of pathogens would be overwhelming by comparison. One may question whether it is appropriate to extrapolate from results such as these obtained in calorimeters, using fed healthy calves, where there is no diurnal variation of the internal environment and no account is taken of the interactions between temperature, relative humidity and air movement, to suggest appropriate ranges of conditions under which calves should be reared.

Several studies have been made on the possibility of climatic calf housing. In this study climatic calf housing is taken to mean naturally ventilated buildings in which there is no supplementary source of heat. The consensus of opinion from studies made in the British Isles suggests that climatic calf houses provide a suitable environment for the rearing of calves. In all the studies made however the results pertain to climatic housing of the particular type used and to the geographical region in which the experiments were carried out. There is however a lack of definition in the literature on the degree of protection which should be afforded the calf when housed in climatic buildings. There is also considerable variation within the British Isles in the climatic conditions characteristic of certain areas.

From the review of the literature it was not possible to define what effect the level of feeding, or feeding management would have on climatically housed calves. If the amount of heat required by the calf to maintain itself is increased as a result of subcritical temperatures then the maintenence requirement of the calf for energy increases. It was postulated that in this situation an increase in dietary energy may be beneficial. Thus it was considered that should the climatic housing yield a sub optimal environment for rearing calves the effect of high levels of nutrition should be examined as a means of overcoming the environmental stress.

It was decided that an attempt should be made to clarify the requirements of climatic housing intended for the rearing of calves. Also it was decided to examine the expediency of climatic calf housing in the South West of Scotland, an area which tends to have a higher relative humidity than other areas in the British Isles. In view of the very high incidence of respiratory diseases in young calves, respiratory ailments being the largest single cause of death in cattle under twelve months of age (M,L.C. 1976), emphasis was placed on the need for adequate ventilation. The building design and degree of insulation were considered to be the main features which could be manipulated in order to produce different environments in which the calves could be reared. It was decided that these factors should be examined by building four calf houses of two different designs, each design incorporating two levels of insulation. Brick construction designs were used in order to provide houses suitable for long term use.

The effect of an increased level of feeding lowering the critical temperature of stock is well documented (Webster 1974). Both an increase in the quantity and a reduction in the quality of food offered

to older stock may increase the thermoneutral heat production and lower the critical temperature. The corollary also applies, that any animal that ceases to eat for any reason such as sickness, indigestion or disease, or that is receiving a reduced level of nutrition, immediately becomes extremely sensitive to cold. Conditions that are optimal for a healthy calf eating well cannot be considered suitable for a young calf that is not being fed. It was, therefore, considered pertinent to employ various levels of feeding in order to examine the productivity of the calves under a range of nutritional conditions which were likely to be met in practise.

The environment within the calf house is modified by the size and numbers of stock present. In order to quantify the environment in which the calves were reared it was considered that an accurate record should be kept of the calf house environment. The effect of insulating the house could only be assessed if it was known how the internal environment behaved in relation to the external environment. It was therefore necessary to record the external environment at the same time.

The value of the house construction in producing environments favourable for calf production was to be measured by examining the performance of the calves in terms of growth and mortality. It was further considered that if the energy consumption of the calves could be partitioned into that required for maintenance and production then the effect of the environment on the energy requirements of the calf would be further illucidated.

The nutrients requirements of the unweaned calf may be supplied by milk and concentrates. It was considered that different levels of milk and concentrate feeding should be the means by which the

level of nutrition would be varied. The milk offered to the calves would be in the form of reconstituted milk replacer.

The value of the project would be greatly enhanced if, beside yielding basic research data, it could clearly relate to the agricultural development and advisory needs of the area. To fulfil this aim the housing and feeding systems were designed to be identifiable with practical calf rearing systems currently in use.

Section 1

Literature Review

FOREWORD

The literature reviewed has been examined initially by considering the adaption of the neonate calf to an existence outside the womb. Total body insulation has been examined plus the thermogenic response to cold. In this respect factors which may affect the perception of cold and the degree of response to a cold stimulus have also been surveyed.

Current literature on calf house environment has been reviewed considering separately and in conjunction with each other the aspects of temperature, humidity, ventilation rate, air capacity and pen size. The three aspects of temperature, humidity and ventilation rate were considered the factors most likely to affect the calf's perception of cold and hence have been considered in detail.

The literature pertaining to nutrition and environmental interactions has mainly considered very severe cold stresses on adult animals. This section has been inserted because it is considered that the results may be extrapolated to include the young calf.

The aspects of calf nutrition pertinent to the present trial have been considered. The effects of level and frequency of milk replacer feeding together with the physiological significance of the different systems has been reviewed. The effects of solid feed intake have been examined particularly with respect to weaning and rumen development.

The determination of the maintenance requirement of the calf has been one of the aims of the trial, hence some presently accepted values have been reviewed.

Finally, the history and some past results obtained using the method chosen to determine the maintenance requirement of the calves has been examined. The success of the method in determining the

maintenance requirement of different classes of livestock is discussed, together with its relevance to the present trial.

The Thermoneutral Environment

It has long been realised that different breeds of cattle and sheep have different tolerances to extreme climatic conditions. Sensations of heat and cold are experienced by each individual, and the characteristics of the external environment that are perceived by cattle as hot and cold differ enormously between individuals, according to breed, nutrition and management.

In regions where the climate appears to adversely effect the ability of the animal to regulate its body temperature, constructive breeding has taken place in an effort to increase animal productivity. Most research has been carried out on the breeding of cattle tolerant to high temperatures, relatively little work having been done to breed increased cold resistance.

In considering environmental parameters the concept of the thermoneutral environment should be considered. Mount (1974), concluded that it is preferable to define a number of environmental zones which are neutral in different respects:-

1. Minimal metabolism; bounded on each side by rising metabolic rate.
2. Least thermoregulatory effort; coinciding with minimal material demand, bounded at the colder limit by rising metabolic rate and at the warmer limit by increased evaporative loss.
3. Zones defined for particular purposes; preferred thermal environment (comfort zone), zone of peak animal productivity and zones which are optimal in any other given respect such as growth rate or the development of thermoregulation in the young animal; these zones do not necessarily coincide with either minimal metabolism or least thermoregulatory effort.

Webster (1974), on the other hand gives a definition of a thermoneutral zone based on thermal stress. Accordingly the thermoneutral zone is that in which both heat loss and food energy intakes are independent of environmental temperature. Within this zone, homeothermy is maintained by wide fluctuations in sensible and evaporative heat loss. At the upper limit of the thermoneutral zone, heat produced in metabolism is dissipated principally by evaporation of water from the skin and from the mucous membranes of the upper respiratory tract. Sensible heat loss in the thermoneutral zone broadly follows the body to air temperature gradient but is regulated by pilocrection, postural adjustments and by varying the rate of blood flow through the superficial tissues of the body. The lower limit of the thermoneutral zone is defined as the lower critical temperature. At air temperatures below this, heat loss to the environment exceeds that which would be produced as an inevitable consequence of metabolism. In order to maintain homeothermy, heat loss must be matched by an increased catabolism of food energy or tissue reserves.

THERMOREGULATION IN THE NEONATE CALF

The thermoregulatory response of neonate mammals to changes in the external environment is considerably limited by their small size, poor thermal insulation, and relative helplessness. Pre-partum the environment of the young mammal is that of the uterus and the requirement for a thermoregulatory response is diminished by the protection offered by the stable environment produced by the dam.

Immediately post-partum there is a need for a rapid means of thermoregulation. External conditions are such that at parturition the young mammal is likely to experience a lower temperature compared

to that within the uterus. The requirement is thus for an increase in heat production together with an adaptation for the conservation of body heat. It is these phenomena in the neonate calf which will be examined.

Brown Adipose Tissue

Brown fat cells of young rabbits have been shown to have an oxidative capacity that is 20 times greater than that of white fat cells. Cold stressed young rabbits were able to treble their heat production and in doing so the temperature of the brown fat deposits rose 2.5°C higher than that in muscle tissue in the back and 1.3°C higher than the deep body temperature. Surgical removal of 80% of the brown fat practically abolished the ability of young rabbits to multiply their oxygen consumption and step up heat production in response to cold. It was concluded that the brown fat cells are the main site of cold - stimulated heat production in the neonate (Dawkins & Hull 1965). The ability of the newborn ox to increase heat production by the oxidation of fat has been reported (Thompson and Clough 1972). Calves kept at a temperature of 5°C were seen to shiver, especially in the first hour of life. After one hour these calves also showed a rise in free fatty acid plasma concentration of 25.6 ± 1.69 mg/100 ml compared to a rise of 7.5 ± 2.43 mg/100 ml in other calves exposed to + 25°C. The proportion of individual fatty acids in the total free fatty acids changed with age, but there was no difference between the animals exposed to different environments.

The new born young of most ruminants that have been examined have at least some multiocular adipose tissue cells (Gemmell, Bell & Alexander). Electron microscopic examination of adipose cells of the new born calf has shown that all adipose cells have the character-

istics regarded as essential for their identification as brown adipose cells with the exception of those from the subcutaneous regions. (Alexander, Bennett, and Gemmell, 1975). Alexander et al (1975) on a dissection of two calves found the total adipose tissue to be 1.81 and 1.51 per cent of body weight respectively. The effect of brown adipose tissue can be seen from the fact that Thompson & Bell (1976) obtained, by an infusion of noradrenaline at the rate of 1 $\mu g\ kg^{-1}\ min^{-1}$, a rise of $0.63 \pm 0.10^{\circ}C$ in perirenal adipose tissue temperature and an increase in mixed venous blood temperature of $0.32 \pm 0.05^{\circ}C$. This was the mean effect recorded over the final 15 mins. of a 30 min. infusion period. Metabolic rate was increased 50% in the experiments of Thompson and Bell (1976) and Alexander et al (1975) found that at higher infusion rates a two or three fold increase in metabolic rate was possible. In the latter instance an infusion rate of 5 $\mu g\ kg^{-1}\ min^{-1}$ was considered to be in excess of the normal physiological level so it was likely that this high infusion rate would cause a more marked response albeit over a shorter period of time than that obtained by Thompson and Bell (1976).

Moulon, Molnar and Gunther (1975), have shown that the perirenal adipose tissue of newborn calves reacted to a venous infusion of noradrenaline with a rise in temperature of about $1^{\circ}C$. The oxygen consumption was eleven times that in perivascular epicardial adipose tissue and twelve times that in perirenal adipose tissue of 100 day old calves. The description of the tissue is equivalent to that described by Alexander et al (1975) and therefore it would be considered as brown adipose tissue.

Alexander et al (1975) recorded a peak rectal temperature during noradrenaline infusion of $42.3^{\circ}C$. Peak rectal temperature was found to occur concomitant with an increase in respiration rate and oxygen

consumption. Thompson and Bell (1976) noticed a similar increase in oxygen consumption and respiratory rate together with a decrease in respiratory quotient following the infusion of noradrenaline.

Using light microscopy it has been shown that in lambs there is a progressive increase in the proportion of large locules of fat in the adipose tissue from all sides with increasing age (Gemmell et al 1972). These changes were apparent by two days, well advanced by 16 days and complete by 32 days. This pattern is similar to that obtained by noradrenaline infusion. The response of the calf to noradrenaline infusion is most marked on the day after birth (Thompson and Bell 1976). A slight response was found at about one month old (Alexander et al 1975) and at 33 days of age (Thompson and Bell 1976). The effect, however, may be modified by environment.

Brown fat was identified in 25 day old calves exposed to continuously changing cold and warm ambient temperatures whilst only white adipose tissue was found in calves kept in warm conditions. White adipose tissue only was found in calves of 50 and 100 days old (Moulen et al 1975).

In an earlier similar series of experiments McEwan, Jenkinson, Noble and Thompson (1968), found an infusion of noradrenaline at 1.0 $\mu g\ kg^{-1}\ min^{-1}$ into calves one to six days old affected heart rate and respiratory rate but did not increase heat production, rectal temperature, skin temperature or skin evaporative loss. As the majority of recordings were made in calves other than day old calves it is pertinent to consider that these results suggest that non shivering thermogenesis constitutes a negligible contribution to the heat production capacity of the calf up to the time it is six days of age. In the newborn lamb non shivering thermogenesis

contributes about 40% of the maximum metabolic response to cold (Alexander, Williams, 1968). In a six to seven day old calf McEwan et al 1968 noticed shivering to occur between -1 and 3°C. It is obvious therefore that the capacity of the calf to produce heat by means other than non shivering thermogenesis is developed at six days of age.

From this review it can be seen that the neonate calf is able to readily produce heat in order to maintain body temperature from stores of brown adipose tissue. Its ability to gain heat from this source declines with age but is still present at 33 days of age. The environment in which the calf is kept may modify the extent to which brown adipose tissue acts as a heat source. The capacity of the calf to produce heat by means other than from brown adipose tissue would appear to be developed by six days of age.

Metabolic Response to Cold

The metabolic rate of the calf declines with age. Gonzalez-Jimenez and Blaxter (1962) calculated regression equations for calves fed 4l of milk in an environmental temperature of 23°C:-

For 24h observations $H = 1963 - 8.8t$

For 12h observations $H = 2485 - 33.2t$

where H is heat produced (Kcal m^{-2} 24h) and t is age in days Heat production per unit of time when measured over 24h was lower than when measured over 12h, suggesting that a diurnal variation in metabolism occurred. When 4l of milk were given and the environmental temperature was 3°, heat production was greater than when measured at 23°. As with observations made at 23° heat production at 3° was higher when determined in 12h observations. A fall in metabolism with age is apparent with both sets of observations, the mean decline being about 1% per day.

There are suggestions that the degree to which a young calf can increase its metabolic rate in response to cold is about twice the resting metabolic rate (Gonzalez-Jimenez and Blaxter 1962; McEwan et al 1968). However, the results of Alexander et al (1975) suggest that the potential for non shivering thermogenesis alone is at least equal to the resting metabolism. From an analogy with the new born lamb (Alexander, et al 1968) it seems likely that shivering coupled with non shivering thermogenic mechanisms, provide the calf with a potential for trebling or quadrupling metabolic rate in response to cold.

Examination of blood flow in the conscious two day old lamb has shown that a cold stress capable of eliciting a three fold increase in metabolic rate increases cardiac output by about 30% (Alexander, Bell, and Hales, 1973). Blood flow to the thermogenic tissues showed a five to six fold increase, whilst a five to nine fold increase was noticed in the flow to the longissimus dorsi, trapesius, gastrocnemius and biceps femoris muscles. A decreased flow in the skin of the leg, ear and midside and some internal organs was recorded. These results coincide with temperature measurements made by Gonzalez-Jimenez and Blaxter (1962) where it was found that during experimental cooling, below 15°C, the temperature of the ear and leg of a calf fell at a greater rate than other areas of the body. The age of the calf during this examination was not recorded. Vasoconstriction occurred in the whole hind limb including the thigh at approximately 12.5°C. The five to ninefold increase in blood flow in the biceps femoris of the cold stressed lamb, (Alexander et al 1973) is much greater than the threefold increase in hind leg blood flow found in Ayrshire steers between 6-8 months of age (Bell, Gardener and Thompson 1974). This may be demonstrating a reduced

capability of the young lamb to curtail an increased flow of blood to the extremeties compared with the older steer. Webster (1974) in a schematic representation of the effect of cold on heat loss from the ox suggested that vasodilation did not occur at temperatures above $0^{o}C$.

Two factors relating to the metabolic rate of the calf are apparent from this discussion. Firstly, metabolic rate is high at birth and subsequently declines. Secondly, at an early age the young calf can increase its metabolic rate in response to cold. It has been shown that at birth there is a thermogenic response from brown adipose tissue and by six days of age the capacity of the calf to produce heat other than from brown adipose tissue is developed. The increase in metabolic rate noted by Gonzalez-Jimenez and Blaxter (1962), McEwan et al 1968 and Alexander et al (1975) is a measure of the increased metabolism as a result of shivering and non shivering thermogenic mechanisms. The total response would appear to be in the region of a quadrupling of the resting metabolic rate.

The increase in metabolic rate has been shown to elicit a 30% increase in cardiac output (Alexander et al 1973). If a comparison can be drawn between the young lamb and calf then the ninefold increase in blood flow shown by Alexander et al (1973) in the lamb would suggest that the calf and lamb are unable to control vasodilation at an early age and that heat loss by this means may be considerable. No mention is made in the literature of a breakdown in thermoregulatory control, however the conditions of $-10^{o}C$, a varying wind and a wet coat over a 20 min. period, utilised by Alexander et al (1973) to promote summit metabolism, which subsequently produced a five to ninefold increase in blood flow to the biceps femoris, would appear to be reaching the point at which the control of vasodilation ceased in the lamb. It has been shown that as the calf grows older the ability

to conserve heat by selective vasoconstriction increases.

Tissue Insulation

Gonzalez-Jimenez and Blaxter (1962) conclude that the young calf is less well insulated than the adult steer. Mean insulation of the tissues in the cold was 18.48 x 10^{-3} $^{o}C/kJ.m^{2}$ 24h. and fell to 7.56 units at 23°C compared with 28.14 and 8.4 units for steers in cold and warm conditions respectively. Results from the measurement of tissue insulation of cattle made at the University of Alberta have related tissue insulation (It) to body weight (W kg) and air temperature below 0°C according to the formula,

$$It = 10^{-3} (115 + 0.378W + 2.07 Ta)$$

where Ta is air temperature (Webster 1973). The units of It in this equation are $^{o}C.m^{2}$ 24h/Mcal. Maximum values for tissue insulation are obtained when vasoconstriction is maximal. Gonzalez-Jimenez and Blaxter (1962) found the regression of tissue insulation on age was

$$It = 2.68 + 0.15t$$

Where t = age of the calf.

It was suggested that one of the main reasons why the overall resistance to cooling of the calf increases with age and why its critical temperature simultaneously falls is because its tissue insulation increases. This phenomenon seems likely to be due to changes in the blood supply to the skin which, according to Webster (1973), would be an increased ability to reduce the blood supply to the periphery, the alternative being a morphological change in skin thickness which could hardly change so rapidly with age.

Insulation of the Hair Coat

Gonzalez-Jimenez and Blaxter (1962) showed that pilorection occurred in the calf in response to cold from four days of age. Webster (1974) showed that the increase in insulation of the hair coat with increasing depth is curvilinear Figure 1.1 and can be described by the equation:-

$$Io = 10^{-3} (118 + 132f - 16.4f^2)$$

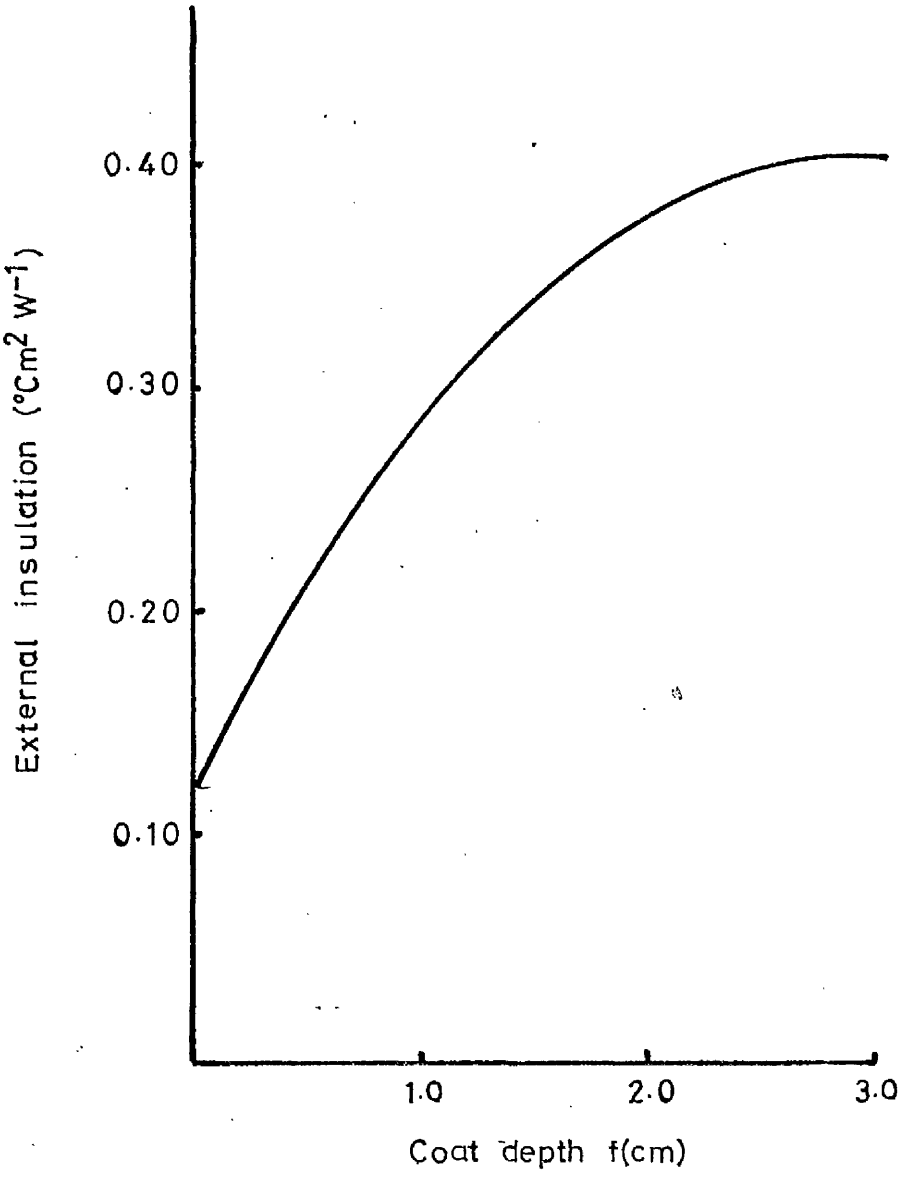
where f = depth of coat in cms

and Io = insulation of the hair coat in $^{o}C.m^2$ 24h/MJ

At coat depths exceeding 1.5 cm, the slope decreases markedly, presumably as the density of the coat decreases. Measurements of the coat depth at various sites on the body (Gonzalez-Jimenez and Blaxter 1962) showed that at 23°C mean coat depth was 1.22cm and that when pilorection had occurred in response to cold the mean depth was 2.33 cm. Calculation of the insulative capacity of the coat shows only a 32% increase in Io for an approximately twofold increase in coat depth. This provides support for the conclusion of Webster (1974) that maximum tissue insulation, which is a function of body weight to surface area ratio and the thickness of the skin and subcutaneous fat should increase as animals grow bigger and the coat becomes more dense. This would imply that sensible heat loss should decline relative to evaporative heat loss as calves grow at a constant temperature. As this was not seen to occur in calves grown at temperatures between 5° and 20°C (Webster, Gordon and Smith 1976), it was suggested that tissue insulation is determined to a great extent by the conscious perception of temperature at the skin surface and therefore by the air and skin temperature to which the animal has become habituated.

Fig.1.1.

External insulation vs Coat depth



Critical Temperature

In the literature concerned with the effect of temperature on the calf a great deal of emphasis is placed on the concept of critical temperature. Caution should however be exercised in interpreting critical temperatures as they presume the existence of a herd of identical animals all responding to the environment exactly in accordance with prediction. It also presumes that it is possible to engineer a satisfactory, dry, unheated, well-ventilated but draught-free building for cattle. Account must also be taken of the feeding level and the heat increment of feeding, both being such as to modify the critical temperature. The critical temperature does however indicate the cold tolerence of the animal under conditions where the coldness of the environment is determined by air temperature alone. Very few of the quoted values define all the relative parameters in order to make the specific value of the critical temperature meaningful. It may be noted that in the preruminant calf, the mode of feeding management, together with lack of rumination, reduces the period during which benefit may be obtained from the heat increment of the feed.

In a review of the literature concerning critical temperature Mitchell (1972) quoted a figure of 0.5°C for a calf with a 23 mm coat at the maintenance level of feeding and at full feed the figure dropped to -0.1°C. It should be noted that the coat depth quoted by Mitchell was considerably greater than that above which thermal insulation of the coat markedly drops (Webster 1973). Figures of 12.8°C for a two day old calf and 8.9°C for calves three weeks old were also quoted by Mitchell, although the level of feeding was not specifically stated.

Gonzalez-Jimenez and Blaxter (1962) quoted a critical temperature on the 3rd day of life of a calf, given an allowance of whole milk at 10% of body weight as being 12.8°C and declining to 8.2°C on the 20th day. With 6l of milk the critical temperature in the 3rd week of life was about 7°C. The environment in which these measurements were made had a low air movement, a low humidity (50% saturation), and a radiant temperature that was the same as the ambient temperature.

Webster (1974) from knowledge of values of the thermoneutral heat production at fasting metabolism, the external insulation of the hair coat, rectal temperature, external temperature and hair depth, quoted a value of 9°C for the critical temperature of a new born calf at a body weight of 35 kg and a critical temperature of 0°C at one month of age for a calf of body weight 50 kg. It is pertinent to consider that in these two instances the heat increment of feeding is minimal although not specifically stated.

In an experiment carried out at the Danish Building Research Institute calves of 14 days of age fed 6.3 MJ/24h had a significantly higher heat production at 5°C than at 17°C showing 5°C to be below the critical temperature of the calf at this age (Feenstra 1973). The value of 8.4 MJ/24h of heat produced for a 15 day old calf kept at 5°C is of the same order as the figure of 9.1 MJ/24h calculated from the regression equation of Gonzalez-Jimenez and Blaxter (1962) for a calf kept at 3°C over a 24h period.

At 23 days of age heat production of calves kept at 5°C and fed 12.6 MJ of ME/24h had fallen to a value equivalent to that of calves kept at 17°C showing that at this age heat production had fallen to a value equivalent to that found in a thermoneutral environment. The conditions under which these measurements were made were of minimal air movement and minimal humidity (Feenstra 1973).

Heat production of very young calves (40-45 kg live weight) with low feed intakes was not increased at temperatures of 25°, 20° and 15°C but higher heat production was noted at 12° and 10°C. Animals of 70 kg growing rapidly had the same heat production at 20, 15 and 8°C (Van Es, Van Weerden and Van Hellemond 1969).

The critical temperatures found in the literature, together with the age and level of feeding, have been summarised in tabular form in Table 1.1. It is assumed although not always stated that conditions were of minimum air movement and minimum humidity.

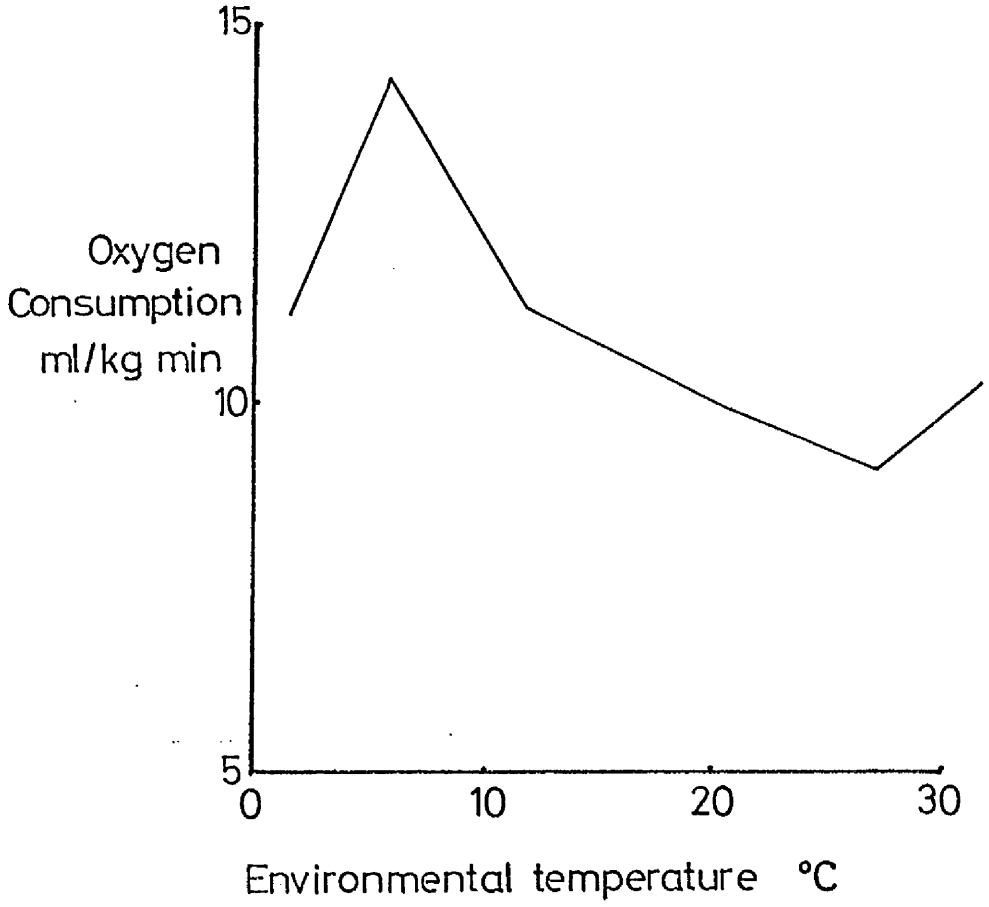
Table 1.1. Summary of Critical Temperatures of Calves of Various Ages

Age in days	Critical Temp. °C	Level of feeding if stated	Reference
Newborn	9	Fasting metabolism	Webster (1974)
Very young	>12	Low level	Van Es et al (1969)
2	12.8	-	NOSCA Calf Rearing Leaflet
3	12.8	4l whole milk 10% B.W.	Gonzalez-Jimenez and Blaxter (1962)
20	8.2	4l whole milk 10% B.W.	Gonzalez-Jimenez and Blaxter (1962)
21	8.9	-	NOSCA Calf Rearing Leaflet
21-28	6.7	6l whole milk	Gonzalez-Jimenez and Blaxter (1962)
23	5	12.6 MJ ME/24h	Feenstra (1973)
28	0	Fasting metabolism	Webster (1974)

It is interesting to compare with these results those of McEwan et al (1968) in which the oxygen consumption was measured between -1 and 30°C, shown in Figure 1.2 in a fed 6-7 day old calf.

Fig.12.

Oxygen Consumption vs Environmental Temperature in a fed 6-7 day old calf.



From these results it would appear that 26°C is the thermoneutral temperature and that below this temperature oxygen consumption increased in response to a drop in temperature. If it is assumed that oxygen consumption increases in response to an increase in metabolic rate, then in this instance the critical temperature is that temperature below which oxygen consumption increases i.e. between 20 and 26°C which is considerably higher than the documented critical temperatures.

The literature pertaining to the critical temperature of the calf is inconclusive. The critical temperatures stated by Mitchell (1972) should be viewed with caution as either the animals had a considerably denser coat and hence greater coat insulation than has previously been found or a considerable amount of heat was being lost from the erect hair coat. The effect of level of feeding in lowering the critical temperature has been demonstrated. It is very difficult to contrast the conclusions drawn from the results of McEwan et al (1968) in which the critical temperature of the 6-7 day old calf was concluded to be between 20 and 26°C, with the value of approximately 12°C obtained from the remainder of the literature. The reduction of critical temperature as the age of the calf increases is evident and it would appear that the critical temperature of the month old calf is in the region of 0°C.

In view of the variation in literature values it is suggested that for practical purposes it should be considered that up to three days of age the critical temperature of the fed calf lies between 9 and 13°C. By approximately one month of age the critical temperature lies between five and zero °C. In view of the fact that the still air conditions under which critical temperature is measured are unlikely to be met in practise, the upper limits of the ranges

given are suggested as being the temperatures below which the housed calf would need to expend energy in order to maintain body temperature.

The Effect of Wind

In the initial discussion on critical temperature it was mentioned that this parameter is modified by various conditions of the animal. It is also very unlikely that draught free, dry, well ventilated conditions are ever experienced in practice. The effect of wind is to increase the heat production of the animal relative to that produced in a thermoneutral environment (Blaxter, Joyce, Wainman, 1963; Holmes, McLean, 1974). At 0°C a wind of 0.6 km/hr increased heat production over that at the thermoneutral metabolic rate by 3.6%. At 0°C a wind speed of 2.6 km/h caused an increase in heat production of 8.2% over that at 20°C and an increase of 5.6% over heat production measured at 0°C and 0.6 km/h, Blaxter et al (1963), Holmes et al (1974) expressed heat production of 7 to 30 day old Friesian and Jersey calves relative to that measured at 20°C and 0.8 km/h. At 3°C, and wind speeds of 0.8 and 5.6 km/h, heat production of Friesian calves increased by 13 and 29% respectively, whilst heat production under similar conditions for Jersey calves increased by 20 and 39% respectively. However, Blaxter et al (1963) could not find any increase in heat production of steers in an environment of 20°C as a result of a wind speed of 2.6 km/h.

The difference in response to cold and wind between the results of Blaxter et al (1963) and Holmes et al (1974) are likely due to the age differences of the animals used, the steers used by Blaxter being over 12 months of age and thus having a lower critical temperature.

The work of Holmes et al (1974) also emphasises that breed differences are likely to occur in tolerance to cold. In this

instance the differences were attributed to the greater weight of hair coat per unit area of skin, and larger body size of the Friesian calf which had approximately 14% greater maximum whole body insulation than the Jersey calf.

Critical temperatures calculated by Holmes et al (1974) were 11°C and 9°C for the Jersey and Friesians respectively at 0.8 km/hr wind speed; increasing the wind speed to 5.6 km/hr increased these by 3 to 4°C. As the ages of the calves were not specifically stated, no comparison can be made between these figures and the values of critical temperature previously quoted.

Blaxter et al (1963) showed that the gain of insulation due to an increase in coat length fell as wind velocity increased. This means that some destruction of the insulation of the hair coat of cattle occurs in mild winds. If this is coupled with the effect noted by Webster (1974) of a decrease in density of the coat during piloerection and a subsequently less than theoretical increase in insulative capacity of the coat from piloerection, there is probably a considerable decrease in the insulative capacity of the coat under cold and windy conditions.

It was stated in the discussion on critical temperature that caution should be exercised in interpreting the results. It has been shown that increases in wind speed per se have resulted in increases ranging from 3-13% in metabolic rate in temperature stressed calves. Increasing wind speed has been shown to raise the critical temperature of calves. This effect is probably due to a destruction of the insulative capacity of the hair coat, resulting in a greater heat loss from the surface of the body.

Acclimation and Habituation

Webster (1974b) has defined acclimation as the changes induced by a single environmental factor and habituation, as a gradual quantitative change in response resulting from repeated stimulation. Slee (1972) has reported that shorn sheep can be acclimatized to cold experimentally by acute or chronic cold or more effectively by both types of exposure in sequence.

During acute exposure, comprising an initial phase of moderate cooling from 30 to 0°C then an acute phase involving wind and a further fall in ambient temperature from 0 to -20°C, Slee found that rectal temperatures of sheep fell to about 8°C and subsequently rose during the early part of the acute phase before irreversibly falling again. This temporary rise in rectal temperature accompanying acute cold exposure is a typical response of sheep and is probably associated with the approach to peak metabolism. Below 0°C metabolic rate rises producing a rise in rectal temperature, showing that the initial body cooling is facultative, this is then followed by an involuntary drop in rectal temperature as hypothermia sets in. Chronic cold conditioning (continuous 8°C temp.) apparently increased resting metabolic rate and increased the subsequent metabolic response to cooling especially in females. Cold shock-treated sheep exhibited facultative cooling, one sheep allowing rectal temperature to fall 4°C below normal when room temperature reached 8°C. Facultative cooling was associated with low shivering intensity and low heart rates in the cold. Insofar as the cold shocks treatment caused a progressive reduction in the physiological (metabolic) response to a repeated stimulus (daily cold shocks) it seems similar to the phenomenon of habituation (Slee 1972).

Slee (1974) found that sheep acclimatized to cold showed an increased ability to resist body cooling. The increased ability

resulted in changes in the critical temperature and the onset of cold induced vasoconstriction together with increases in heart rate and skin temperature, resulting presumably from an increased metabolic rate. The increased resistance to cooling induced by chronic cold began to decay after two weeks at thermoneutrality. The increased resistance to cooling induced by one acute exposure was maximal two weeks after exposure and had disappeared by eight weeks. Increased resistance to cooling induced by two acute exposures combined with chronic cold showed little difference even after eight weeks at thermoneutrality. Two components of cold acclimatization were distinguished:-

(1) Increased resistance to body cooling probably caused by an enhanced peak metabolic rate capability.

(2) Increased resting metabolic rate evidenced by high heart rates.

After the cessation of cold treatment the rates of decay of these two components were different.

Acclimation may be induced in unshorn sheep by natural exposure to winter temperatures (Webster, Hicks and Hays 1969). A breed difference has also been shown in the ability of sheep to acclimate when it was shown that Merino sheep showed a 50% lower initial cold resistance and a lower increase in resistance to cooling following acclimatization than did equivalent Blackface sheep (Slee 1974).

A general conclusion can be drawn that the kind of physiological adaptation produced by cold exposure varies according to the mode of administration and the dosage of cold. Acute exposure increases cold resistance probably by an enhanced peak metabolic rate capability. Chronic exposure likewise increases cold resistance, probably by a similar means as acute exposure by an enhanced peak

metabolic rate however the resting metabolic rate also increases. It should be noted that whilst acclimation is beneficial to the animal in increasing its resistance to cooling the process overall requires more energy and hence less energy is available for production.

Repeated short cold shocks do not increase cold resistance but tend to induce habituation, involving facultative body cooling and a decreased metabolic response to cold. Habituation is erased by severe, acute cold exposures which produces antagonistic effects involving an increased metabolic response to cold and decreased rates of body cooling (Slee 1972). Habituation is a less energy demanding process than acclimatization as rather than maintaining body temperature facultative body cooling occurs. For this reason it is more economical in energy terms than acclimatization.

Initial (pre-acclimatization) levels of cold resistance were affected by variations in body weight caused mainly by differences in previous nutritional status. After acclimatization levels of cold resistance were less closely associated with body weight (Slee 1974).

Calves may be acclimatized to heat by a relatively small number of intermittent exposures to a hot humid atmosphere. The acclimatization is evident from a progressive decline in rectal temperature, skin temperature and heart rate with repeated exposures to heat. As a consequence of these changes there was a pronounced increase in the time for which the animals could tolerate the standard hot environment. Evidence also exists for a reduction in metabolic rate during acclimatization (W. Bianca 1959).

Webster, Gordon, and Smith (1976) on several occasions, have shown that neither growth rate nor metabolic heat production of calves was affected by air temperatures within the range 5 to 20°C,

these temperatures thus being thermoneutral for calves of 80 kg. live weight or more. However, it was shown that in veal calves of 100 kg live weight kept at 5°C evaporative heat loss declines from 26.4 watts/m^2 body surface area at 100 kg to 16.6 watts/m^2 at 200 kg, the calves thus appearing to have habituated in such a way as to reduce progressively the work of thermoregulation by active water loss.

Four year old pregnant beef cows, fed close to maintenance, previously acclimated for half a winter at temperatures as low as -25°C had resting metabolic rates when exposed to temperatures of -30, 0 and 30°C, which were 37% higher than cows previously acclimated at 18°C. Resting metabolic rate was only 18% higher in cows acclimatised outside after one quarter of the winter when compared with housed cows. Furthermore, the minimum resting metabolic rate values were estimated to have occurred at lower temperatures after the cows had more exposure to the winter conditions. Winter acclimatisation and downward shift in the thermoneutral zone was also evident in the outside cows from the increases in respiratory frequency and on occasions up to a 1°C rise in rectal temperature when they were exposed to the 30°C test temperature (Young 1975). This shift in the thermoneutral zone as well as a shift in the level of resting metabolism may be considered as a mechanism providing the animal with some protection against the stresses of winter.

In the above experiment woodshaving bedding provided to the outside housed cows had no effect on resting metabolic rate. Also, the resting metabolic rate of the cows was unaffected by their body condition. This latter point would suggest that changes in metabolic rate occur as a result of the conscious perception of temperature at the skin surface which is influenced by the temperature to which the animal has been acclimatised and is not affected by tissue insulation.

It is obvious from the foregoing discussion that the effects of acclimation and habituation are time dependent and are also dependent on the degree of stress imposed. The significance of the effects in the neonatal calf is therefore questionable. However, it is pertinent to consider that the effects of acclimation and habituation may increase with the age of the calf. Although acclimation has not been demonstrated in the calf as a result of low temperature stress it is considered that the effect shown by Webster et al (1976) equivalent to habituation demonstrates an ability of the calf to modify its physiological response as a result of a continued environmental stress. It is therefore pertinent to consider that a response equivalent to acclimation may develop in the calf. If this is the case then it can be seen that the treatment of any calf prior to experiments carried out in order to determine the critical temperature of the animal may seriously affect the results of the experiment. This effect would be more pronounced as the age of the calf increases and the ability to acclimate develops. Considerations of this sort shed further doubt on the significance of critical temperatures.

CALF HOUSE ENVIRONMENT

The environment within the calf house is composed of conditions which influence the health, growth, development and general well being of the calf. The climatic environment is influenced by the conditions of temperature, humidity, air movement and radiation.

Calf House Temperature

The requirement of the calf for supplementary heat is poorly understood and there is a wide variation in the literature, in the recommended temperatures for calf houses. Bourne (1974) observed that young calves gain a beneficial effect from straw when housed

at 8°C and that a temperature of 13°C is necessary for the first three weeks of life. A temperature of 13 to 15°C is suggested for calves of up to three weeks of age, particularly when bucket fed (Mound, 1971). However, over three weeks of age the same calves thrived at 8°C. A recommendation that temperature should be maintained at between 13 and 16°C for the first month of life and thereafter gradually reduced to a minimum level of 7°C at twelve weeks of age, has also been made (Agriculture, 1971). Temperatures considered ideal for calf fattening were 18°C at the beginning and 12°C at the end of the fattening period (Martig, Boss, Nicolet and Steck, 1976). Although these latter figures most probably refer to veal calves the figure of 18°C is directly relevent to the present discussion. Appleman and Owen (1975) however, concluded that an air temperature between freezing and 21°C was satisfactory for raising young calves.

Those calf house temperatures which are above ambient in temperate regions and which require supplementary heating in order to maintain them, are difficult to justify in view of the increasing amount of evidence showing the successful rearing of calves in climatic buildings.

Little difference was found in the performance of calves housed in a controlled environment building, initially held at 13°C and from the first week onwards at 7°C, compared with calves housed in a non-controlled house or in straw bale pens under a Dutch barn (Turner, 1974). However, when very cold weather alternated with spells of high humidity the controlled house calves showed the best performance.

Fallon (personal communication) found no difference in performance between calves ranging from 7 to 56 days of age, penned either

individually or in groups housed indoors, in a Patterson type house or in straw bale shelters. In a subsequent trial, a higher incidence of chills and poorer performance was noted in calves individually housed outdoors in spartan pens with polythene roofing. The weather during the second to the fourth week of this trial was frost at night and sun during the day which resulted in wide fluctuations in the temperature of the outdoor pens. In this instance it was considered that temperature fluctuations were more detrimental than low temperature alone. Housing three day old calves in an open shed had no adverse effect, even when temperatures reached a low of -10.5°C (Murley and Culvahouse 1958). More recent work in which an outdoor group showed better performance to weaning than a control group kept indoors, supports the findings that low temperature per se is not detrimental to calf performance (Jorgenson, Jorgenson, Schingoethe and Owens 1969). Disease losses have been found to be higher in calves reared between 10 and 15°C compared with those reared between -4 and 4°C (Solovev 1955).

Support for the effect of temperature fluctuation is gained from the fact that performance of calves housed in straw igloos was marginally poorer than that of calves housed in a converted cow shed. Although the average temperature in the igloos was slightly higher than in the conventional calf house the variation in temperature was greater in the igloos than in the house (Bridget Drew 1975). At six months there was no difference in performance between the two groups of calves. However, in a study in which the diurnal variation in temperature was recorded in a climatic calf house and compared with that in a controlled environment calf house the performance of the calves was unaffected by the house conditions (Mitchell 1972b). The mean house temperatures, together with their standard deviations,

were as follows:-

Controlled Environment calf house	11.2°C	S.D. ± 2.04
Climatic calf house	7.0°C	S.D. ± 3.83
Outside	5.3°C	S.D. ± 4.03

It can be seen that in this instance the climatic housing raised the mean temperature to which the calves were exposed compared with the outside conditions but did not significantly alter the range of temperature about the mean. The controlled environment house increased the mean temperature and reduced the fluctuations about the mean.

The evidence in the literature on the effect of calf house temperature is conflicting in that in some cases temperatures above 7°C are recommended for rearing calves whilst other workers have successfully reared young calves with temperatures dropping below freezing point. Those workers carrying out experiments in the British Isles have noted a depression in the performance of calves reared out of doors and although varying temperature conditions have been commented upon at the time of depression in performance, they have not been directly correlated with performance. Under British winter conditions, when large diurnal fluctuations in temperature occur, a drop in temperature may cause severe condensation in a poorly ventilated building. Such damp conditions may be a factor which is deleterious to calf performance.

Feed conversion efficiency was found to be poorest in calves in a roofed, two sided shelter, compared to calves housed at night in an open yard, but was best for calves in an enclosed house. The poor performance in the two sided shelter is in accord with the conditions under which condensation is most likely to occur (Adam, 1965).

Relative Humidity

Although there is a large variation in the standards recommended for relative humidity an underlying theme exists in the recommendations. Appleman and Owen (1975) stated that a relative humidity of 85% should be avoided due to the fact that condensation and damp bedding have a deleterious effect on calf health. Mound (1971) considered relative humidity of between 70 and 80% quite satisfactory, whilst Martig et al (1976) considered values of between 60 and 80% to be ideal when coupled with a temperature latterly of 12°C. It has been suggested that when relative humidity falls below 65%, the atmosphere becomes dry and dusty; this figure, however, was not related to a specific temperature. Relative humidity of 90/100% although normally considered detrimental to health was shown to directly cause discomfort only when combined with temperatures of 25-30°C (Bianca and Blaxter 1961). Roy, Stobo, Ganton, Canderton and Shotton (1971) found that when calves were raised in a 15°C environment, incidences of lung lesions increased with increasing relative humidities. In a 23°C environment lung lesions occurred less frequently with increasing relative humidities. From this relationship it was possible to postulate a temperature at which extremes of relative humidity would have a minimal effect in predisposing calves to lung lesions. This temperature would appear to be a little over 17°C. Roy et al (1971) emphasised that care should be taken in interpreting this result due to the small number of animals used in the experiment. This work also tended to show a greater adaptability to extremes of temperature and relative humidity in the Ayrshire breed when compared with the Friesian and Jersey breeds.

It may be noted that average values for relative humidity of 80-85% in January and 60-75% in July are quoted for the British Isles over the period 1921-35 (Scottish Farm Buildings Investigation Unit, Ventilation of Livestock Buildings 6-8 April 1971). It is not surprising, therefore, that under normal livestock production conditions the absolute levels of external temperature and relative humidity normally experienced are not detrimental to the breeds that are indigenous to the British Isles. It is only when extremes of management conditions or production are required that the stresses of the system so effect the animal that it is unable to withstand normal climatic conditions.

However, if relative humidity is allowed to rise under conditions of high temperature, then it is obvious that the atmosphere becomes capable of supporting a higher concentration of pathogens. Coupled with a low ventilation rate this immediately exposes calves to an increasing pathogen load in the atmosphere. A high humidity at a low temperature is less beneficial to the multiplication of pathogens. Thus humidity is more likely to indirectly affect calf performance than directly per se.

Ventilation Rate

In view of the previous conclusion it would appear that the young calf should be able to withstand wind conditions normally experienced in the British Isles. West coast average wind speeds are quoted as 6.7 to 7.8 m/sec. with the tendency for a decrease going from west to east. Under natural range conditions the young calf is able to seek shelter from the wind by remaining close to its dam. This is not the case for young calves removed from their dams and housed in calf pens. Ventilation rates and hence rates of air movement in controlled

environment houses are automatically controlled in order to take account of the temperature and relative humidity in the building and the need to remove toxic gases. The ventilation rate may also effect the build-up or otherwise of pathogenic organisms in the air as a result of a contaminated animal or bedding in the house.

It is generally accepted that intensively housed livestock are less tolerant to a slight draught than their counterparts on open range to much stronger natural wind movement. (S.F.B.I.U. 1971). Calves are particularly susceptible to draughts (Sainsbury, 1967) hence the ventilation system should be such as to prevent any draughts.

Smith (1973) concluded that the airflow rate in barns for 45 to 136 kg calves should be 0.40 m^3/min per calf in winter conditions ($< -7^oC$), 0.91m^3/min in mild climates (-7 to 10^oC) and 3.40m^3/min in warm weather ($> 10^oC$). These ventilation rates are for calves raised in enclosed insulated structures. Mitchell (1976) suggested that when mechanical (fan) ventilation systems were used they should be designed to provide a minimum winter ventilation rate of 0.56m^3/min and in summer at least 1.75m^3/min. Mound (1971) found that between 15.5 and 18.5^oC ventilation rates below 1.6m^3/min did not affect calf performance whereas above this figure performance was slightly reduced. At 7^oC ventilation rate similar to 1.6m^3/min did not significantly affect performance but there was an indication that lower ventilation rates were more beneficial during the first three weeks.

A ventilation rate of 0.56m^3/min was found unsatisfactory for 4 to 5 week old calves housed at a temperature of 15.6^o. Ventilation rates of up to 3m^3/min per calf at temperatures between 7.2 and 15.6^oC were tested but on no instance was performance significantly better

than that of calves housed in a naturally ventilated compartment which provided conditions of high ventilation rate and temperatures occasionally below 0°C. (Turner 1974).

Whilst ventilation rates in the literature show a wide range in the rates acceptable to calves these can only be accepted in conjunction with the rates of air movement at calf level. Martig et al (1976) stated that air draught around the animals should not exceed 0.2m/sec. except during the hot season, when 0.3m/sec. may be acceptable. Mitchell (1972) considered an air current at calf level of above 0.25 m/sec. to be detrimental when the air temperature is below 10°C.

It has already been stated that the relationship between the insulation of the calf's coat and the depth of the coat is curvilinear (Webster 1974). The effect of air movement is to further reduce the insulative capacity of the coat by breaking down the external air layer. High relative humidity decreases the ability of the coat to lose moisture by evaporation thus there is an increase in the moisture content of the coat which may cause a further reduction in its insulative capacity. Thus it can be seen that air movement and relative humidity may act in unison to reduce the capacity of the calf's coat to prevent heat loss and thus raise the critical temperature of the animal.

Air Capacity

Increased air capacity has the advantage that it allows air to be introduced well above the level of the calf, thus preventing draughts at calf height; it acts as a buffer against inadequate ventilation and for a given ventilation requirement the air speed through the house will be lower, thus reducing the possibility of draughts. Bourne (1974) recommended a minimum cubic air capacity

of $7m^3$/calf as a safe minimum: Mitchell (1972a) in a review of the literature found the minimum suggested requirement to be $4.25m^3$/calf and the maximum $7.36m^3$/calf. The calf house used by Roy et al (1971) had a cubic capacity of $20m^3$/calf, whilst that of Turner (1974) was of $7.3m^3$/calf.

It is obvious therefore that an advantage of increased comfort for the calf is to be gained by erring on the side of increased cubic capacity per calf. In view of the comments on cubic capacity and its effect on draughts and ventilation rate it can be seen that the air volume requirement per calf is intimately related to the design of the building. Pointer (1969) emphasised this by differentiating between the cubic capacity required for fan and naturally ventilated buildings, suggesting 5.66 m^3/calf and 7.08 m^3/ calf respectively for the two types of ventilation.

Fan size

The young calf spends a much higher percentage of its time lying than does the adult animal (Mitchell 1976). The space requirements of the calf depend on the system being used. Roy (1970) discriminated between the space requirements of individual and group penned calves suggesting a minimum of 1.7 and 2.0 m^2 per calf for individual and group penned animals respectively. A minimum of 1.6 m^2 for 80 kg calves was recommended by the Rumbell Committee (1965). Bourne (1974) suggested an area of 1.1 to 1.2 m^2 for calves up to six weeks of age. Appleman and Owen (1975) reported that previous work had shown a stress effect when calves were housed in 1.86 m^2 metal pens, compared with 2.42 m^2 wooden pens, resulting in a higher scour index, lower consumption of starter feed and slower growth rate.

Roy (1970) considered the absolute minimum floor area for a new born calf to be $1.1m^2$ whilst Bourne (1974) suggested 1.1 to 1.2 m^2

for calves up to six weeks of age. Calves differ in weight according to breed and according to the rate at which they grow. It is difficult, therefore, to recommend a minimum space requirement for a calf. However, considerations such as the ability of the calf to groom itself, to lie and to turn around, should be made in conjunction with the breed type and the length of time for which the particular penning will be used, in planning calf accommodation.

General Conclusion

The evidence on the effect of temperature in calf houses would suggest that supplementary heating may be beneficial to young calves of under three weeks of age, especially in very cold weather. The evidence on the effect of temperature per se on calves older than three weeks of age suggests that the temperatures generally encountered in temperate climate regions are not such as to affect calf performance. There is, however, a consensus of opinion which suggests that there may be a depression in the performance of calves climatically housed in the British Isles. This may be a result of fluctuating temperatures in the calf house which follow the fluctuations of the ambient temperature. Further research is necessary to examine whether fluctuating temperatures are detrimental to calf health and to what extent protection should be afforded the calf by the house construction. With respect to relative humidity, the range of 70 to 80% is suggested as the most appropriate. The importance of relative humidity would appear to be greater as a result of the correlation between relative humidity and the pathogen supporting capacity of the air. The evidence against draughts at calf level is unanimous. In order to overcome draughts at calf level but to ensure efficient air change a high cubic air capacity per calf is recommended.

NUTRITION INCLUDING ENVIRONMENT AND NUTRITION INTERACTIONS

The Effect of Environment on Appetite

The effect of cold on feed intake is well documented. Webster, Chlwaoky and Young (1970) in a group of experiments on 12 heifer calves of average weight 150 kg at the start of the experiment obtained increases in total hay consumption, over a nine month winter period, of 26 and 21% by sheltered and exposed calves respectively compared with control calves kept in a pen at 20°C. Calves in both the sheltered and exposed groups suffered a minimum air temperature of -43°C, and the mean air temperature in January was -28°C. The feed intake of lambs was increased by 21% when housed at 5°C compared with controls housed at 29°C. (Moose, Ross, and Ffandor 1969). The concentrate level of the diet also affected food intake in the latter experiment. Lambs fed a high concentrate ration increased feed intake by 2% and 16% in cold environments of 17° and 5°C compared with controls at 29°C whilst the same environmental difference increased the food intake on a low concentrate diet by 15 and 32% respectively. The heat increment of the low concentrate diet was greater than that for the high concentrate diet. In this situation the higher heat increment of the low concentrate compared with the high concentrate diet may contribute more to the maintenance requirement of the animal. It was suggested that the maintenance requirement would then be reduced and hence a greater proportion of the total energy of the diet would be available for production on the low concentrate diet. Thus live weight gains at low temperatures were higher for lambs fed low concentrate high roughage rations compared with lambs fed a high concentrate ration (Moose et al 1969).

An initial decrease was found in the dry matter intake of sheep moved from 20°C to -10°C; however, after a period of eight to nine weeks intake had recovered and was close to that obtained during exposure to 20°C (Christopherson 1976). The sheep used in this experiment were adult animals and the level of stress imposed by the change of environment may not have been as severe as that used on the lambs by Moose et al (1969). Calves on ad libitum feeding had 15% greater feed intake when exposed to an outdoor winter climate where average temperatures remained below 0°C compared with calves housed in a controlled environment at 18.5°C (Christopherson and Milligan 1973).

Amos and Brink (1977) found that temperatures of -5.0 and 5°C depressed the average daily live weight gain of four-months-old wether lambs. Cold thermal stress reduced feed efficiency apparently because the net energy for gain was a smaller portion of the total net energy. This was because feed intake decreased and not energy for maintenance increased.

The available energy was additionally restricted by a lowering of the digestibility of the feed during cold exposure. Temperature lowered digestibility by 0.14% per degree centigrade fall in temperature. Low ambient temperature was also found to depress nitrogen retention.

Appleman and Owen (1970) found that young calves born in early December gained from 1.4 to 8.6 kg between birth and weaning but calves born during the remainder of December only maintained weight. December minimum temperatures averaged -10°C. Both groups of calves experienced a considerable chilling effect from the wind, especially during early January. Calf starter intake was very poor for all

calves and whereas similar calves would have been consuming approximately 0.5 kg of starter per day food intake in the temperature stressed calves was 0.5 kg of starter per week. Weaning at 21 days also caused a drastic deterioration in health. The calves were obviously unable to compensate for the increased energy requirement by an increase in food intake and showed a deterioration in health and a decrease in food intake.

The method of feeding has also been shown to affect feed intake. Wethers allowed access to pelleted feed for only 1h/day, showed a 7-10% reduction in feed intake during the first week of exposure to -5°C, but intake recovered during continued exposure. Four rams, with continuous access to pelleted feed, increased their intake gradually. A new level 10% above the pre-exposure level was reached (Anderson and Barlott, 1973). After 8-10 weeks of cold exposure food intake returned towards pre-exposure levels.

The Effect of Environment on Feed Digestibility

Bailey (1964) did not find any change in average coefficients of apparent digestion of dry matter and protein of hay when three year old Cheviot cross wethers were exposed to 20°C and -11°C at weekly intervals. However, average coefficients of apparent digestion of dry matter and fibre were significantly greater during the subsequent period at 20°C. The conclusion was drawn that the digestibility of the hay was affected by changes of temperature. Graham (1964) showed that the apparent digestibility of food offered at low rates of feeding to shorn sheep housed at 10°C was lower than when the sheep were housed at 35°C. The digestibility decreased by 0.47 units/°C. Although 10°C would not normally be below the critical temperature of the sheep, the conditions employed in this

experiment were sufficient to cause a temperature stress in the sheep. Using complete feed mixtures Moose et al (1969) showed that the digestibility of high concentrate rations dropped when the temperature was lowered from 23° to 0°C but low concentrate rations had a greater coefficient of digestibility when fed at 0°C. The trial was not conclusive however as the position was reversed when the minimum temperature was +5°C.

Results obtained by Young et al (1974) showing the digestibility of various rations at different temperatures are given in Table 1.2. In none of the experiments was statistical significance obtained.

Table 1.2 The Effect of Exposure Temperature in Apparent Dry Matter Digestibility

Animal	Wt.range kg	Ration	Exposure temp.(°C)	Apparent DM dig.%	Change in % DM dig. per 1°C
Sheep	65-90	Alfalfa pellets	21	52.0	
			-6.5	44.5	-0.27
		Alfalfa-grass pellets	20	55.3	
			-8	48.4	-0.25
		Grain & Alfalfa pellets	20	69.0	
			-8	57.9	-0.40
Calves	150-350	Grain & chopped Alfalfa	18	70.4	
			-10	65.1	-0.19
		Grain & chopped Alfalfa	18	69.8	
			-9	60.7	-0.34
Cows	360-550	Alfalfa-grass long hay	21	61.3	
			-11	61.6	+0.01

Animals were exposed to the treatment environments for at least three weeks prior to taking measurements.

In a later series of experiments Christopherson (1976) showed a drop of 0.31% in dry matter digestibility per degree centigrade drop in environmental temperature for sheep, 0.21 units per degree for calves and 0.08 units per degree for steers. The calves ranged in weight from 200 to 300 kg and the steers averaged 475 kg live

weight; the calves and steers were fed at a rate of 0.1 kg/kg $W^{0.75}$. There was also a suggestion that the decrease in digestibility of the hay/grain ration fed to the sheep was greater than the decrease in digestibility of the all hay ration. Dry matter, nitrogen and gross energy digestibilities were all lower for the outdoor temperature stressed calves but with the steers only dry matter and acid detergent fibre had lower digestibilities. In the steers nitrogen digestibility was not lowered. The apparent digestibilities of dry matter and acid detergent fibre tended to be directly related to the mean outdoor temperature.

The reduction in apparent digestibility of the dry matter of hay in sheep acclimatized to 0.8°C for four weeks compared to sheep maintained at 17.7°C on the same diets and at equivalent intakes was found to be associated with a significant reduction in the mean retention time of the particulate marker ^{144}C in the gastrointestinal tract (Westra 1975).

Kennedy, Christopherson and Mulligan (1976) using sheep kept at -1° to 1°C compared with others kept at 18° to 21°C found a reduction in apparent dry matter digestibility from 0.482 to 0.450 and in apparent digestibility of the organic matter from 0.511 to 0.477 in the cold housed sheep. Neither apparent digestibility nor retention of nitrogen was affected. It was shown that the amount of organic matter apparently digested in the stomach was related to the retention time in the rumen. Retention time decreased during cold exposure. The quantity of food nitrogen escaping digestion in the stomach was greater in the sheep exposed to -1 to 1°C. The ability of the intestine to absorb nutrients was not altered by change in temperature and the changes in apparent

digestibility of the organic matter and the dry matter were attributed solely to a decreased retention time in the rumen as a result of temperature stress with a consequent reduction in fermentation rate.

Significant reductions in weight gains and efficiency of food conversion during winter months have been shown in feed lot production data from both Canada and the U.S.A., even although the effective ambient temperature was rarely if ever below the critical temperature of the animals (Young and Christopherson 1974).

Whilst the increase in food intake and reduction in food digestibility has so far been emphasised as a result of cold temperature stress the converse of reduction in food intake (Warren, Martz, Asay, Hilderbrand, Payne and Vogt 1974) and increase in digestibility (Olbrich, Martz, Johnson, Phillips, Lippincott and Hilderbrand 1972) has been noted in cattle high temperature stressed at 32°C. In the latter mean retention time was greater at 32°C than at 18°C and thus probably resulted in increased fermentation.

From the discussion it can be seen that low temperature stress may lower the digestibility of nutrients entering the ruminant stomach. It would appear that the lowered digestibility is the result of a lowered retention time of the organic matter in the rumen. The reason for the lower retention time is not stated although it could be either increased gastric motility or an increased flow of gastric secretions into the rumen, increasing the overall flow rate. No work has been carried out on the effects on milk digestibility in the young calf but in this respect a direct analogy cannot be drawn with the present results. The retention of milk in the stomach of the calf depends more on

the formation of a milk clot and the stability of the clot than on gastric motility per se. However, it may be postulated that the increased motility of the gut may not be confined to the rumen but may also occur in the large intestine. In the young calf this would be particularly significant as it would allow undigested nutrients to reach the lower gut causing bacterial proliferation and possibly scour.

Level of Milk Replacer Feeding

Young calves are more prone to nutritional scours when liquid fed compared with dry fed. If a once daily system of milk feeding is used this has the disadvantage of placing a very high feed load on the stomach of the young calf over a short period of time. If the amount of feed ingested is in excess of that which the calf can digest then undigested feed may reach the lower gut with the consequent proliferation of bacteria and resultant scour. As calves grow their ability to digest larger amounts of feed in one feed increases, thus any system of milk feeding should allow for the growth of the calf and hence be suitable for a range of live weight.

Leaver and Yarrow (1972a) fed three levels of milk replacer, 320, 480 and 640 g/day, at a concentration of one part by weight of powder to five parts of water warmed to 30°C, to calves ranging in initial live weight from 32.5 to 49.0 kg. The incidence of scouring on the 320, 480 and 640 g/day feeding was 9, 18 and 23% respectively showing a positive relationship between level of feeding and nutritional scour. Between five and 32 days of age there was a significantly greater live weight gain by the calves fed the higher levels of milk replacer. Post weaning, calves previously fed the high level of milk replacer continued to grow

faster, but the differences obtained were not significant.

Mitchell, and Broadbent (1973) using a system of twice daily bucket feeding of warm milk replacer to appetite, found that the maximum intake attainable was 5.7 litres at a concentration of 160g/litre. This represents a total intake of 456g of milk replacer per feed i.e. 912g/day. The average weight of the calves prior to weaning was 91 kg. Calves on an ad libitum consumption of cold milk substitute constantly on offer, reconstituted at the rate of 100g per litre, consumed a maximum of 850 or 910g of milk replacer per day depending on whether the calves were housed in climatic or controlled environment buildings. Concentrates were offered to all the calves on these experiments.

Pettyjohn, Everett and Machrie (1963) measured the voluntary intake of pre-ruminant calves fed milk replacer constantly on offer at concentrations of between 5 and 25% dry matter. Calves fed the 15% diet gained faster, increased more in height at withers and had equal or better nutrient utilization than calves fed other concentrations. Performance was optimum when the level of dry matter intake for liquid fed calves was in the range of 24-28g per kg body weight. For a 40 kg calf this represents between 960 and 1120g of milk replacer per day. In interpreting these results care should be taken to stipulate the system of feeding, whether it be once or twice daily or a continuous feeding system.

Lineweaver and Hafez (1969) measured the ad libitum intake of milk replacer fed at either 6.5% or 19.5% total solids to Holstein calves of 45 kg birth weight and Hereford calves of 26.5 kg birth weight. The milk replacer was fed either four times daily or constantly on offer. The ad libitum intake of the Holstein calves was lower when the milk replacer was offered on

four separate occasions as compared with constant offer (dry matter intake was 1.27 and 1.45 kg/day on the four times daily and constant offer feeding systems respectively). Dry matter intakes of the two breeds when fed ad libitum were 1.27 and 1.45 for the Holstein calves and 0.83 and 1.06 kg per day for the Hereford calves at each of the two reconstitution rates of 6.5 and 19.5% respectively. When fed ad libitum and four times daily the calves receiving milk replacer reconstituted at the rate of 6.5% total solids consumed significantly less DM per kg live weight than calves receiving milk replacer reconstituted at 19.5% total solids. Thus, liquid intake was probably limiting the dry matter intake of calves receiving the 6.3% reconstituted milk replacer. Calves fed the 6.5% total solids ration ad libitum consumed from 13 to 20 kg of fluid, whereas those on the 19.5% total solids ration consumed 5 to 7 kg of fluid per day. The difference in liquid intake between the two groups suggests that dry matter intake was limiting in the group receiving the 19.5% reconstituted milk replacer.

This would go some way to explaining the discrepancy between the maximum dry matter intake of 912g of milk replacer by 91 kg Friesian and Ayrshire calves in the experiment of Mitchell and Broadbent (1973) when the calves were offered reconstituted milk replacer to appetite twice daily. The figure of 912g DM intake achieved on twice daily feeding is considerably less than the DM consumption of 1.27 kg/day achieved on a four times daily feeding system by the Holstein calves of Lineweaver and Hafez (1969) which were slightly greater than half the weight of the Friesian calves. It must also be borne in mind that the calves of Mitchell and Broadbent (1973) were receiving a concentrate allowance.

Roy and Stobo (1974) concluded that the maximum intake of the preruminant calf was about 2, 3 and 4 kg DM/day at 100, 200 and 300 kg live weight respectively. They also concluded that in terms of metabolic size, maximum dry matter intake was likely to increase from approximately 60g/$kg^{0.75}$ at birth to a maximum of 62g/$kg^{0.75}$ at 125 kg live weight, declining thereafter to about 55g/$kg^{0.75}$ at 300 kg live weight. The figure of 2 kg dry matter at 100 kg live weight is considerably more than the dry matter intake of 0.91 kg at 91 kg live weight achieved by calves on ad libitum cold milk feeding in the experiments of Mitchell and Broadbent (1973) but is in agreement with that of 24-28g per kg body weight obtained by Pettyjohn et al (1963) for warmed milk replacer. It would thus appear that the maximum intakes are only attainable, when on liquid feeding, if the milk is warmed.

Pettyjohn et al (1963) referring to the difference in dry matter intake between calves fed the 5 and 10% concentrations compared with the 15, 20 and 25% diets considered physical capacity as being the over-riding factor. This is in direct contrast to the results of Lineweaver et al (1969) when calves being offered milk replacer at the low rate of reconstitution consumed about three times as much liquid as those on the high rate of reconstitution.

Two groups of four Holstein-Friesian calves given either a low energy (6.5% fat) or a high energy (16% fat) milk replacer fed to appetite twice daily up to 14 days of age did not differ in the total amount of milk replacer consumed. (Milligan and Grieve, 1970). Calves offered the low energy milk replacer had very poor rates of gain and were unable to obtain sufficient energy from the concentrate portion of the diet. This suggests that in this instance volume was limiting and calves receiving the low energy milk replacer were unable to

consume sufficient additional liquid to maintain energy intake.

Liquid Feed Digestion

It is generally accepted that most of the ingested milk enters the abomasum directly via the oesophageal groove. It is therefore pertinent to consider that the ability of the calf to digest milk replacer and hence the voluntary intake of the animal is governed by the capacity of the abomasum and its ability to digest the milk replacer. There exists however the possibility that milk may spill into the rumen by leakage from the oesophageal groove or spillage from the abomasum. The effect of this depends on whether the rumen can digest the milk, which relies on whether fermentation has begun, or whether the milk remains undigested and is allowed to putrify.

The feeding of milk replacer at levels above that which the calf can safely digest may lead to calf scour. Radcliff and White (1972) fed a commercial milk replacer at two levels to calves between 27 and 41 kg live weight. The level was also adjusted according to the live weight of the calf. Calves on the low level of feeding received 1.4, 1.7 and 2.7, l of a 10% suspension at live weights of less than 27 kg, between 27 and 34 kg and between 34 and 41 kg respectively. Calves on the high level of feeding received 70% more of the 10% suspension at each of the live weights. A combination of fixed housing and the high rate of feeding significantly increased the number of animal scouring days. However, in moveable sheds the number of scouring days was similar for each level of feeding. One is, therefore, led to conclude that under favourable management conditions the high level of feeding was not in excess of the maximum digestive capability of the calf. In this piece of work the maximum volume fed was 4.59, l representing 459 g of milk replacer per feed. The daily maximum intake of calves between 34 and 41 kg live weight was 918 g. This is in good agreement with the

maximum intake obtained by Mitchell and Broadbent (1973), but their results pointed to a value of 918g/day being in excess of the digestive capability of a calf housed under adverse environmental conditions.

In order to consider the digestive capacity of the calf several factors must be assessed in conjunction. There is a physical maximum capacity of the abomasum. If this is exceeded milk may pass into the rumen and putrefaction may occur. Secondly, there is the possibility that although the physical capacity of the abomasum may not be exceeded, the capacity of the digestive secretions may be overcome. Undigested food may then pass through to the lower gut again resulting in nutritional disorders.

Digestive Secretions

Roy and Stobo (1974) found that increasing the intake of food resulted in increased abomasal output, partly due to an increased volume of secretion. Also, that although vagal stimulation in anticipation of food was important, a more important factor is the flow of ingesta into the abomasum. Roy and Stobo (1974) also concluded that acid secretion was not affected by the dilution of the diet.

The addition of an inert bulk, in the form of oat hulls, to commercial milk replacer was found to significantly lower the abomasal pH from 5.8 in milk replacer only fed calves to 4.9 in calves fed milk replacer with added bulk (Garrill and Nicholson, 1969). It was found however that the size of the abomasum was not significantly larger in the calves fed the increased bulk although the dry matter concentration was higher in the bulk fed calves. Roy and Stobo (1974) found increased acid concentration in calves fed the higher dry matter concentration although this was attributed to a volume effect of the liquid fed. The results of Garrill and Nicholson (1969) can only be interpreted as indicating an increased acid flow and a lack of neutralising effect

by the oat hulls.

A high pH of 5.1 for the pyloric outflow has been associated with diarrhoea in the young calf (Roy, 1969). The dominance of saccharolytic flora and the production of fermentative diarrhoea were associated with abnormal amounts of peptides and proteins in the chyme.

Most calves show a transition from a secretion containing predominantly rennin during the first two weeks of life to one containing predominantly pepsin at eight weeks of age (Porter, 1969). Roy and Stobo (1974) considered the optimum pH for coagulation was for rennin 3.5 - 6.5 and pepsin 5.25, whereas for proteolysis the optimum pH for rennin and for pepsin was 2.1. It can thus be seen that for optimum milk digestion, the milk should reach a medium of initially high pH and that with increasing acid secretion the pH drops and proteolysis may occur.

High pH values have been found to be beneficial to escherischia coli bacteria and a decline in the number of these organisms has been associated with a fall in pH (Roy 1969). Before feeding, the abomasal contents consist of a fairly clear, slightly viscous fluid containing small milk clots and having a pH value of 1-2 (Porter 1969). It can thus be seen that for efficient digestion, the volume of the milk should neutralise the contents of the abomasum so that the pH rises and clotting occurs. The subsequent fall in pH should then allow proteolysis to occur to such an extent as to produce readily absorbable peptide fragments. The pH of the digesta of young calves was found to rise from a basal level of about 2 to about 6 immediately after a feed and returned to the basal level within 8 hr. when feeding was twice daily and within 13 hr with once daily feeding. (Jane Leibholz 1975). It was also found that in calves fed on milk substitute the pH of the digesta was higher after feeding than in

those fed on whole milk. For milk replacer fed calves the pH was higher for the first 12 and 6 hrs. after feeding in the calves fed once and twice daily respectively. Subsequently, the pH was lower than for calves fed on whole milk. In order to prevent the proliferation of putrefactive diarrhoea producing organism digestion should be complete so that the pH of the abomasum should again fall. This emphasises the importance of not exceeding the digestive capacity of the abomasum when undigested milk may cause the pH to remain high and also the importance of any factor which aids digestion and the subsequent decline in abomasal pH.

A strong case can be made for relating level of feeding, even in the young calf, to body weight for it has been found that although total volume of pancreatic secretion increases with age, it remained approximately constant in relation to body weight at 0.7 - 0.8 ml/kg live weight/h (Roy and Stobo 1974).

Frequency of Feeding

In all calves the flow of digesta into the duodenum decreases as the time after feeding increases. The flow of dry matter during the last 8 hrs. of collection via re-entrant cannulae, from calves fed once daily was lower than at any stage after feeding twice daily. A more uniform flow of nutrients to the duodenum was therefore found in calves fed twice daily compared with calves fed once daily (Jane Leibholz 1975). It was also found that the flow of digesta in calves fed twice daily was greater than for calves fed once daily, which suggested that feeding per se stimulated secretion of saliva or gastric juices or both. This is contrary to the findings of Roy and Stobo (1974) who concluded that the rate of flow of the fluids seemed to be affected mainly by the level of intake.

Roy and Tenmouth (1972) found that the complete passage of the whey fraction from the abomasum of milk replacer fed calves required about 9 to 9.5 h at an intake of 3.8 l milk of 9-12% dry matter. However, 85% of the liquid phase passed from the abomasum within 6 h of feeding. Leibholz (1975) found that the highest flow of casein nitrogen from the abomasum occurred within 30 min. of feeding and was greater in calves fed once than in those fed twice daily. This latter effect was likely due to the greater surface area exposed to pH2 when two abomasal clots are formed daily.

Roy and Stobo (1974) found that the volume of pancreatic secretion, trypsin and protease activity, when measured over a 24 h period were all less on once daily feeding compared to twice daily feeding the same quantity of milk. This is in agreement with Leibholtz (1975) that feeding per se stimulates secretion of digestive enzymes.

Holstein calves fed milk replacer at various levels consumed more and had better live weight gains when fed ad libitum compared with feeding to appetite at six hourly intervals. Feed conversion efficiency did not differ on the two feeding systems (Lineweaver and Hafez 1969). Appleman and Owen (1970), recognised that to promote high levels of consumption of milk, more frequent feeding is necessary. This is however at variance with the requirement for a reduction in labour.

Mitchell and Broadbent (1973) found that the intake of reconstituted cold milk replacer offered ad libitum was greater than that offered warm twice daily when both were reconstituted at the same rate. An intake of 1.59 kg/calf of air dry milk replacer plus concentrates was achieved earlier on the ad libitum milk replacer diet compared with the twice daily feeding system although concentrate intake was greater

on the latter system. It is considered that this is not an effect of increased appetite for the milk replacer on the ad libitum system but rather a decreased appetite for concentrate dry matter as a result of an initial lower palatability of concentrates compared with the milk replacer. In the same work it was found that once daily feeding of warm milk replacer reconstituted at 160 g/l compared with twice daily feeding of a similar concentration did not significantly affect live weight gain although gain was greater on the twice daily feeding system. Concentrate intake was not affected by once daily compared with twice daily milk replacer feeding and on the two systems calves weaned according to level of dry matter intake were weaned within the same period. This agrees with the work of Hardy (1972) who found that once versus twice daily feeding of 340 g of high fat milk replacer did not affect daily live weight gain or appetite for concentrates.

Calves on an ad libitum milk feeding system took longer to reach a required dry matter intake of concentrates under a controlled housing situation compared with calves on once or twice daily milk feeding. In this particular experiment an interaction was found between controlled environment housing and ad libitum versus bucket milk feeding. Thus under controlled environment conditions concentrate intake was not as great as that under climatic conditions and it was further depressed by an ad libitum milk feeding system (Mitchell and Broadbent 1973).

A further comparison of once daily compared with twice daily feeding of milk replacer showed that when the same quantity of milk replacer was fed to beef calves, in either one or two feeds per day, performance was not affected. (Randall and Swannack 1975). Calves did however tend to start eating concentrates earlier on once daily

milk feeding. Feeding a lower level of milk replacer (0.34 kg per day compared with 0.45 kg per day) significantly reduced live-weight gain and reduced appetite for concentrates. Thus calves weaned when they were consuming 0.9 kg of concentrates per head on two consecutive days took longer to weaning on the low level of milk replacer feeding compared with calves receiving 0.45 kg of milk replacer per day. In a second comparison using lighter Friesian dairy heifer replacements no advantage accrued from twice daily feeding although the lighter calves on the once daily feeding system took longer to reach the weaning concentrate consumption of 0.91 kg on three consecutive days.

A subsequent trial with beef calves in which milk substitute (0.45 kg powder in 2.27 l of water) was offered once daily cold or warm showed that during a spell of severely cold weather calves receiving the cold milk replacer were additionally stressed, several refused to drink the milk replacer and two died (Randall and Swanmack 1975).

Feeding an isocalorific milk replacer diet either once or twice daily was shown not to have any effect on the performance of calves up to weaning at ten weeks of age (White and Radcliffe 1970). Calves on the once daily feeding system received initially 2.27 l, rising to 4.55 l at 22 days of age, of a 15 per cent milk replacer suspension. Calves on the twice daily feeding system received initially 1.70 l per feed of a 10 per cent suspension, rising to a maximum of 3.41 l per feed. It was considered that the lower volume of milk replacer offered to the once daily fed calves contributed to the lower incidence of scour on this treatment. There was no difference between treatments in lucerne hay intake offered <u>ad libitum</u>.

No significant difference was found in the live weight-gain or faecal consistency of calves fed either whole milk or milk replacer, once or twice daily. Significant differences were, however, found in the levels of blood glucose (Fieber 1972). Davis, Woodward and Rusoff (1970) obtained slightly better live-weight gains on a twice daily feeding system compared with once daily feeding and experienced a higher incidence of scours on the latter system. Experiments carried out at experimental husbandry farms have confirmed that there is no difference in performance between calves fed once or twice daily on high (15-18 per cent) or low (4-5 per cent) fat milk replacers whether mixed in warm or cold water. It was also suggested that 2.84 l was the maximum volume of milk replacer that could be readily taken at one feed by small calves (Clench 1972). It was however mentioned that once daily feeding may render young calves more prone to 'stress' and various infections. Leibholz (1975) considered that calves fed once daily may suffer nutrient deprivation. Flow of lipid was only 10% of the total lipid intake between 18 and 24 h after feeding in calves fed once daily. Reservations were also expressed about feeding cold milk replacer once daily to very young calves during the winter months.

Appleman and Owen (1975) having reviewed the literature on the frequency of feeding concluded that for once daily feeding, dry replacer should be restricted to about 363 g per day in about 3.18 kg of total liquid for breeds of larger calves and proportionally less for the smaller breeds.

Wood, Bayley and MacLeod (1971) found a trend which suggested that calves fed twice daily compared with once daily showed better utilization of digestible protein and energy. The difference was consistent from birth to 125 kg body weight. The conclusion was also drawn that

the anabolic activity of calves up to 125 kg body weight is primarily concerned with lean and bone tissue growth which can be affected by dietary feeding.

Once daily feeding of calves has been developed as a management aid. Feeding of calves on less than a seven day week basis may further lighten the load on the stockman. No difference in performance was found between calves fed from two weeks of age on a 5½ day week basis compared with those offered milk replacer seven days per week. However, water, early weaning concentrates and hay were available at all times (Clench 1972). Wood et al (1971) imposed a 39 h fast each week on some calves out of groups offered milk replacer only, once or twice daily. The calves were fed reconstituted milk replacer at 12% body weight and the treatments were retained until they reached 125 kg live weight. Treatment effects on the mean daily gain from birth to 91 kg and from 91 to 125 kg body weight were non significant. Non fasted calves, however, had a significantly greater longissimus dorsi area compared with fasted calves. Appleman and Owen (1975) concluded that the elimination of one day's feeding may be practical, especially for healthy calves beyond 10 days of age. It must be remembered however that calves would be further stressed by this withdrawal of milk feeding and that the feeding of cold milk or the occurrence of unfavourable weather conditions, would place the calf at great risk by lowering resistance to infection.

Evidence on the digestive processes in the young calf would suggest that the more uniform the rate at which milk enters the abomasum then the more efficient is the digestive system. Also, that the length of time for which digestion occurs in the abomasum governs the rate at which energy is made available to the calf. Supplying the total energy requirements in one feed necessitates an efficient energy storage system which in the young calf may not be well developed.

Feeding often in a 24 hour period has definite advantages over once or twice daily feeding. Feed consumption and live weight gain are both greater. There does not appear to be a great advantage in twice daily feeding compared with once daily feeding although dry matter appetite may be increased on the latter system. It is obvious that calves on the once daily system of feeding are additionally stressed and the incorporation of further stresses such as low levels of feeding or cold milk feeding in conjunction or singularly should be avoided.

The choice lies, in the increased performance, increased cost and better health of calves fed ad libitum requiring greater management compared with the reduced performance on the less management intensive and cheaper systems which involve either once or twice daily feeding, although the latter would not appear to have any advantage over once daily feeding.

The development of solid food intake and subsequent weaning of the young calf may appreciably reduce the risk of nutritional disorders and also facilitate a reduced management input. This may be achieved at an early age, at the sacrifice of the large daily live-weight gains which may be achieved whilst milk feeding. The main criterion for weaning is that the calf should be able to maintain itself on the amount of dry food it is consuming. This in turn depends on its appetite for dry food and the development of the rumen to an extent such that the calf is capable of digesting the solid food once it has been consumed.

Rumen Development

The development of a functional rumen in the calf depends not only on the anatomical and physiological development of the organ but also the development of a bacterial and protozoan fauna capable of digesting the material which passes into the organ.

The anatomical development of the reticulo-rumen has been reviewed at length (Huber, 1969, Warner and Flatt 1965). At birth the omaso-abomasum weighs more and occupies a greater volume than the reticulo-rumen. The abomasum constitutes 56 to 62% of the total stomach volume at birth. There is some disagreement as to when the relative size of the rumen reaches adult proportions, however, in calves fed normal concentrate and hay diets the rumen reaches its relative adult volume between thirteen and sixteen weeks of age (87% of total stomach volume). Godfrey (1961) showed that when expressed as a percentage of body weight, the weight of the empty reticulo-rumen was still increasing at 17 weeks of age. This is most probably due to the fact that the musculature of the organ was still developing although the volume had reached adult proportions relative to body size.

The development of ruminant digestion in the calf has been found to be rapid (Leibholz 1975). A considerable digestion of nutrients occurred only seven days after dry feed was first offered. By 14 days after weaning the apparent digestibility of dry matter and nitrogen in the stomach was approaching that found eight weeks after weaning. The digestion of acid detergent fibre in the stomach was 20% in the first week after weaning and increased to 52% by 8 weeks. The flow of microbial nitrogen to the duodenum increased from 32% of the total nitrogen flow, during the first week to 74% by 7 weeks after weaning. The diet offered post weaning in this experiment contained 60% barley, 20% soya bean meal and 15% wheat chaff. Calves were weaned off milk over a two day period at five weeks of age.

Effect of Diet on Rumen Development

The development of the rumen may be affected by the diet. The muscular pillars were much thicker and better developed in 12-week-old

calves given solid food than in 3-week-old milk fed animals but there was no apparent effect of the level of concentrate intake on the size and thickness of the muscular pillars in calves that had been weaned on to solid food at 5 weeks of age. (Stobo, Roy, and Gaston 1966). Huber (1969) concluded that rumen weight proportional to body weight can be increased during the period from four to thirteen weeks of age by the inclusion of grain and hay in the diet. However, Warner et al (1965) cited work which showed that the feeding of concentrates alone may retard the growth of the organ. Stobo et al (1966) showed that some hay in the diet may encourage development of rumen papillae and that increasing the level of concentrates fed with the hay also tended to increase the length of the papillae. As the production of propionic and butyric acid has been shown to increase with an increase in the proportion of concentrates in the diet and acetic acid is produced in greater proportions on high roughage diets, Stobo et al (1966) concluded that the greater increase in papillae growth obtained on the high concentrate ration was the result of a greater production of longer chain acids. This is in agreement with the conclusions of Huber (1969) who considered the order of effectiveness of volatily fatty acids in stimulating growth of rumen papillae to be in decreasing effectiveness butyrate, proprionate and acetate. Garrill and Nicholson (1969) in an experiment to determine the affects on digestion of added bulk, found that the feeding of oat hulls, but not sawdust or wood cellulose, increased the size of the abomasum and the combined rumen, reticulum and omasum per unit body weight of the calves compared with those fed whole milk or milk replacer alone. It was found that the sawdust and wood cellulose tended to stay in suspension in the milk replacer whilst the oat hulls fell to the bottom of the pail and were consumed separately. Rumen papillae development was evident only in calves fed oat hulls and the rumen fluid contained relatively higher levels of volatile fatty acids

particularly butyric and valeric.

The ability of the rumen to respond to changes in diet has been shown to be well developed by thirteen weeks of age. Following a diet low in concentrates rumen papillae development was rapid in a thirteen weeks old calf when the proportion of concentrates in the diet was considerably increased. (Stobo, Roy and Gaston 1966).

Rumen motility was recorded with a view to examining the functional development of the organ (Asai 1973). Activity indicating a degree of ruminal fermentation in which gases are given off was achieved between 3 and 10 weeks of age in calves fed milk, hay and grain. Fermentative type motility was found at 3-5 weeks of age in calves receiving sponge, volatile fatty acids (VFA) and milk replacer. Calves receiving milk replacer plus either sponge or VFA did develop rumen activity but it was not of the kind associated with fermentation. Rumen contractions were lacking at 15 weeks of age in a calf fed milk replacer only. It was concluded that the development of reticulo-ruminal motility was influenced by dry matter intake and concentration of ruminal VFA, but not pH which varied from 6.6 to 7.4.

The development of the rumen as an organ has been shown and the effects of its contents on growth demonstrated; however, its ability to add to the nutrient absorption of the animal depends on the establishment of the ruminal microflora and consequent fermentation capacity.

Rumen Microflora Development

Cellulolytic bacteria were found in the rumen contents of isolated calves at 5 to 7 days of age. The levels of this type of bacteria in calves two weeks of age were equivalent to the levels found in 34 weeks old calves. It was suggested that cellulolytic bacteria became established early in the rumen contents of calves reared free of

ruminal ciliated protozoa (Williams and Dinusson 1972). Since cellulolytic bacteria are obligate anaerobes it was suggested that these were transferred in the first 24 to 48 hrs. after birth when the calves remained with their dams. This work showed that calves reared in isolation developed ruminal bacterial populations as they matured which were equivalent to mature ruminants. However when kept in isolation, calves could be reared free of ruminal ciliated protozoa. It is obvious therefore that calves reared separately from adult animals may not develop a microbiological fauna equal to that of calves reared in proximity to adult ruminants.

These results agree well with those of Smith and McAllen (1974) who found that calves reared in a calf house without contact with adult ruminants did not possess ruminal ciliated protozoa in their rumens. It was found that the rumen bacteria of these calves differed from the bacterial fauna of the rumens of calves which were allowed contact with adult ruminants. Part of this difference was explained by the fact that the presence of protozoa has been shown to reduce the numbers of bacteria in the rumen and to affect the types present. It was concluded that for calves receiving cereal or hay type diets, from which by microbial action more than half of the N compounds and the L-dextran-like compounds entering the duodenum are derived, the nutrients entering the duodenum may be markedly influenced by changing the environment in which the calves are reared. The bacterial synthetic effort of calves reared in isolation from adult ruminants yielded a smaller total amount of N compounds than a similar effort from non isolated calves.

Rumen development has been shown to be affected by the solid portion of the diet of the calf. Physiological development of the rumen is rapid from the onset of solid feeding and may be influenced

by the type of solid feeding. Fermentation develops rapidly in the rumen and may develop without the presence of mature animals to seed the developing microflora. Calves reared in the absence of adult ruminants may possess a rumen microflora differing considerably from that found in the mature animal. This in turn may influence the products of fermentation passing from the rumen.

Weaning

Weaning is defined as the process whereby an infant or other young mammal is accustomed to food other than milk. In the case of the young calf the meaning of the word tends to be corrupted in that it usually refers to the point in time at which milk or milk substitute diet ceases to be offered to the calf. Weaning in the present context will refer to this latter case and any transitionary period in which milk and solid food is offered will be stated.

Several criteria for weaning have been considered, namely, the age of the calf (Strickland 1968), dry matter intake (Mitchell and Broadbent 1973) and level of concentrate intake (Hardy, 1972, Leaver and Yarrow 1972b). A successful weaning system should be such that the young animal is transferred from a liquid to a solid feeding system without incurring a deterioration in health. It is thus considered that systems whereby the calf, at weaning, is allowed to lose weight are not to be recommended as during this period the calf is more likely to be susceptible to infection.

Weaning According to Solid Food Consumption

In early studies the development of the alimentary tract was related to the age and weight of the animal (Godfrey 1961 and Large 1964). Hodgson (1971c) in an examination of the relationship between solid food intake and the development of the alimentary tract concluded that

the absolute and relative sizes of the four stomachs of a young ruminant can be markedly affected by the amount and nature of the solid food offered. It is likely that in the young calf allowed access to solid food the factors of age, weight and solid food intake are complementary. However in calves denied access to solid food the development of the four stomachs is unlikely to be equivalent to calves receiving solid food in the diet.

In subsequent work, Hodgson (1971d) concluded that initially the intake of solid food after weaning is limited by oropharyngeal factors and not by the fill of the digestive tract or by metabolic factors. It was found that the ability of the calf to compensate for the removal of dry matter from the rumen equalled that of the adult ruminant when the level of intake on a given diet exceeded 1.5 kg DM per day. Thus the young Friesian calf is unlikely to be adapted to a solid diet until it is eating 1.5 kg DM per day. It is not true, however, that the adverse effect of weaning upon growth of the calf will be minimized if the intake of solid food approaches this level before weaning. The energy balance of the diet should also be considered. Hence a drop in live weight gain at weaning can be overcome only if the energy loss, as a result of the withdrawal of milk feeding, can be compensated for by an increase in solid food intake. The effect of weaning on the performance of the calf therefore depends on the relative contribution to the energy requirements of the calf by the milk and the solid food intake at the time of weaning. A general conclusion could therefore be drawn that dry food intake should be encouraged in order to successfully wean a calf.

Leaver and Yarrow (1972a) found high fat milk replacer and lower levels of milk feeding induced a greater intake of concentrates. In a further experiment to examine these effects it was found that calves weaned abruptly were unable to compensate for the removal of milk

feeding by increased concentrate intake. Calves receiving 320 g/day of high fat milk replacer suffered a drop in energy intake, when energy was calculated as multiples of the maintenance requirement of 0.05 x maintenance at weaning compared with those receiving 480 g/day of milk replacer which suffered a drop of 0.27 x maintenance. The drop in maintenance occurred irrespective of whether calves were weaned when they were consuming 400, 650 or 900 g of concentrates per day. This is in agreement with the results of Hodgson (1971c) and confirms that at the levels of intake at weaning used by Leaver and Yarrow (1972b) concentrate intake was not fully developed.

Leaver and Yarrow (1972b) found that the level of concentrate intake at weaning significantly affected the length of time to weaning but that post weaning performance was not affected by the level of concentrate intake used as the weaning criterion. It was concluded that calves could be weaned when consuming 400 g/day of concentrates.

Clench (1972) in a review of experiments carried out at M.A.F.F. Experimental Husbandry farms found no significant difference in the live weight performance to twelve weeks of age between calves weaned at concentrate intakes of 453 or 906 g/day. However weaning at 453 g (1 lb) of concentrates significantly reduced the period to weaning by 8-10 days. Reservations were however made at weaning calves when consuming 453 g of concentrates per day having only been fed milk replacer for 10 days. These calves appeared to perform less well than those weaned off milk at 40 days of age. A similar experiment comparing calves weaned when consuming 453 g (1 lb) compared with 906 g/day (2 lb) of calf starter showed that the composition of the starter did not affect the performance of calves weaned when consuming 906 g/day. In the trial when calves were weaned when consuming 453 g/day

of solid food, performance was poorer on a simple barley:beans ration than on a complex formulation (Hardy 1972).

Weaning According to Age

Several instances have been cited of calves having been weaned at specific ages although Leaver and Yarrow (1972b) pointed out that this did not take any account of between calf variation in their ability to adapt to a dry feeding regime. Milligan and Grieve (1970) in an examination of the effect of age at weaning offered calves a complex or a simple calf meal from 10 days of age. No difference was found in the performance of calves on each starter up to 120 days of age.

The effect of age at weaning appears to depend on the energy content of the milk replacer. In an experiment in which calves were restricted in milk replacer consumption during the week prior to weaning, those calves receiving a low energy (6.5% fat) milk replacer and weaned at 21 days of age appeared to be under considerable stress during the third and fourth weeks. Similar calves fed a high energy (16% fat) milk replacer and weaned at 21 days of age, also appeared to be under some stress at weaning, but feed consumption and rate of gain to 120 days of age were as good as those of the calves weaned at 4 weeks. Calves abruptly weaned off a low fat milk replacer at 4 weeks of age suffered a significant decrease in growth rate during the following month. Total concentrate intake of the calves weaned at four weeks of age was similar to that of calves weaned two weeks later. Calves weaned at six weeks did not suffer a similar decrease in live weight gain (Wickes, White, Lewis and Radcliffe 1972). The data on concentrate intake is in agreement with that of Hodgson (1971d) and suggests that calves weaned at four weeks of age are unable to compensate for the reduction in energy intake by an increased level of concentrate consumption.

Faster growth rate was found in calves weaned off whole milk at three weeks compared with those weaned off milk replacer at five weeks of age. This difference was due partly to the better food conversion of whole milk during the period 4-21 days, but also to a better growth rate in the post weaning period. Both feeding treatments, however, were successful in rearing calves under practical conditions, (Strickland 1968). Srinivasan and Martin (1974) compared the live-weight gains of Angus calves weaned at either 120 or 210 days of age. Early weaned calves were on average 10 kg heavier than late weaned calves at 210 days of age.

In an experiment to study the effects of environment on the young calf no deleterious effect was noted from weaning calves when the daily intake of air-dry milk substitute powder plus concentrates reached a mean of 1.59 kg/calf, providing at least 0.45 kg of this intake was from concentrates (Nitchell and Broadbent 1973).

Summary

From the foregoing discussion several criteria can be identified on which a calf may be weaned. In the experiments in which calves were weaned at or under four weeks of age appreciable depressions in liveweight gain were noted. These occurred whether concentrates were offered from 10 or 18 days of age. It can be concluded that at this age dry matter intake is not sufficiently developed to support live weight gain, but is sufficient to maintain the calf. It has been stated that the effect of age at weaning appeared to depend on the energy content of the milk replacer. This is likely not to be so much an effect of the milk replacer but more the fact that calves previously receiving a low energy intake do not possess the energy reserves to tide them over a period of even lower energy intake. It can be concluded therefore that a system of weaning should be based

on the energy requirements of the calf at weaning. The system should be flexible in order to take account of the differences in weight of calves at specific ages. Having considered that the result of weaning is that the calf receives its food supply in a solid form it is pertinent to consider the nature of the solid food which is most acceptable to the calf.

The Nature of Solid Food Intake

The difference between the level of consumption of a pelleted and a coarse diet was considered to be primarily influenced by the physical characteristics of the two diets, (Hodgson 1971a). Although in this work the *in vivo* digestibility of the diet and the time of retention in the alimentary tract were reduced by grinding and pelleting this was compensated by a 50% increase in voluntary dry matter intake which resulted in a 100% increase in live weight gain. Subsequent work showed pelleted dried grass consumption was 45% greater than when the diet was fed coarse (Hodgson 1971b).

Clench (1972) found a slight advantage when feeding a simple mixture as a coarse meal compared to when pelleted. This agrees with the results of Hardy (1972) who found that calves fed a simple ration as a coarse meal tended to consume more dry concentrate than those fed their rations as pellets. Food conversion efficiency of concentrates fed as meal tended to be poorer than those fed pellets although dry matter intake was greater. This confirms the statement of Hodgson (1971d) that oropharyngeal factors initially control the intake of solid food.

The literature is therefore contradictory on the point as to whether meal should be fed coarse or pelleted. There exists a large range of physical forms of diet which are readily acceptable to the calf. Within this range highly compressed pellets or dusty over

fine meal probably constitute the boundaries within which little overall difference exists in palatability.

The experience of solid food prior to weaning has been shown to influence that rate at which solid food intake increases post weaning, (Hodgson 1971a). This may account to some extent for the reason when Leaver and Yarrow (1972b) were able to wean calves when consuming 400 g of concentrates per day. Their calves had access to concentrates as soon as they arrived on the unit between 3 and 7 days of age. Thus although energy intake fell at weaning the calves rapidly compensated by increasing dry matter intake.

The composition of the concentrate whether it was of a simple type and whether the protein was supplied from a variety of animal or vegetable sources did not affect voluntary intake or dry matter digestibility (Hardy 1972, Clench 1972).

The Effect of Long Fodder Consumption

Work carried out on the effects of hay consumption on the performance at weaning of young calves is inconclusive. Hay is usually offered ad libitum with the solid portion of the diet (Leaver and Yarrow 1972a, Mitchell and Broadbent 1973, Randall and Swanmack 1975). Roy, Stobo, Caston, Ganderton, Shotton and Thompson (1971) found that calves offered a good quality milk substitute ad libitum showed very little desire to consume roughage. Calves were offered either meadow hay or barley straw from 1 week of age. Of twelve calves offered roughage only three calves were consuming any meadow hay and only two any barley straw at 7 weeks of age.

A cautionary note on the feeding of roughage was expressed by Roy et al (1971) when it was found that a higher incidence of lung lesions was found in calves offered hay compared with others which did not have access to hay.

Strickland (1968) in a comparison of the intake of pellets with or without hay found that the group receiving hay ate more pellets and gained weight significantly faster than those which received no hay. It has been suggested that whole milk feeding compared with skim milk feeding increased the ability of the calf to digest hay. The apparent digestibility of hay increased from 34 per cent at three weeks of age to 64 per cent at 5 weeks and remained constant at this level to 14 weeks (Sunthiraseegaram and Watts 1970).

Supplementation of all concentrate diets with chaffed lucerne hay or chaffed wheat straw was found not to affect performance of weaned calves. Maximum weight gain was calculated to occur when the concentration of acid detergent fibre (ADF) in the diet was 18%. Maximum feed intake was calculated to occur with a diet containing 20% ADF (Hi Shin Kang and Leibholz 1973). In this work it was found that the feed intake and weight gain of calves between 5 and 11 weeks of age were increased significantly by the inclusion of 15% milled wheat straw, but were reduced by 30 or 45% straw in a pelleted all-concentrate diet. The digestibility of both dry matter and organic matter was decreased by the inclusion of wheat straw in the diets. The maximum digestibility of ADF was calculated to occur when the ADF content of the diet was 27.5%. Increasing the wheat straw content of the diet to 30% or 45% reduced weight gains to 83% and 53% of the maximum.

In a subsequent experiment to determine the effect of quantity and quality of ground roughage included in a pelleted diet on the performance of early weaned calves, feed intake tended to increase with increasing roughage content, but this effect was non significant (Jane Leibholz 1975). Weight gains in this paper were reported as decreasing with increasing roughage content of the diet. Diets containing ground lucerne were more digestible than those containing

wheat straw and gave greater weight gains. In the previous work (Hi Shin Kong and Leibholz 1973) it was shown that intake fell when the inclusion of hammer milled wheat straw in the diet was raised above 15% to 30 and 45%. In the latter experiment (Leibholz 1975) feed intake was not reduced if the proportion of finely ground wheat straw in the diet was increased from 20 to 40%. The method of forage treatment used in this case may have yielded a finer product, although the particle sizes were not specifically stated. Feed intake and weight gain were not increased by offering chaffed wheat straw ad libitum although intake of this roughage was only 5% of the total intake. The inclusion of a methane inhibitor in the diet improved the performance of the calves.

Summary

Chaffed hay and straw intakes obtained by Hi Shin Kong et al (1973) and Leibholz (1975) tend to support the conclusions of Roy et al (1971) that the appetite of young calves for long roughage is very low. A beneficial effect has been obtained from the inclusion of roughage in the diet although its form and level of inclusion are important. Fine grinding would appear to have an advantage over hammer milling and there is also an advantage in feeding good quality roughage.

The Maintenance Requirement of Calves

Van Es, Wijkamp, Van Weerden and Van Hellemond (1969) in experiments using growing veal calves (50-150 kg live weight) calculated that 0.447 MJ.ME per kg metabolic weight ($W^{0.75}$) were required for maintenance. A similar conclusion was drawn in trials where the feeding level was reduced from 2.5 to 1.5 times maintenance. The utilisation of metabolisable energy for gain was 69%. In another series of experiments using Normande calves of between 145 and 188 kg

live weight, Vermorel, Bouvier, Thouvond and Toulec (1974) obtained a value of 0.401 MJ.ME per $W^{0.75}$ for maintenance with an efficiency of utilisation of ME for gain of 69.4%. It is suggested that in this instance the difference in maintenance requirement was the result of a breed difference. In both cases a regression technique, regressing energy deposition against metabolizable energy per unit metabolic weight, was employed.

Johnson and Elliot (1972b) used a comparative slaughter technique and from a prediction of the energy content of the calves at the start of the experiment (Johnson and Elliot 1972a) obtained a value of 0.422 MJ.ME per $W^{0.75}$ for the maintenance requirement of Friesian calves between four and twenty-four days old. The efficiency of utilisation of ME above maintenance was 63%. An interesting aspect of this experiment was the curvilinear trend of energy intake and retention.

In a subsequent experiment (Johnson and Elliot 1972c) the maintenance requirement for calves between four and twenty-four days of age was calculated to be 0.461 MJ.ME per $W^{0.73}/d$. Again curvilinear (semi log) regressions described the relationships between the estimated energy retention in skinned, digesta-free bodies of the calves and the Gross Energy and Metabolizable Energy intakes per kg $W^{0.73}$. When energy retention was related to ME intake above the estimated maintenance ME requirement a linear relationship was obtained.

The maintenance requirement calculated by Johnson and Elliot (1972b) was 8.5% lower than that obtained by Johnson and Elliot (1972c). The reason given for this was that the calves in the latter study were reared under more exposed conditions, being kept in an open sided shed. Previously the calves had been reared in a meta-

bolism room.

It is interesting to note that the environmental conditions, under which many experiments of this type are carried out, are seldom quoted.

Webster, Gordon and Smith (1976) obtained a linear relationship between ME intake and energy retention by methods of direct and indirect calorimetry. The interpolated value for ME requirement when energy retention was 0 was 0.675 MJ.ME/kg $W^{0.75}$/24h. The efficiency of utilization of ME for growth in this experiment was 72%. In this piece of work the relationship between ME and heat production was found to be linear. Had the high maintenance requirement been a result of a higher level of feeding then this relationship would not have been linear. The higher level of feeding used in this work can thus be ruled out as a factor affecting maintenance requirement. There is a discrepancy of 40% in the estimated value of maintenance between the figure of Webster et al (1976) and Vermorel et al (1974).

Holmes and Davey (1976) in an attempt to resolve the differences obtained in the values of maintenance requirement of calves carried out a series of experiments using Friesian and Jersey calves of approximately 45 and 28 kg live weight respectively. The calves were fed at two levels to allow on the high level of feeding a growth rate of 0.7 and 0.5 kg/dy for the Friesians and Jerseys respectively, while the corresponding value for the lower level was 0.25 kg for both breeds. There was no effect of breed on fasting heat production but there was a significant effect of level of feeding. Maintenance requirements for the Friesian and Jersey calves were 0.376 and 0.410 MJ/kg $^{0.75}$/24 hr respectively. These values were significantly

different at the 1% level. The net efficiency of utilization of ME above maintenance was for the Friesians 63% and the Jerseys 71%.

The values of ME for maintenance obtained by Johnson and Elliot (1972b), Van Es et al (1969) and Holmes and Davey (1976) are in reasonable accord and suggest a mean value of 0.42 MJ ME/kg$^{0.75}$ for the maintenance requirement of the Friesian calf. In the light of these results it is very difficult to interpret the results of Webster et al (1976). As stated in this work, the results were obtained from two differing calorimetric techniques. There is therefore unlikely to be a systematic error in the results and the values represent the true ME for maintenance of the animals on trial.

The calves used by Johnson and Elliot (1972) varied in age from 4 to 24 days, those of Holmes and Davey (1976) from 3 to 14 and 16 to 37 days of age during the two trial periods. Webster et al (1976) used young Friesian entire male calves which were 80 kg at the start of the experiment and had been accustomed to handling and the calorimeters for about three weeks before the experiment began. It is unlikely therefore that the difference in ages of the calves would account in full for the differences in the maintenance requirements.

Webster et al (1976) tentatively suggested that social environment may be the cause of the increased metabolic rate. There was an appreciable difference in the prior handling and management of the calves used by Webster et al (1976) compared with the very little handling experienced by the calves of Holmes and Davey (1976) and those of Johnson and Elliot (1972). It is suggested that, although handling had been used to accustom the calves to the treatment, this did not in fact occur. Experience of the author would suggest that young calves do not become accustomed to handling as do older cattle

but retain a nervousness even in the presence of the stockman. This could explain the higher maintenance requirement of the calves of Webster et al (1976), the calves having been preconditioned into a more stressful state.

Estimation of Maintenance Requirement

Blaxter and Wood (1951) first studied the effect of starvation in the preruminant calf with a view to further understanding the effects of the treatment for diarrhoea of complete inanition. The results are important in that they showed a fundamental difference in the reaction of the young calf to starvation compared with those found in man and mature animals. In man, the cow and sheep a plateau in metabolism occurs at varying times after the postabsorptive state has been reached. In the young calf, heat production and consequently metabolism of the animal per kg body weight declines markedly and is not affected by the earlier nutrition of the individual within the limits employed (Blaxter and Wood 1951). Thus while it is easy to define the external conditions under which measurements are made of fasting metabolism, it is less easy to define what is happening to the animal as it attempts to adjust its metabolism to cope with the problem of a sudden fuel shortage (Webster, Brockway and Smith, 1974). The question therefore arises as to the significance of basal metabolic rate in the pre-ruminant calf.

In the present work one aim has been to measure the maintenance requirement of the calf and to examine the effect of the environmental conditions under which the calf is reared on the energy requirement for maintenance. It has already been stated that in practice it is difficult to reach the fasting metabolic state in the young calf.

Wood and Capstick (1926) in an analysis to determine the maintenance requirement of sheep from previous digestibility studies

considered that the rations provided for (1) the basal metabolism; (2) the energy consumed in muscular movements; (3) the change in weight which may be positive or negative and (4) the growth of wool. The latter is very small compared with the other three and hence can be neglected. Thus we may write:

$$\text{Ration} = (1) + (2) + (3) \quad - (1)$$

In this original work all units were expressed in starch equivalents. The basal metabolism was taken to be proportional to the surface area of the animal. Energy required for muscular effort was difficult to determine. As the experiments were carried out when the animals were kept under normal conditions, the sum of the basal metabolism and the energy of movement so determined provided an average value of the maintenance requirement.

Factors (1) and (2) were therefore combined in a single term, written Am where A was the surface area and 'm' the ration required to provide for the basal metabolism and muscular effort.

Equation (1) was therefore re-written:-

$$R = mA + cG \quad - (2)$$

where:- R = ration fed to the sheep

A = surface area calculated from the weight

m = ration required per unit of basal metabolism plus muscular effort

G = the gain of weight

c = the ration required to produce 1 lb. of gain

It was pointed out that by including (1) and (2) in a single term Am then it was assumed that the average expenditure of muscular energy was proportional to the same power of live weight as was

surface area. The power of 0.66 was used which was not markedly different from the currently used value of 0.75. It should also be noted that the factor c was modified according to whether the animals gained or lost weight. The coefficients of m and c were determined essentially by solving fourteen equations in the form of equation 2 above by a method of least squares.

Coop (1962) in a later estimation of the maintenance requirement of pen fed sheep used an extension of the equation of Wood and Capstick (1926). Digestible organic matter (DOM) intake of an animal was given by the equation:

$$\text{daily DOM intake} = a\,W^{0.75} + bG$$

where, $aW^{0.75}$ is the maintenance requirement which was assumed to be proportional to $W^{0.75}$, 'b' was the DOM requirement per lb of gain and 'G' was the daily gain. It was also noted that 'b' would be a function of W, varying according to the energy content of the tissue which was being stored. In trials where the aim was to measure maintenance alone, live weight changes were kept small. Where the aim was to measure both maintenance and gain requirements the regression of intake on gain was calculated. Since 'b' varies with weight the value obtained was only applicable to the mean live weight of the sheep. It was also stated in this work that in the determination of feed requirements the main source of error in pen fed sheep was in the measurement of live weight change. Precautions were therefore taken in an attempt to increase the accuracy of this measure.

This method of partitioning energy for maintenance and live-weight gain was considered appropriate for range conditions because the estimated maintenance requirement included the energy expenditure of the muscle activity of the grazing animal. Lambourne (1962)

again in a trial designed to determine the maintenance requirement of sheep making substantial gains fed on cut pasture used least squares regressions on feed intake to obtain the intake at zero weight change as an estimate of maintenance intake. This value would be identical with the simple mean where no overall weight change occurred, but less or greater than the means if there was an overall rise or fall in weight during the course of the experiment. On further consideration it was considered that the use of the regression equation in this manner to estimate maintenance implied that the rate of weight change was being viewed as the independent variate and a more correct procedure would be to use the corresponding regression of DOM intake on weight change. The new intercepts did not however alter the general interpretation of the results.

In view of the presumably random error obtained in both the variates, Lambourne (1962) considered the least squares method of regression analysis inappropriate. The method of Bartlett (1949) for two variates subject to error was applied. This new line, established through the general mean but with a slope determined by the general trend of the variates from the means of the two terminal thirds of the population again did not alter the earlier interpretation. The method finally used for the analysis of the results was that of Kormack and Haldane (1950) in which the data was analysed with no specification as to the independent variable. This method in effect combines the regression of Y on X with that of X on Y and necessarily lies between the two.

Langlands, Corbett, McDonald and Fullar (1963) made estimates of the energy requirements for maintenance of adult sheep kept indoors in two separate experiments, (1) from measurement of fasting heat loss and (2) from statistical analyses of data for feed intake and animal

performance. The latter approach was using a modified version of equation (2) where again the right hand side could be interpreted in terms of the requirements for maintenance and gain, i.e.

$$D = aW^k + bG \quad - \quad (3)$$

where:-

W^k = the metabolic live weight

D = Digestible Organic Matter Intake

'a' and 'b' = the unit requirements for maintenance and production respectively

Again the point was stressed that caution should be exercised in extrapolating such equations to animals showing live weight gains out with the observed ranges, due to the changing nature of 'b'. In a preliminary investigation to determine the value of 'k', the standard errors were sufficiently large for the results to be compatible with values of 'k' of either 0.73 or 1.00, the best estimate being 0.85. Following the criticism of Lambourne (1962) concerning the use of regression analysis, Langlands et al (1963) used both regression analysis and an estimation of the underlying or functional relationship between the true values of the variables. The method used in the latter instance was a generalised form of that described by Williams (1959) for two variables. Langlands et al found there was a substantial difference between the results obtained depending on the method of analysis. Using the method of underlying functional relationships the preferred estimate of the maintenance requirement was in good agreement with that obtained in their calorimetric studies (0.82 lb DOM per day for a sheep weighing 100 lb compared with 0.79 lb DOM per day respectively). When the results were analysed by standard regression analysis the estimate

was 0.92 lb DOM. In these experiments it was emphasised that in order to estimate the relationship between feed intake, live weight and growth rate in any species then the experiments should be designed to include an element of heterogeneity in the species used and in the rations given to them.

In other work using the same technique as Langlands et al (1963) the live weight changes of fattening lambs were calculated by regression using weekly weighings (Forbes and Robinson, 1969). The mean daily DOMI of each animal, their weight raised to different exponents and their live weight changes were analysed by a multiple regression technique to estimate the proportions of the DOMI utilized for maintenance and production. The analysis was carried out for different values of 'k' ranging from 0.60 to 1.00. Forbes and Robinson suggested that the larger residual standard deviations obtained in an experiment carried out over 47 days compared with one carried out over 100 days was due to the reduced length of time over which the recordings were made. The results obtained for the different exponents of body weight for the relationship of the form $D = aW^k + bG$ showed that in the experiment carried out over 100 days the residual standard deviation increased markedly between the values of 0.73 and 1.00. However results from the 47 day experiment showed only a marginal difference between the residual standard deviations for different values of 'k'. In the case of the relationship:

$$D = aW^k + bG + C \qquad - (4)$$

the residual standard deviations for the exponents of 'k' between 0.60 and 1.00 differed only marginally. A similar conclusion was drawn to that of Langlands et al (1963) that there was no significant difference between the exponents 0.73 and 1.00.

The inclusion of a constant in the equation as in (4) had only a marginal effect on the coefficients for body weight gain. It had also only marginal effects on the residual standard deviations, although it did reduce the differences previously obtained between different values of 'k'.

The estimate of DOM required for maintenance by a 35 kg lamb obtained by multiple regression analysis was 3.4% higher than that obtained by Langlands et al (1963) by the use of functional relationships (320 g DOM per day and 309 g DOM per day respectively). The estimate of the requirements of a 45 kg lamb was also similar to that obtained by calorimetry and by feeding trials carried out by the same workers (400, 359 and 372 g DOM per day respectively).

This technique of apportioning energy intake into live weight gain and maintenance was further used in an attempt to distinguish breed differences in the energy needs for gain and maintenance of steers (Chestnut, Marsh, Wilson, Stewart, McCullough and Callian 1975). Three breeds, Aberdeen Angus cross, Hereford x Friesian and British Friesian steers were reared at a high level of intake, designed to give 0.7 kg live weight gain per day and at a lower level which was 75 to 80% of this intake. For each animal during each test period the regression coefficient of live weight on time was used as the estimate of daily live-weight gain.

The ME intakes were subjected to a multiple linear regression analysis with ME intake (I) as the dependent variable and mean metabolic live weight ($W^{0.73}$) and mean daily unfasted live-weight gain (G) as the independent variables according to the equation. $I = aW^{0.73} + bG$ which is of the form of equation (4), except for the absence of the constant. The coefficient for metabolic weight was

significantly greater ($P<0.05$) for the British Friesian than for the other two breeds which were not significantly different. The coefficient for gain was significantly greater ($P<0.05$) for Angus cross cattle than for British Friesian and intermediate for Hereford x Friesian. The ME requirement for a gain of 0.75 kg was 4.87 and 3.04 MJ for the Angus and Friesians respectively. This was compared with the theoretical requirement obtained from dissection data. From dissection data it was calculated that the Angus should require 8% more energy per kg of live-weight gain. From the multiple regression technique it was calculated that the Angus should require a 60% greater energy input per kg live-weight gain.

The results were also compared with the A.R.C. recommendations for 300 kg animals gaining 0.75 kg per day. A comparison of the results is shown in Table 1.3 from Cheatnut et al 1975.

Table 1.3

ME Requirements of 300 kg Animals of Three Breeds Compared with A.R.C. Standards (MJ. ME for a daily gain of 0.75 kg)

	Maintenance	Gain	Total	Maintenance as % of total
Angus	42.84	20.45	63.29	67.7
Hereford x Friesian	44.18	17.05	61.23	72.1
Friesian	48.76	12.77	61.53	79.2
ARC (breed unspecified)	41.16	20.58	61.74	66.7

As can be seen the partition of energy is somewhat different to that obtained from the A.R.C. recommendations. This together with the comparison between carcase dissection data and calculated requirements led Cheatnut et al to doubt the approach used to partition ME between maintenance and gain.

It was considered that the approach assumed a linear relationship between gain and ME available for gain. In mature cattle exhibiting high rates of gain this is probably incorrect because the tissue laid down will have a higher proportion of fat and hence a higher energy requirement. The maintenance term is also obtained by extrapolation down the 'b' slope, which will possibly be subject to variations depending on the energy content of the gain. It is also assumed that maintenance is a linear function of $W^{0.73}$; however, this assumption was substantiated by Webster et al (1974).

It is difficult to reconcile the good agreement of results using this technique of partitioning the energy requirement for maintenance and gain adopted by Lambourne (1962), Langlands et al (1963) and Forbes and Robinson (1969) with the poor agreement obtained by Chestnut et al (1975). There exists between the four reports quoted an essential difference between the animals used. Langlands et al (1963) used mature sheep fed ad libitum and 70% of ad libitum. Live weight gains ranged from -0.004 kg to 0.25 kg/day in the first experiment and from -0.005 to 0.25 kg/day in the second experiment. Lambourne (1962) used adult wethers and in two experiments the sheep were offered feed to such a level that their weight remained constant over the period of the trial. In these four experiments it is doubtful whether the composition of the gain, or of the animal, in terms of fat and muscle would differ appreciably over the duration of the trial. Thus the energy apportioned to gain was likely to be linear throughout the period of the trial.

In the work of Forbes and Robinson (1969) the average weight of the lambs used was 36 kg and it has been estimated that the average weight of a mature animal of the same cross would be 70 kg. The

animals were therefore approximately 51% of their mature weight. Live weight gain on both experiments was approximately 40 g/day, thus during the 100-day and 47-day experiments total live-weight gain was 4 and 1.88 kg respectively. At the end of the experiments the animals were therefore 57 and 54% of mature live weight respectively. It is therefore likely that as in the work of Langlands et al (1963) and Lambourne (1962) the energy content of the gain was uniform over the period studied. This inference is drawn from the fact that the fat content of the gain is related to the maturity of the animal. The experiments of Chestnut et al (1975) used steers ranging in mean live weight from 201 to 508 kg at the beginning of the first and third experimental periods respectively. It is realised that a breed effect lies within these weights. A mature weight for the steers has been estimated at 650 kg (estimate based on cow and bull weights). Thus during the experiment the animals varied from 31 to 78% of mature body weight. Over this age range the energy content of the gain would not be linear, as it would probably increase considerably, hence it was not appropriate to compute regression equations combining all three periods within each breed.

The experiment of Chestnut et al (1975) also used high rates of live-weight gain. The lowest mean daily live weight gain achieved was 0.46 kg/day. It is considered that extrapolating to zero live-weight gain would give rise to considerable error in the prediction of the maintenance requirement.

In the present work an attempt has been made to obtain a range of live-weight gains including low values of 0.25 kg/day over a period when live weight was changing from approximately 5% to 11% of mature body weight. In these circumstances it is considered that extra-

polation to zero live weight gain would be appropriate and that during the period of the trial the content of the live-weight gain in terms of fat and protein would not significantly change.

Section 2

(2a) Buildings and (2b) Environment

2a BUILDINGS

INTRODUCTION

Recent work (Mitchell and Broadbent 1973) has suggested that climatic calf housing is suitable for young calves. The value of insulation and protection provided for the young calf by a climatic calf house is as yet unexamined. It was decided to construct four calf houses of differing design in a manner which would afford differing degrees of protection to young calves.

In designing these houses it was recognised that specialised housing for calves is often not provided on farms and that a more usual approach is to rear calves in various types of accommodation not needed for other purposes. As it is difficult to justify expenditure on specialised housing solely intended for young calves the present houses were designed to provide accommodation for calves from a few days to about six months old.

It was also desired to examine the possibility of climatic calf housing in the West of Scotland.

Site

The experimental calf unit was located at the Animal Husbandry Experimental Unit, Auchincruive, Ayr. The site is approximately three miles from the West Coast of Scotland between 30 and 45 m above sea level. The four houses were erected to face due south and were partly surrounded by trees.

Houses

Four new calf houses were constructed, each to accommodate 32 calves from birth to six months of age. Two of these houses were of an open fronted 'lean to' type design, differing from each other in level of insulation. The other two houses were of a different design consisting of an enclosed cubicle area plus feed stance.

Again the two houses were of a similar design but differed from each other in the degree of insulation of the building and the protection afforded to the calf.

Henceforth the 'lean to' type houses will be termed the 'A' houses and those incorporating the cubicle units the 'B' houses. Within each type of housing the minimum insulated and additionally insulated houses will be numbered 1 and 2 respectively. Thus:-

A1 = open fronted, lean to type, minimum insulated
A2 = open fronted, lean to type, additionally insulated
B1 = cubicle type, minimum insulated
B2 = cubicle type, additionally insulated

A description of the structures of the four houses, together with detailed plans is given in Appendix 1. A brief summary of the differences between the houses is given in Table 2a.1.

Table 2a.1.
Summary of House Differences

Structure	Minimum Insulated	Additionally Insulated
	House A1	House A2
Exterior walls	Cavity to 1.37 m single brick above	All cavity brick walling
Roofing	Single asbestos sheet	Cavity asbestos roof with glass fibre insulation
Floor	Concrete base	Concrete base
Front protection	Absent	Hinged flap 1 m deep
	House B1	House B2
Exterior walls	Cavity to 1.37 m single brick above	All cavity brick walling
Nursery protection	Half open front	Completely enclosed
Roofing	Single asbestos sheet	Cavity asbestos roof with glass fibre insulation
Floor	Concrete base	Concrete base
Front protection	Canopy	Completely enclosed

Plates 1-5 show the four calf houses used in the environment project.

Plate 1 shows the minimum insulated version of the A type house. The four cells are clearly visible. The calves were individually penned and the straw bale wall erected at the front of each cell to prevent draughts at calf level is clearly visible. The single sheet asbestos roof can be identified together with the fact that the gable walls are only cavity walls to approximately half their height.

Plate 2 shows the additionally insulated version of the A type house. The animals were group penned and one feed trough is visible in the cell in the foreground of the picture. It can be seen that the internal cell walls were only half cavity but the external gable wall was cavity brick to its full height. The position of the wind speed and direction measuring apparatus can also be seen.

Plate 3 again shows the minimum insulated version of the A type house. The main feature to note is the cage at the rear of the cell which housed the environment monitoring instruments. The straw bale wall and the protection it afforded to calves can be seen.

Plate 4 shows the minimum insulated form of the B type house. The non insulated roof can be seen together with the open aspect of the four cells. The solarimeter can be seen at the apex of the roof.

Plate 5 shows the additionally insulated form of the B type house. Its completely enclosed nature should be noted. Also visible through the open gate is the door leading into one of the cubicle cells. The completely enclosed nature of the cell can be seen.

A Type Houses

(plate 1) A1

(plate 2) A2

A Type House

(plate 3) A1

B Type Houses

(plate 4) B1

(plate 5) B 2

Management of the Houses

During the nursery period when the calves were penned individually in crates it was considered that additional protection was required at the front of the A type houses in order to prevent wind blowing directly onto the calves. During the Spring '74 intake a straw bale wall approximately 2 metres high was built at the front of each A type house. During subsequent intakes the height of the wall was reduced to 1.5 m high.

On no occasion was the honeycombed wall at the rear of the A1 house or the ventilators in the A2 house opened. The front flap of the A2 house remained in the vertical position throughout the duration of the four trials. During the period to weaning the hopper windows in the B2 house were occasionally opened together with one ventilator flap in each cell. These precautions were taken in order to prevent an excessive build up of ammonia in the air and occurred mainly during the Spring '74 intake until the floor falls were corrected (see Appendix I). During the period to weaning the gates between the cubicle area and the feed stance in the B house were kept closed except for access. In the B2 house this had the effect of producing a completely enclosed calf nursery during the period to weaning.

A system of built up dung was used in the A houses and for this reason allowances were made in head room for a tractor fitted with a safety cab plus some allowance for the height of the dung. Dung was barrowed from the nursery area of the B houses when the calves were weaned and regrouped.

House Insulation

In order to examine the performance of the houses both the practical measure of animal performance and a theoretical approach

were considered. The practical assessment of animal performance is given in Section 3c. A theoretical assessment of the buildings was made by examining the heat loss through each of the external structures of the four houses and is presented in the following.

From the data and figures given in Appendix 1 the transmittance ('u' values) of the various structures was calculated and is shown in Table 2a.2 and 2a.3. The conductivity of the materials was obtained from the A.J. Metric Handbook (Fairweather and Sliva Dipling, 1968). Where individual structures consist of more than one material or of different qualities of the material a composite transmittance value, measured in watts per metre per degree centigrade (W/m.deg C) was calculated.

In calculating the transmittance values for the rear North facing walls of the A1 and A2 houses, the effects of the honeycombed wall of A1 and the ventilator bricks of the A2 house have been ignored. Throughout the duration of the trial these structures were blocked and thus have been considered as being equivalent to the part of the wall in which they were sited.

Transmittance values for the windows in the B1 and B2 houses have been included.

Table 2a.2

Transmittance Values (W/m.deg C) of A Type Houses

Structure	Area m^2	Transmittance U (W/m.deg C) A1	A2
Gable walls			
E facing	16.05	2.69	1.81
W facing	16.05	2.52	1.74
Rear wall	40.63	2.49	1.81
Floor	110.82	0.6115	0.6115
Roof	112.20	5.98	0.66
Total Area	294.37		
Composite U value (W/m.deg C)		3.13	0.93
Total volume (m^3)		296.44	296.44

U values for the structures were calculated from the resistivity values of the elements:-

$$R = \frac{1}{fo} + \frac{1}{c} + \frac{b'}{k'} + \frac{b''}{k''} \ldots\ldots + \frac{1}{fi}$$

where R = air to air resistance

$\frac{1}{fo}$ = inside effect; due to air film

$\frac{1}{c}$ = resistance of the cavity

b' = thickness of material in metres

b'' = thickness of material in metres

k' = resistance of material

k'' = resistance of material

$\frac{1}{fi}$ = outside effect, due to air film

and for a 115 mm brick wall where

$U = 3.64 \quad fi = 8.12 \quad fo = 18.30 \quad k' = 1.15$

$$R = \frac{1}{8.12} + \frac{1}{18.90} + \frac{0.115}{1.15} = 0.276$$

$$U = \frac{1}{R} \quad \text{hence} \quad U = \frac{1}{0.276} = 3.622$$

The average transmittance $U' = \frac{(\text{Area} \times \text{individual 'U' values})}{\text{Total area}}$

Hence for house A1 the average transmittance U' was calculated:-

$$\frac{(2.69 \times 16.05) + (2.52 \times 16.05) + (40.63 \times 2.49) + 6.98 \times 112.20) + (0.6115 \times 110.8)}{294.37}$$

$$= 3.13 \text{ (W/m.deg C)}$$

Composite U values were calculated for the A2 and B houses in a similar manner. Transmittance values for the structures of the B houses are shown in Table 2a.3.

Table 2a.3

Transmittance Values (W/m.deg c) of B Type Houses

Structure	B1 House		B2 House	
	Area m^2	Transmittance 'U' W/m.deg C	Area m^2	Transmittance 'U' W/m.deg C
Gable Walls				
E Facing	16.41	2.665	16.41	1.81
W Facing	16.41	2.49	16.41	1.74
Rear Wall	45.05	2.69	45.05	2.02
Feedstance Wall	14.50	1.59	45.81	3.05
Floor	80.17	0.61	80.17	0.61
Roof	80.31	5.98	80.32	0.66
Total area	252.86		284.17	
Composite U value		3.00		1.37
Total volume (m^3)	250.52		250.52	

Heat loss from a building is a function of the heat lost by conduction through the structure plus heat lost by convection:-

where $Q = Q_c + Q_v$

Q = total heat lost

Q_c = heat lost by conduction

Q_v = heat lost by convection

now $Q_c = A \times U \times \Delta t.$ (Watts) (1)

where A = total surface area (m^2)

U = composite transmittance (W/m.deg C)

Δt = temperature difference ^oC

and $Q_v = 0.36 \times V \times N \times \Delta t$ (2)

Where $0.36 = {}^{1300}/_{3600}$ = volumetric specific heat of air (1300J/m^3 deg C)

and 3600 = conversion of hours to seconds

V = total volume of structure (m^3)

N = number of air changes per hour

Δt = temperature difference ^oC

House Cell Effects

The difference between internal and external cells (each house has 2 inner and 2 outer cells) is that the two outside cells each have one external wall. Calculations were carried out to determine the expected heat loss from the external and internal cells of the four houses. Heat lost by conduction was calculated as a function of Δt. In these calculations the within cell partitioning walls have been ignored. As will be seen if only heat loss by conduction is considered then ignoring the partitioning walls may lead to considerable error. Heat lost by conduction from inner and outer cells of the four houses is shown as a function of Δt in Table 2a.4. The calculations were carried out using the East facing gable walls as these were the most exposed.

Table 2a.4
Heat Lost by Conduction (W/m^2) from inner and outer cells

House	Cell Heat loss W/m^2 outer	inner	% increase
A1	253.12 Δt	109.95 Δt	130.2
A2	82.87 Δt	53.82 Δt	53.9
B1	212.10 Δt	168.31 Δt	26.0
B2	112.67 Δt	83.17 Δt	35.7

As can be seen, there is a considerable increase in conductive heat loss from an external compared with an internal cell. However, heat lost by conduction represents only a portion of the total heat loss, the remainder is represented by convective heat loss. Heat lost by convection is a function of the volume, number of air changes per hour and Δt. The two functions V and N are probably the same for an internal and outer cell as the shape of the two cells is the same.

Small differences in convective heat loss may occur as a result of differences in Δt. As total heat loss is the sum of conductive plus convective heat loss then the significance of the difference between internal and external cells declines as the convective term increases. Heat lost by convection increases with increasing rate of air change thus the significance of the difference between inner and outer cells declines with increasing rate of air flow. A similar effect will be shown for the significance of total insulation.

The Effect of Conductive and Convective Heat Loss

Conductive and convective heat loss was calculated as a function of Δt, the temperature difference between inside and outside and N the number of air changes per hour. Conductive and convective heat loss for the four houses together with the ratio of $Q_v : Q_c$ at different rates of air change are shown in Table 2a.5. As Δt for both conductive and convective heat loss is a constant function then the two terms are directly comparable when values of N are substituted in Q_v.

Table 2a.5

Value of Q_c and Q_v (Watts) for the Four Houses

House	Q_c (Watts)	Q_v (Watts)	Ratio $Q_v : Q_c$		
			N = 1	N = 4	N = 10
A1	$921.37\Delta t$	$106.72\ N\Delta t$	0.1	0.5	1.0
A2	$273.76\Delta t$	$106.72\ N\Delta t$	0.4	1.5	4.0
B1	$758.58\Delta t$	$90.19\ N\Delta t$	0.1	0.5	1.2
B2	$389.31\Delta t$	$90.19\ N\Delta t$	0.2	1.0	2.3

This information is shown for up to 16 air changes per hour in Fig. 2a.1. Also shown on the figure are the minimum recommended winter and summer ventilation rates for the number of calves in the building calculated from:-

Minimum recommended winter ventilation rate 34 m^3/h/calf

Minimum recommended summer ventilation rate 105 m^3/h/calf

(Mitchell 1976)

From the total volume of the houses and total number of calves viz. A1 Volume = 296.44 m^3 total number of calves = 32 ∴ recommended winter ventilation rate = $\frac{32 \times 34}{296.44}$ = 3.67 air changes per hour.

Minimum winter and summer ventilation rates are shown at points X and Y on Figure 2a.1.

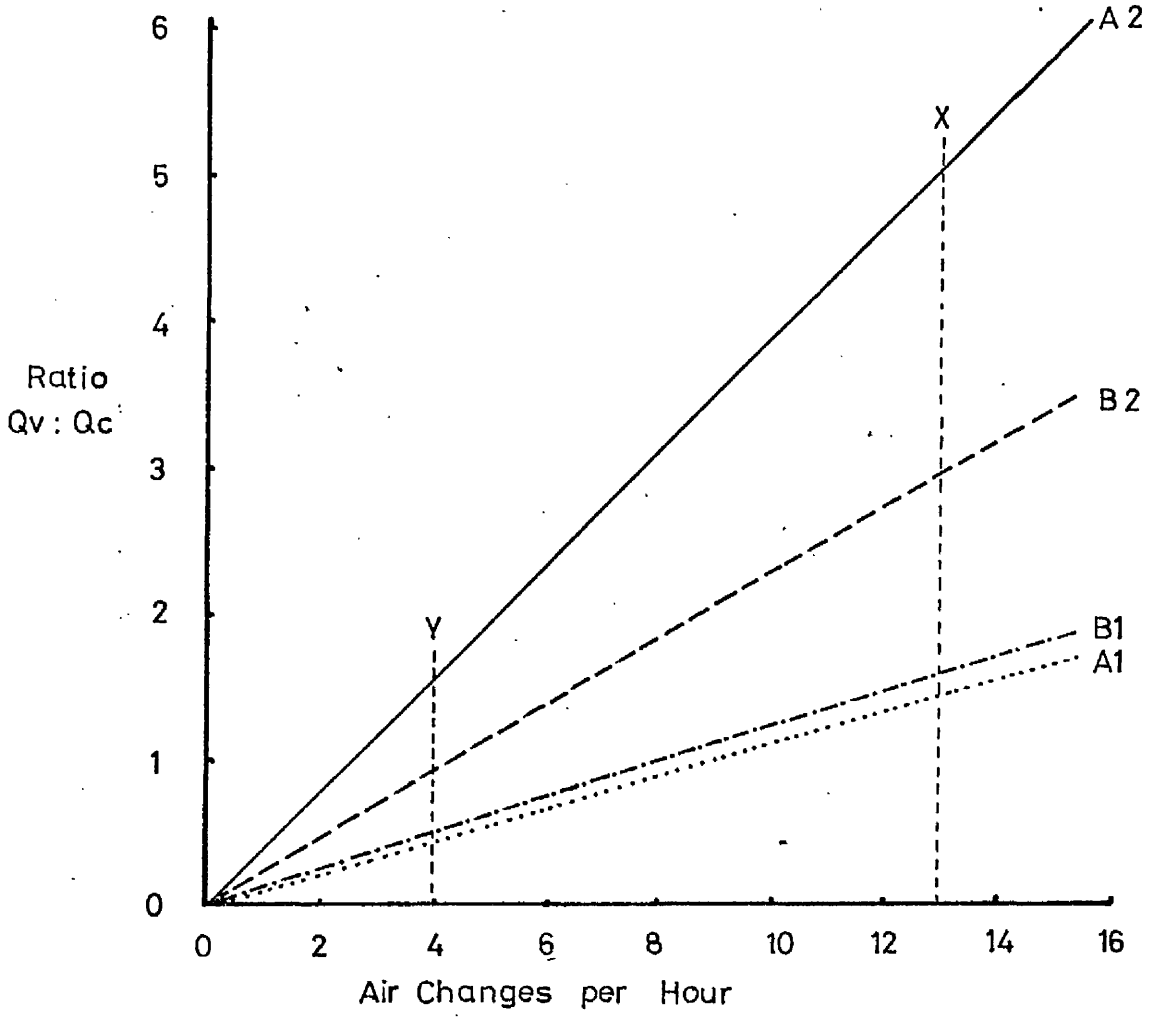
At Y heat lost by ventilation is half that lost by conduction in the A1 house and 1.5 times that lost by conduction in the A2 house. However, total heat loss from A1 is approximately twice that from A2 (1345 Δt of 697 Δt for the A1 and A2 houses respectively). At X heat lost by ventilation is 1.5 and 5 times that lost by conduction in the A1 and A2 houses respectively. At this point total heat lost from A1 is 1.4 times that lost from A2 (2299 Δt of 1651 Δt for the A1 and A2 houses respectively).

It can thus be seen that as the ventilation rate increases then the value of insulation in preventing heat loss is reduced. The relative importance of ventilative heat loss is greater in the insulated houses compared with the minimum insulated buildings shown by the slope of the lines in Fig. 2a.1. It can also be seen that as ventilation increases the difference between the houses in their ability to retain heat is reduced.

In open fronted buildings where the rate of ventilation cannot be controlled and is dependent on external air movement and wind velocity then the above discussion would suggest that the value of insulation is questionable. In the B2 house where ventilation rate is more controllable then there may be value in insulating the building.

Fig. 2a.1.

The Affect of the Rate of Air Change
on the Ratio of Qv:Qc



X Minimum summer ventilation rate

Y Minimum winter ventilation rate

CONCLUSION

CONCLUSION

The previous discussion based on a theoretical examination of the houses has suggested that ventilation rate may have an overwhelming influence on the climate within the four houses. However, assumptions have been made in the absence of information pertaining to temperature and ventilation rate which will be examined further in the present study.

2b ENVIRONMENT

INTRODUCTION

In controlled environment and climatic calf housing the external environment exerts an influence on the conditions within the house. With a controlled environment house the relationship between the internal and external environment is determined by the control measures applied whilst in climatic housing the external environment exercises a direct effect on the conditions within the house.

This particular experiment was concerned with climatic calf housing. The relationship between the environment within the house and the external environment was modified by the insulation of the house and the stocking density within the house.

It was hoped that at the conclusion of the experiment comment could be made as to the value of any particular house in aiding the survival or productive ability of the animals within the house. This would be based on a comparison of the survival or productivity of calves in one house with those in one of the other houses on the unit. However, the better performance of calves in any particular house might be attributed to the management of the calves and to the environment within the house. As two houses of each design were constructed there would be no difference in management between the minimum insulated and the additionally insulated house of one particular design. Between the two designs of housing minor differences in management necessarily occurred. It was not considered that these were of a magnitude that would in any way affect calf performance. It was thus decided to determine what differences existed between the environments in the two houses, and whether these differences gave rise to any changes in animal

performance. To do this it was necessary to monitor the internal house environment of the four houses and also to monitor the external environment in a similar manner.

The point may be made at this juncture that no replication of the calf unit site existed in any other geographical area. The conclusions drawn will refer to the Brickrow calf unit only, as it is presently sited. Assumptions may be made as to the likely performance of any one of the buildings if sited elsewhere and it is hoped comment may be made as to the effect of insulation on the environment within the house. The precise environmental recordings, however, refer only to the four buildings sited in their exact present positions and at the specific times during which recordings were taken.

Specification of the Environment

A description of the indoor environment at any one point and time was provided by measurement of:-

Air temperature (thermometer screened against radiation)

Globe temperature (thermometer affected by radiation)

Air humidity (wet bulb thermometer or dewcell)

Air movement (draughts)

Air freshness (estimate of air change rate)

The outdoor environment could be described by air temperature and humidity as already outlined, supplemented by measurements of:

Wind speed (cup anemometer)

Wind direction (vane)

Radiation intensity (solarimeter)

Rainfall and sunshine records

Some of these were available from existing local measurements.

MATERIALS AND METHODS

Measurements to be Recorded

The unit consisted of four houses each with four living compartments (cells) and a feeding area in each, plus one outside site, giving a total of 21 potential measuring sites. The environment was continuously varying, superimposed on this was a diurnal fluctuation which varied according to day length and hence the time of the year. In order to monitor these changes and the fact that no one set of environmental readings could adequately describe the daily change, hourly recording over 24 hours was considered necessary in order to describe the environment. Thus, if approximately five parameters were measured hourly at each site, 2520 measurements would be obtained per day from 105 points. It was considered that this quantity of data would pose difficulties in processing.

A compromise was therefore decided upon. It seemed reasonable to assume that if cells of the same house were treated identically as regards stocking rate and level of feeding, then humidity, air movement and air freshness at least would not vary appreciably between the four compartments of each house, and that air and globe temperatures would not vary much in this respect either.

Each house contained four cells, these were considered as two outside and two inside cells. Excluding the front, outside cells had two exterior walls and inside cells one exterior wall. Any differences in environment between cells were envisaged to occur as a result of these differences. The decision was therefore taken to fully record the environment in one inside cell. Reference recordings were made in the other three cells which could then be

compared with the reference point in the fully recorded cell. It was thus hoped to be able to correlate the environment in the three singly recorded cells with that in which total recordings had been obtained.

The positions of the thermocouples, the dewcells, globe temperature recorders and hot wire anemometers in the A and B type houses are shown in Figures 2b.1 and 2b.2 respectively. A key to the figures is given in Table 2b.1.

The object of the environmental recording was to be able to precisely quantify the macro environment which a calf experienced in any of the four houses. The environment experienced by the calf consisted of the microclimate adjacent to it, this in turn being affected by the macro climate in any particular cell. The siting of all the measuring equipment was such that it could not be damaged, or interfered with, by the animals. This fact was in direct conflict with the close proximity of the measuring devices to the animals required in order to measure the micro climate.

The instruments were therefore sited in positions which would best meet these two requirements. The thermocouples were placed above the calves, just above the reach of the animals. The positioning of the hot wire anemometer was such as to record draught at approximately calf body height. It was considered that there was unlikely to be a vertical gradation in humidity, the dewcells were therefore positioned for convenience.

Instrumentation

The instrumentation used during the trial for environmental recording was as follows:-

Table 2b.1

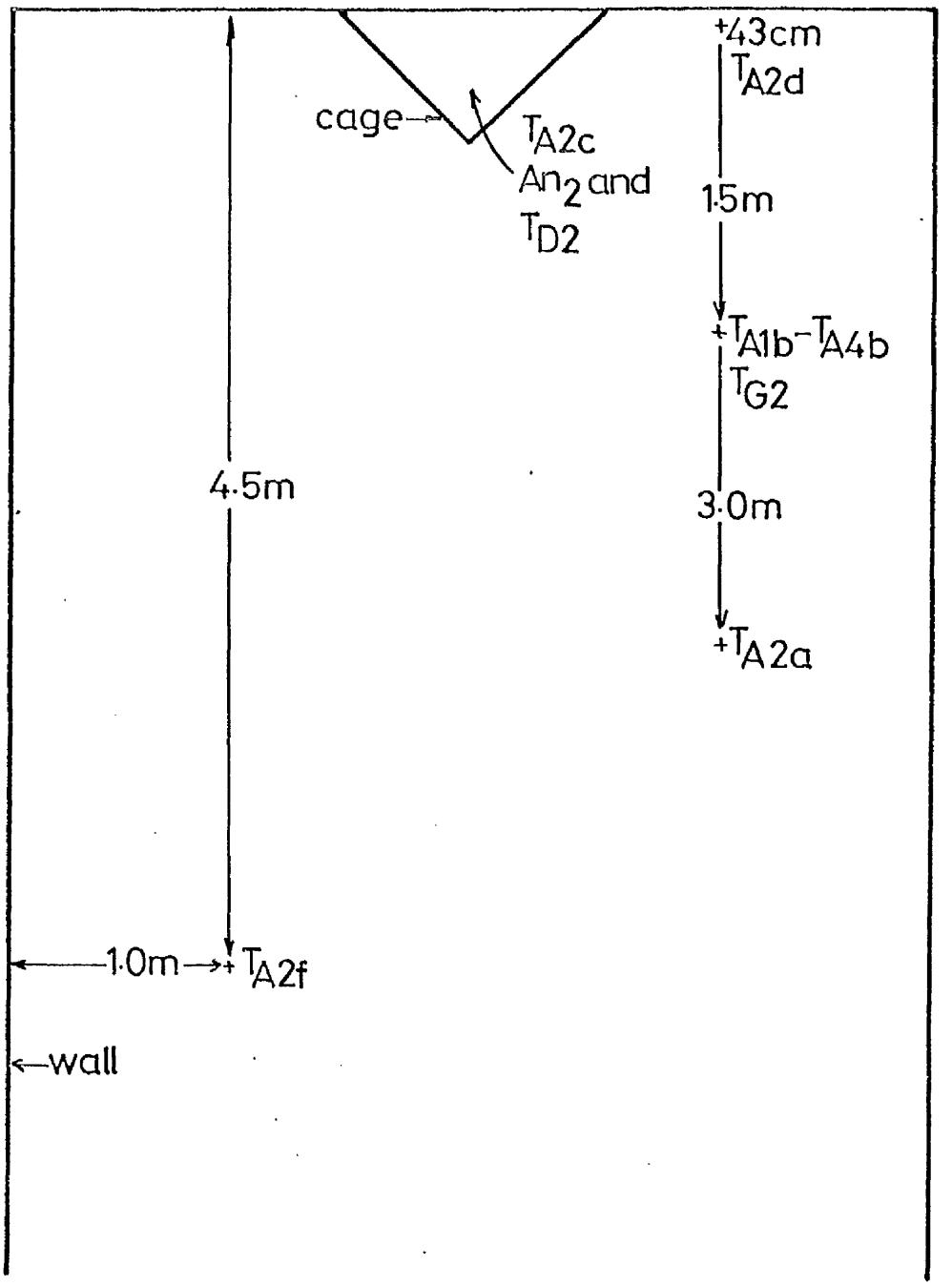
Brickrow Data Logger Channel Identification

Reference Junction/Calf House	A_1	A_2	B_1	B_2
Instrument Room temp. T_1	0	10	20	30
Compartment 1 air temp. $T_{A1\ b}$	1	11	21	31
Compartment 2 air temp. $T_{A2\ b}$	2	12	22	32
Compartment 3 air temp. $T_{A3\ b}$	3	13	23	33
Compartment 4 air temp. $T_{A4\ b}$	4	14	24	34
Compartment 2 cage air temp. $T_{A2\ c}$	5	15	25	35
Compartment 2 dewcell temp. T_{D2}	6	16	26	36
Compartment 2 globe temp. T_{G2}	7	17	27	37
Compartment 2 feeding area air temp. $T_{A2\ f}$				
Compartment 2 air movement (anemometer) An_2	9	19	29	39
Compartment 2 air temp. (extra) $T_{A2\ d}$				
Compartment 2 air temp. (extra) $T_{A2\ a}$				
Outside air temperature (Stevenson Screen) T_{OA}		43		
Outside dewcell temperature T_{OD}		44		

Wind velocity range	42	Solarimeter	45
Wind velocity measurement (V)	46*	Zero	8, 18, 28, 38, 40, 41, 48
Wind Direction (D)	47*	Anemometer set volts	49

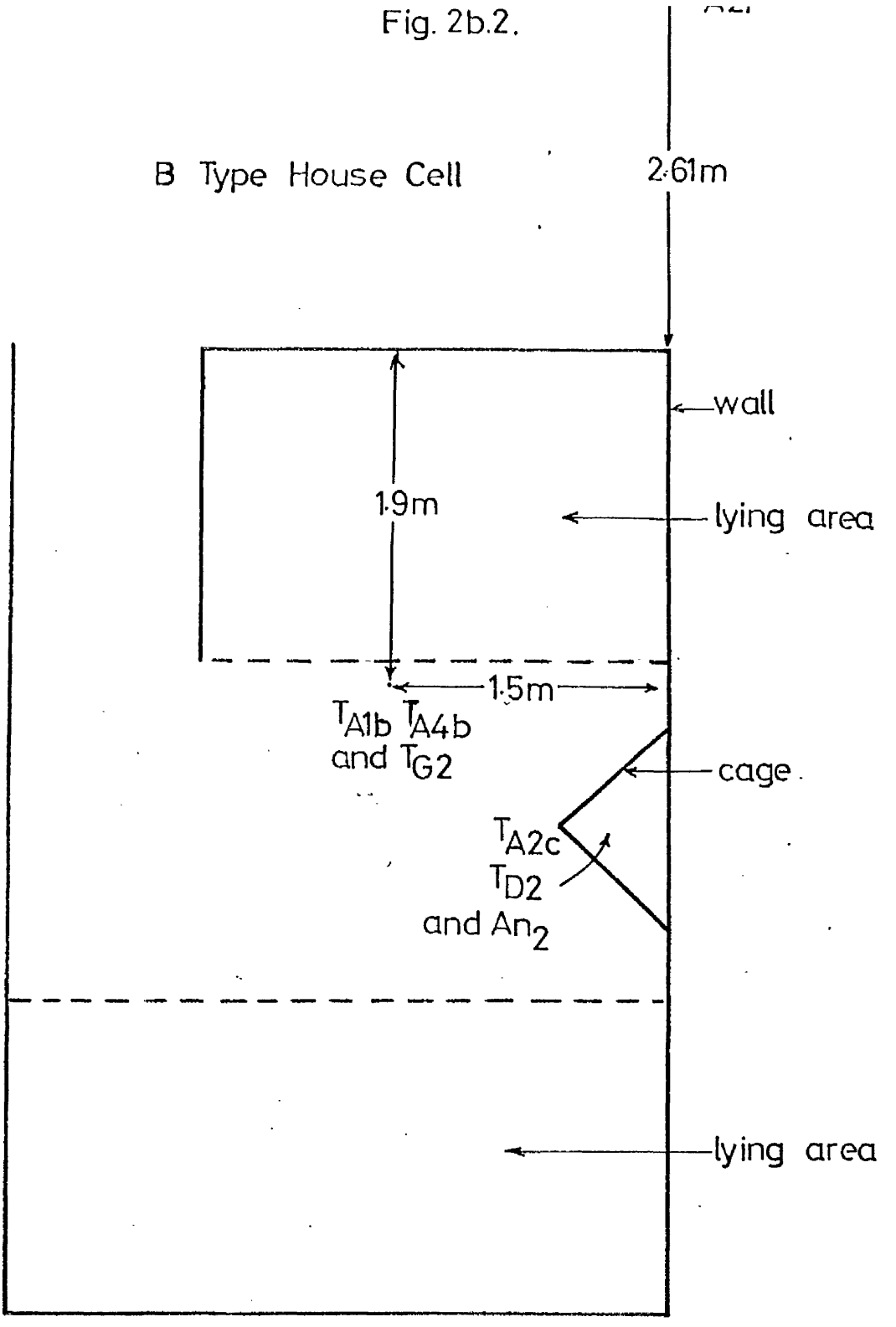
Fig. 2B.1.

A Type House Cell



Dewcells in A Houses 1·95 m above floor.
Hanging thermocouples 1·33 m above floor.
Anemometers and T_{A2c} thermocouples 80cm above floor.

Fig. 2b.2.



Dewcells in B Houses 2·15m above floor.
Hanging thermocouples 1·33 m above floor.
Anemometers and T_{A2c} thermocouples 80cm above floor.

1. Temperature Measurement (T) by copper constantan thermocouples using a cold junction thermostat, type CJ1 (Satchwell Sunvic Limited, Watling Street, Motherwell, ML1 3SA), the system calibrated against a mercury and glass thermometer.

2. Humidity by Foxboro dewcell elements (T_D) model 2711 TG. (Foxboro Yoxall Limited, Redhill, Surrey).

3. Air Movement by Tinsley anemometers (An), type 51150 (H. Tinsley and Company Limited, Werndee Hall, South Norwood, London).

Subscripts

o refers to outside conditions

h refers to conditions inside the house

(h-1) refers to the previous days inside condition

Temperature

This was regarded as the most important of the environmental factors expected to influence calf performance. The most important influence on internal temperature was external temperature which accounted for, together with a constant, at least 30% of the variance (% variance being defined as $\left[1 - \frac{\text{residual MS}}{\text{Total MS}}\right] \times 100$)

The average standard error for a prediction based on the regression was a maximum of $1^{o}C$. The inclusion of other independent variates such as wind velocity, solar radiation, calf weight and lagged values of internal temperature reduced this maximum to $\frac{1}{2}^{o}C$. The importance of internal temperature at a lag of one day varied from house to house and in general the coefficient values ran from smallest to largest in the order A1, B1, A2, B2. This would be

expected since this can be regarded as an insulation coefficient, having a damping effect on the changes in external temperature.

Mean daily internal temperatures were slightly (up to 4°C) above the external temperatures and were generally consistent between the cells of any one house. A comparison of the temperatures (°C) of different cells in each house is shown in Table 2b.2 together with the mean levels found in each house.

Table 2b.2
Comparisons of Temperature (°C) of Different Cells in Each House

Cell	1	2	3	4	2 cage	2 globe	S.E.	Mean
A1	11.64	11.63	11.05	11.08	11.38	12.07	0.07	11.52
A2	12.41	12.35	12.43	12.31	12.03	12.54	0.06	12.38
B1	11.04	10.97	10.86	10.97	10.86	11.35	0.05	10.96
B2	12.70	12.87	12.74	12.76	12.38	12.90	0.14	12.77

The figures in Table 2b.2 refer to the Spring '74 intake and in some respects these results were a typical. During this intake the differences ($T_h - T_o$) appeared to be time dependent and increased steadily during the period for which the results were analysed. The period when the calves were weaned and the straw bale protection was removed was also identified as a change in slope of ($T_h - T_o$) with time. This phenomenon was not identified in any of the subsequent periods of recordings. It was initially thought that the effect was due to the increasing heat production of the animals as they grew. During the Spring '74 intake a greater degree of protection was afforded to calves in the A type houses compared with the other three intakes by building a higher straw bale wall at the front of each house. During subsequent crops this wall was appreciably

reduced. It was thought that this greater protection may have retained a greater proportion of the heat produced. When during subsequent calf crops and upon the removal of this protection the time dependency of $(T_h - T_o)$ was removed from all four houses an alternative explanation to that of the effect being due to the heat production of the animals was sought; during subsequent crops the degree of enclosure of the B type houses was not altered. It was considered that the effect may have been due to an initial chilling of the houses when they were newly built caused by drying out of the cement and brickwork.

Analysis of Daily Mean Internal Temperatures

Two separate approaches were tried in order to define and quantify the factors that determined internal temperature in each type of house. These were multiple regression analysis and time series analysis. Although the latter method gave a fuller description of internal temperature in that the residual variation was less than for regression analysis, the latter method has been adopted in view of its simpler interpretation. Six models were examined selecting what were considered to be appropriate parameters to use as independent variables. The models used are shown in Table 2b.3.

Table 2b.3

Independent Variates Used in Regression equations with Internal Temperature as the Dependent Variate

	Variates
1	External temperature and solar radiation
2	External temperature and internal temperature at a lag of one day
3	External temperature, solar radiation and internal temperature at a lag of one day
4	External temperature, solar radiation, wind velocity internal temperature at a lag of one day
5	External temperature, solar radiation and calf weight
6	External temperature, external temperature at a lag of one day, internal temperature at a lag of one day solar radiation and calf weight

Of these, model 6 gave the closest fit but was considered unnecessarily complex. Model 2 had much to commend it for simplicity but it did not contain wind velocity which, according to model 4, had a significant effect. Of those available model 4 was the one of choice. The values and standard errors of the parameters a, b, c, d and e in the equation.

$$T_h = a + bT_o + cT_{(h-1)} + dS + eW$$

are shown in Table 2b.4. Examination of the table shows that the values of the parameters are clearly different for the houses and vary from batch to batch. The inter batch variation is fairly consistent between houses except for the radiation term 'd'. An abridged version of Table 2b.4 is shown in Table 2b.5 in which averages have been taken over all four cells and in which the two Spring and Autumn intakes have been grouped together. In view of the inconsistent behaviour of the radiation parameter a series of regressions was carried out excluding this parameter. The data expressed in this form is shown in Table 2b.6.

The coefficients of T_o and $T_{(h-1)}$ in both tables 2b.5 and 2b.6 when added together were always near unity. This indicates that the level of T_h was primarily determined according to a weighted average of these two variables. It can be seen from Table 2b.5 that the effect of T_o decreased in the order A1, B1, A2, B2 and that $T_{(h-1)}$ increased in the order A1, B1, A2, B2. Thus the effect of insulation was to reduce the importance of external temperature but to increase the value of the previous days temperature in determining the daily temperature of the house. The effect of the previous days temperature was consistently greater during the two Spring intakes compared with the Autumn crops.

The constant 'a' represents the mean amount by which T_h was greater than T_o in the absence of any wind or sunlight and may be taken to represent the trend in insulation afforded by the structure.

Table 2b.4

Estimates of Parameters of Model 4 of Table 2b.3 with Standard Errors

Parameter	House	Spring '74		Autumn '74		Spring '75		Autumn '75	
		Est.	SE	Est.	SE	Est.	SE	Est.	SE
Constant 'a'	A11	.70	.28	1.19	.13	.17	.15	1.47	.22
	A21	1.90	.28	3.23	.19	1.10	.19	2.94	.24
	B11	.33	.24	.86	.09	.099	.12	.49	.09
	B21	1.59	.33	3.69	.34	2.82	.29	2.41	.22
External Temperature 'b'	A11	.806	.045	.897	.020	.981	.024	.892	.027
	A21	.706	.043	.811	.024	.891	.029	.818	.025
	B11	.809	.039	.872	.014	.921	.019	.865	.012
	B21	.403	.041	.549	.032	.592	.033	.671	.021
Internal Temperature at a lag of 1 day 'c'	A11	.197	.036	.041	.022	.057	.022	.084	.029
	A21	.280	.036	.055	.029	.174	.026	.125	.028
	B11	.169	.034	.079	.016	.109	.018	.104	.013
	B21	.575	.038	.317	.044	.333	.037	.304	.026
Solar radiation (watts/sq m) 'd'	A11	.069	.011	.046	.007	.047	.005	-.027	.017
	A21	.049	.010	.010	.008	.033	.006	-.030	.015
	B11	.052	.009	.031	.005	.035	.004	.002	.008
	B21	.032	.012	-.015	.011	-.003	.007	-.017	.013
Wind Velocity miles/day x 10^3 'e'	A11	-2.97	.59	-1.48	.28	-1.69	.55	-4.5	1.05
	A21	-3.45	.57	-2.64	.34	-2.97	.66	-6.11	.95
	B11	-1.62	.52	-1.58	.19	-1.97	.43	-2.22	.45
	B21	-2.62	.63	-3.18	.46	-3.66	.83	-5.38	.80

Table 2b.5

Coefficients of the Equation: $T_h = a + bT_o + cT_{(h-1)} + dS + eW$

Coefficient for			T_o	$T_{(h-1)}$	Sun	Wind
House	Batch	a(°C)	b	c	d °C m²/watt	e °C day/mile
A1	Spring	.46	.882	.126	.058	$-2.83(\times 10^{-3})$
	Autumn	1.17	.882	.060	.030	-2.74
A2	Spring	1.64	.794	.202	.040	-3.24
	Autumn	2.98	.814	.090	-.005	-4.08
B1	Spring	.19	.848	.146	.042	-1.43
	Autumn	.86	.850	.099	.011	-1.99
B2	Spring	2.20	.505	.437	.022	-3.00
	Autumn	2.67	.572	.350	-.014	-3.32
S.E.		.21	.029	.029	.009	.55
Range of radiation (watts/m²) and Mean wind (miles/day) values					0 - 360 100	30 - 600 220

Table 2b.6

Coefficients of the Equation: $T_h = a + bT_o + cT_{(h-1)} + eW$

Coefficient for			T_o	$T_{(h-1)}$	Wind
House	Batch	a (°C)	b	c	e °C days/mile
A1	Spring	.76	.917	.177	$-3.16(\times 10^{-3})$
	Autumn	1.32	.874	.078	-3.00
A2	Spring	1.80	.820	.250	-3.50
	Autumn	2.90	.812	.089	-4.05
B1	Spring	.43	.876	.184	-1.84
	Autumn	.93	.848	.106	-2.09
B2	Spring	2.24	.521	.455	-3.41
	Autumn	2.62	.571	.350	-3.25
S.E.		.24	.032	.032	.60
Range of wind values					30 - 600
Mean " "		miles/day			220

Structural insulation would then increase in the order B1, A1, A2, B2. The negative coefficient 'e' is a measure of the extent to which Th was reduced by wind. It can be seen that the effect of wind in reducing Th is greater in the more insulated buildings. This is in good accord with the conclusions drawn in the examination of the interactions between building design and insulation (Section 2.a). The coefficient 'd' is a measure of the effect of radiation and although inconsistencies were found, especially during the Autumn intakes, the values of 'd' would tend to suggest an increased effect of solar radiation in the uninsulated houses. The effect of wind on internal temperature is depicted in Figs. 2b.3 and 2b.4 and it can be seen that the effect of wind tends to be greater in the insulated compared with the non insulated houses, shown by the shallower slope of the minimum insulated structures.

Daily Variations in Temperature

The daily pattern of diurnal variation over 2 days for the four house temperatures and outside temperature is shown in Fig. 2b.5. The reduced amplitude of diurnal temperature range with increasing insulation is evident. These effects were very consistent. Regressions were calculated for each batch of the daily range of temperature within each house on the range of external temperature. The mean slopes expressed in terms of daily temperature range within the house as a percentage of daily temperature range outside were 94, 87, 73 and 40% for A1, B1, A2 and B2 respectively. The value of insulation in reducing the amplitude of the internal house temperature fluctuations compared with external temperature fluctuations may be seen from these results.

Although the results presented in this manner give an accurate description of the environment they do not give any indication of

Fig. 2b.3.

Regression of $(T_h - T_o)$ on Wind Speed

Series 3 (W.S.A.C.)

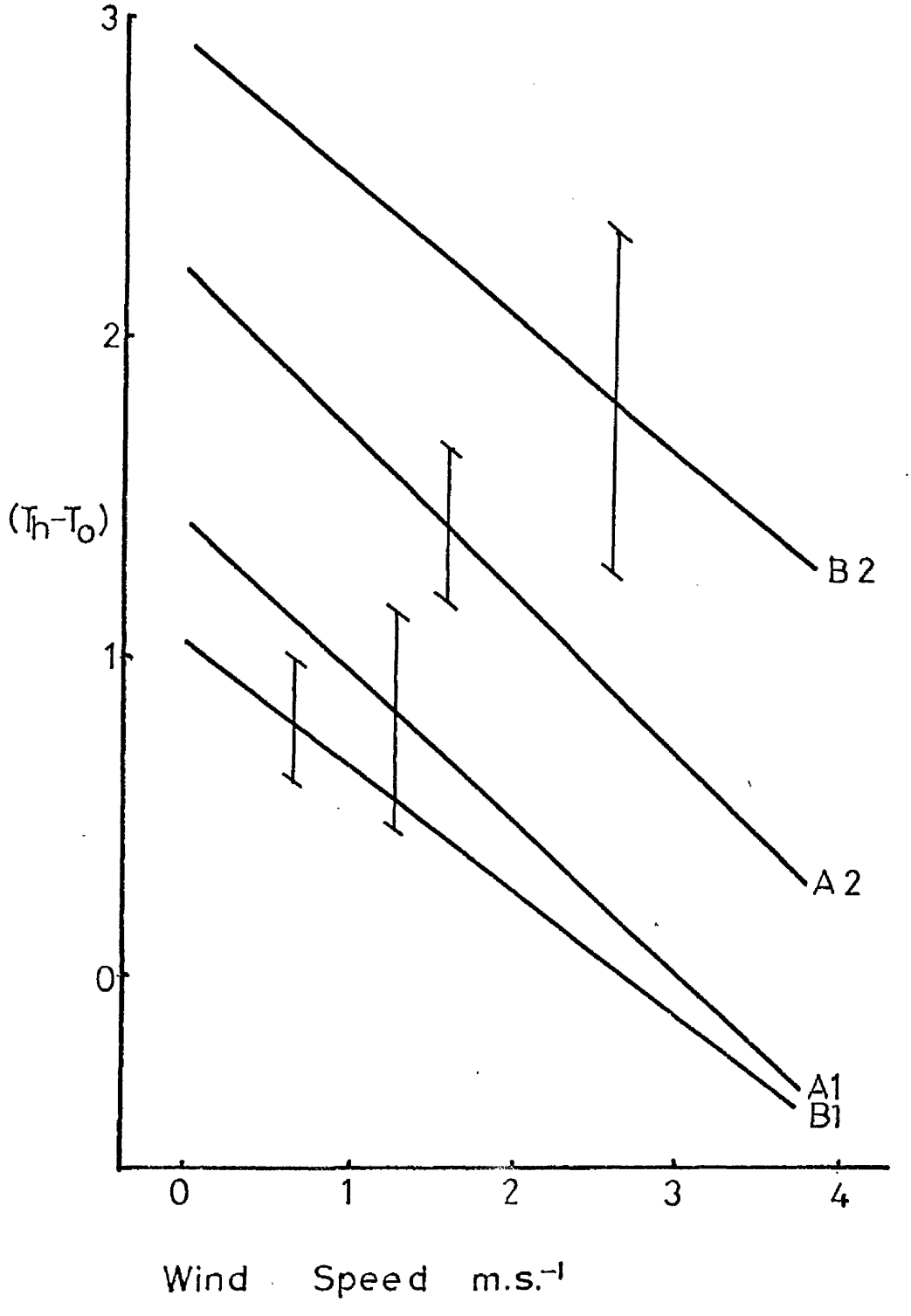


Fig.2b.4.

Regression of $(T_h - T_o)$ on Wind Speed
Series 4 (Brickrow)

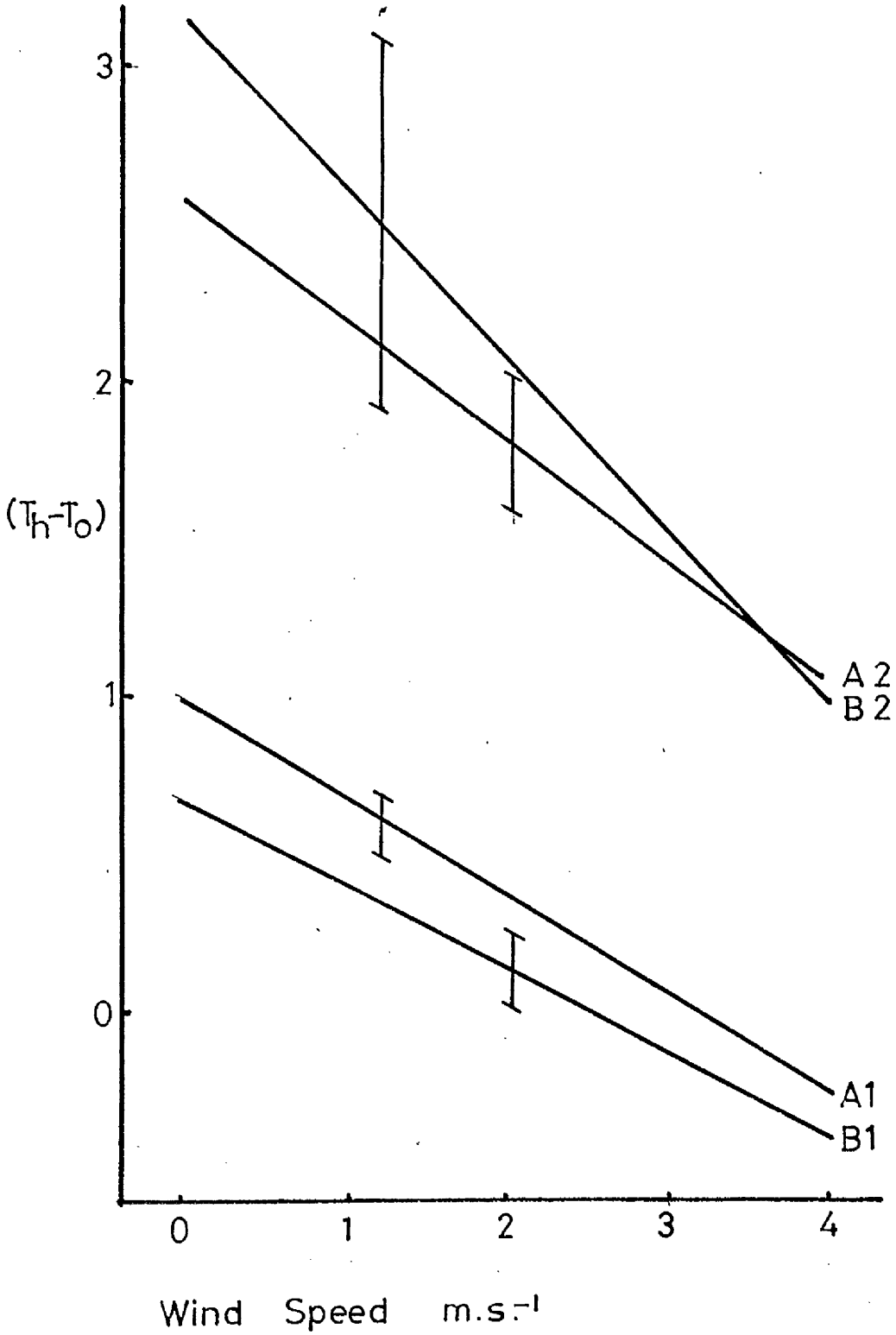
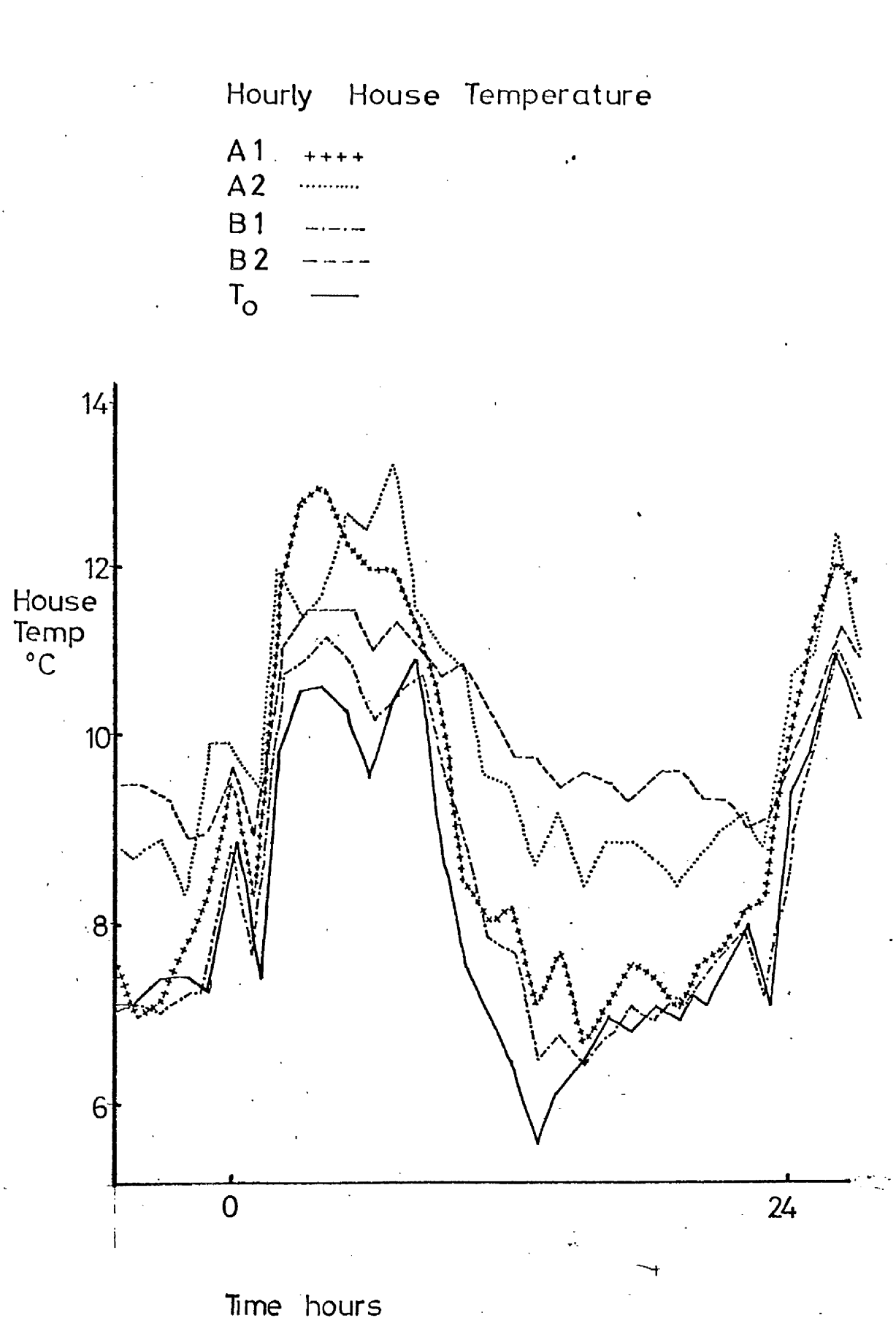


Fig. 2b.5.


Hourly House Temperature
A1 ++++
A2 .....
B1 -.-.-
B2 - - - -
T_o ——
14
12
10
8
6
House Temp °C
0
24
Time hours

their relevance in terms of animal production. It was considered that a more relevant interpretation may be achieved by examining the frequency of occurrence of temperatures below selected key levels. The key levels chosen were 10°C, which would provide a cold stress only to very young calves, 4°C, which might stress the animals at all ages covered by the present experiment and an intermediate level of 7°C. The results for three selected 10-day periods in February, September and October are shown in Table 2b.7. These results may be interpreted by examining the data pertaining to the key temperature of 4°C. Thus during September on no occasion were temperatures found which would be considered to affect calf performance. During October the A1, B1 and A2 houses were unsatisfactory 5, 6 and 12 per cent of the time respectively. During February the A1, B1, A2 and B2 houses had unsatisfactory temperatures for 54, 52, 32 and 2 per cent of the time respectively. The results would also suggest that during exceptionally cold weather when the maximum outside air temperature was 9.6°C none of the houses were able to maintain temperatures above 10°C.

Spatial Distribution of Temperatures Within Houses

This aspect of house temperature was not measured comprehensively in all houses however a more detailed examination was made in house A1 during the Spring '74 intake. No evidence of a consistent temperature gradient on a horizontal plane was found anywhere in the cells. The temperature measured at the normal location (above the animals) was usually higher than that measured in the cages (lower down and against the wall) in all houses but the difference was small and always less than 1°C. This small temperature gradient is to be expected as heat produced by the animals would tend to rise. Windy days tended to dispel the vertical temperature gradient.

Table 2b.7

Frequency of Occurrence of Sub Critical Temperatures During Selected 10-day periods in February, October and September

Key Temp °C	4				7				10				Outside Temp.		
House	A1	B1	A2	B2	A1	B1	A2	B2	A1	B1	A2	B2	Min	Max	Mean
February	54	52	32	2	86	89	84	85	100	100	100	100	-3.6	9.6	3.6
September	0	0	0	0	0	0	0	0	9	9	5	0	6.2	16.5	12.6
October	5	6	12	0	29	27	12	0	75	78	59	35	1.4	14.2	7.9

Globe Temperature

The difference between globe temperature and air temperature ($T_g - T_2$) gave a mean value of the influence of radiation from all sources. The regressions of ($T_g - T_2$) on solar radiation are shown for the Spring '75 intake in Fig. 2b.6. The observed values of ($T_g - T_2$) were small and usually within $\pm$ 0.5°C.

Humidity

Mean humidity inside each house followed an almost identical time pattern to mean humidity outside, but at a different level. Fig. 2b.7. The pattern of mean outside humidity was such that hourly fluctuations which resulted in diurnal variations of humidity were duplicated within the houses although at a different level. Wind was not shown to have any effect on internal humidity. The ranking of houses in order of increasing humidity (A1, B1, A2, B2) was consistent between the four intakes and conformed with the degree of enclosure. Internal humidity relative to outside is shown in Table 2b.8.

Table 2b.8

Humidity Inside Each House Relative to Outside Humidity ($E_h - E_o$, mm Hg)

Batch	A1	A2	B1	B2
1	.8	.95	1.5	3.0
2	.55	.65	-	1.2
3	.4	.4	.7	1.95
4	.25	.9	.6	2.0
Mean	.50	.72	.93	2.04

An inconsistency between different series in absolute humidity values may have been due to calibration errors of the different dewcells used.

Fig. 2b.6.

Regression of $(T_G - T_2)$ on Radiation

Series 3

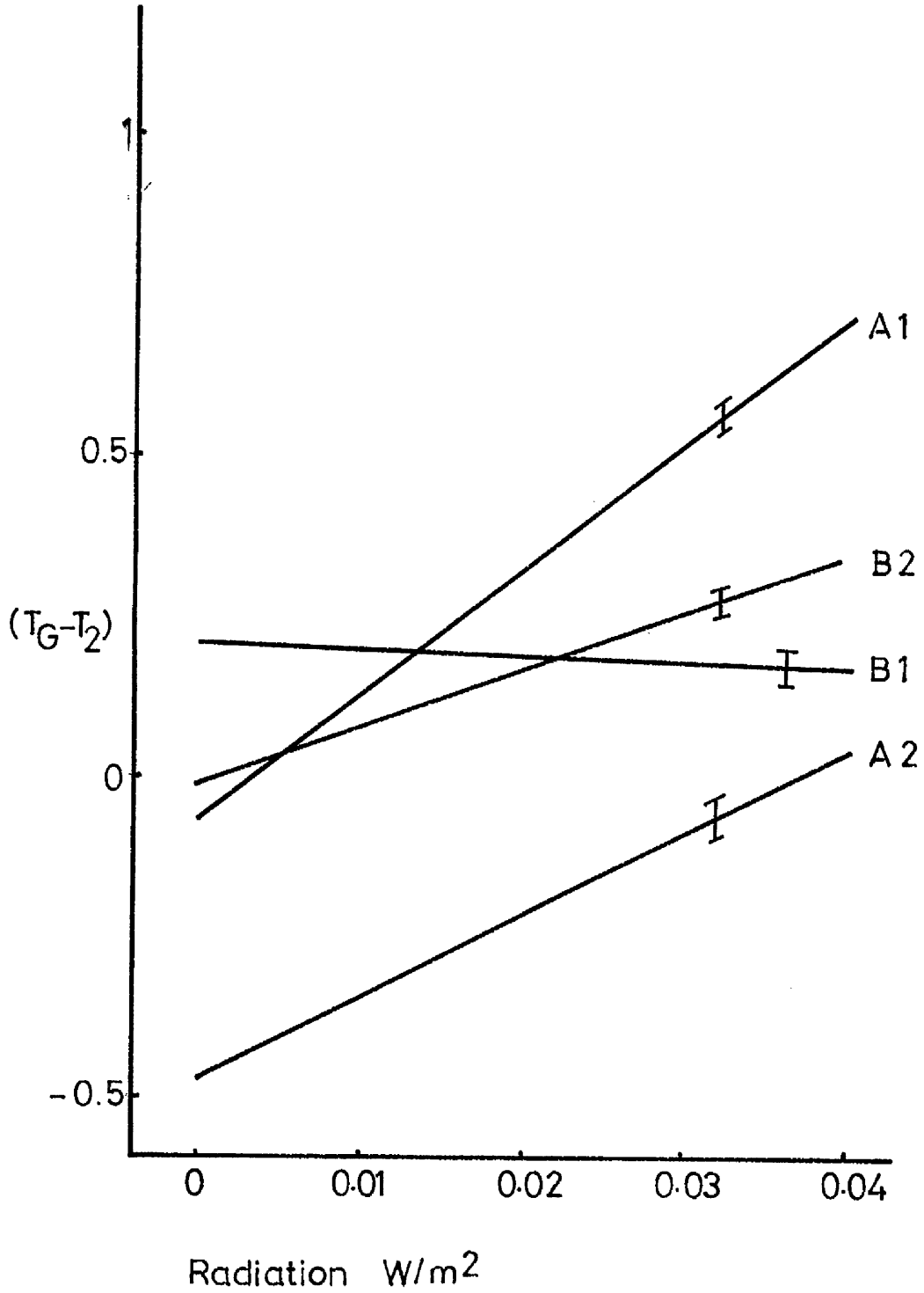
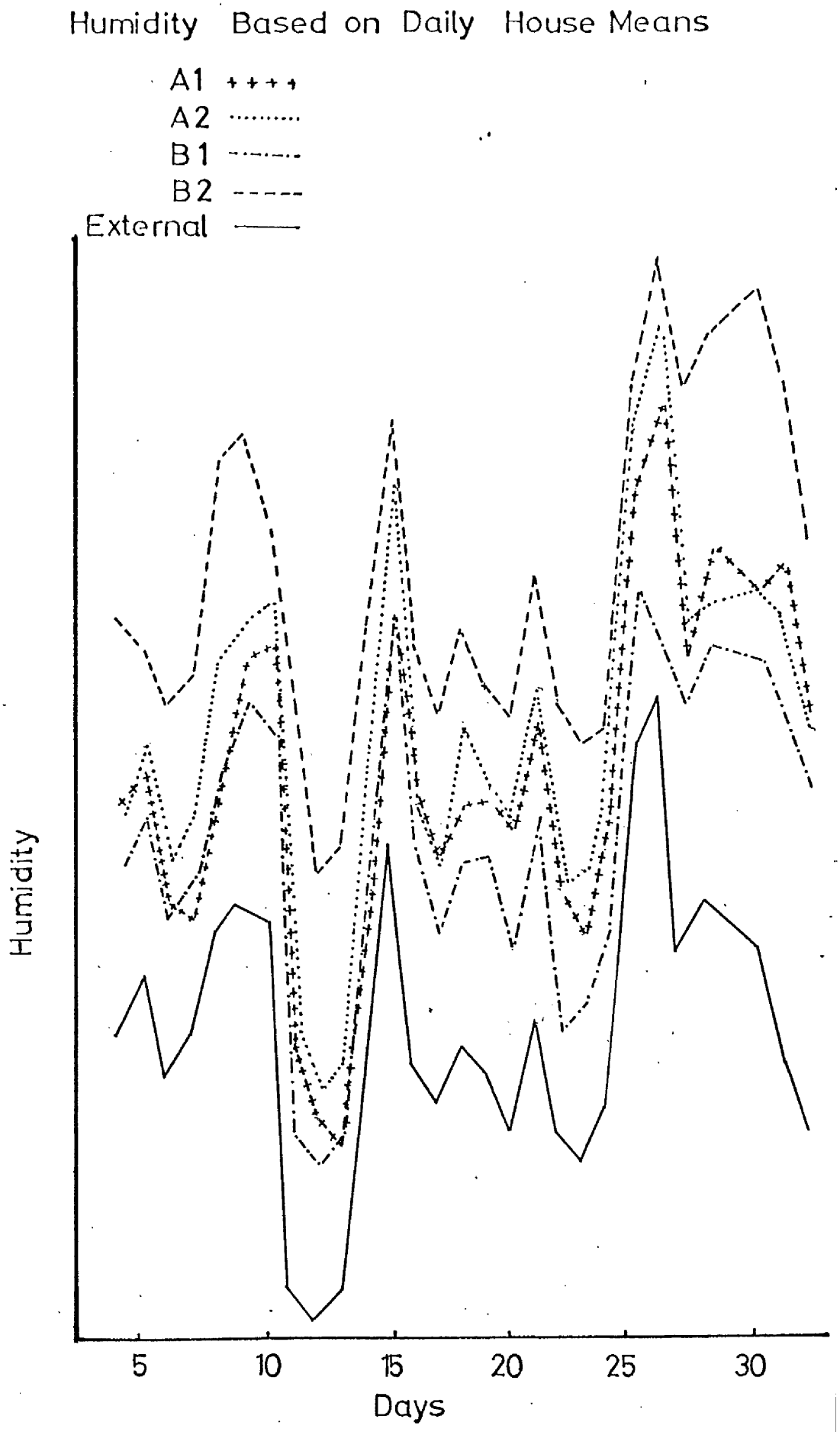


Fig.2b.7.


Humidity Based on Daily House Means
A1
A2
B1
B2
External
Humidity
5
10
15
20
25
30
Days

Air Movement

Both regression analysis of external wind speed on internal air movement and time series plots showed that air movement increased with increasing wind speed in all four houses and highest air movement occurred in the A houses, less in B1 and least in B2. The regression of air movement on wind speed data obtained at Brickrow is shown in Figure 2b.8.

Air Composition

During the weaning period the maximum measured decrement in oxygen concentration relative to outside air (20.95%) was only 0.07% and occurred in the B2 house. The maximum measured decrement in the other three houses was 0.03%. After weaning when the houses were somewhat opened up the oxygen decrement fell but gradually rose again to reach a maximum value of 0.05% in A2 and B2. It may be assumed that the oxygen decrement was equal to the carbon dioxide increment. These results would therefore suggest a negligible carbon dioxide increment in the four houses. During a further series of samplings no significant increases in the concentrations of carbon dioxide or ammonia were detected in any of the houses.

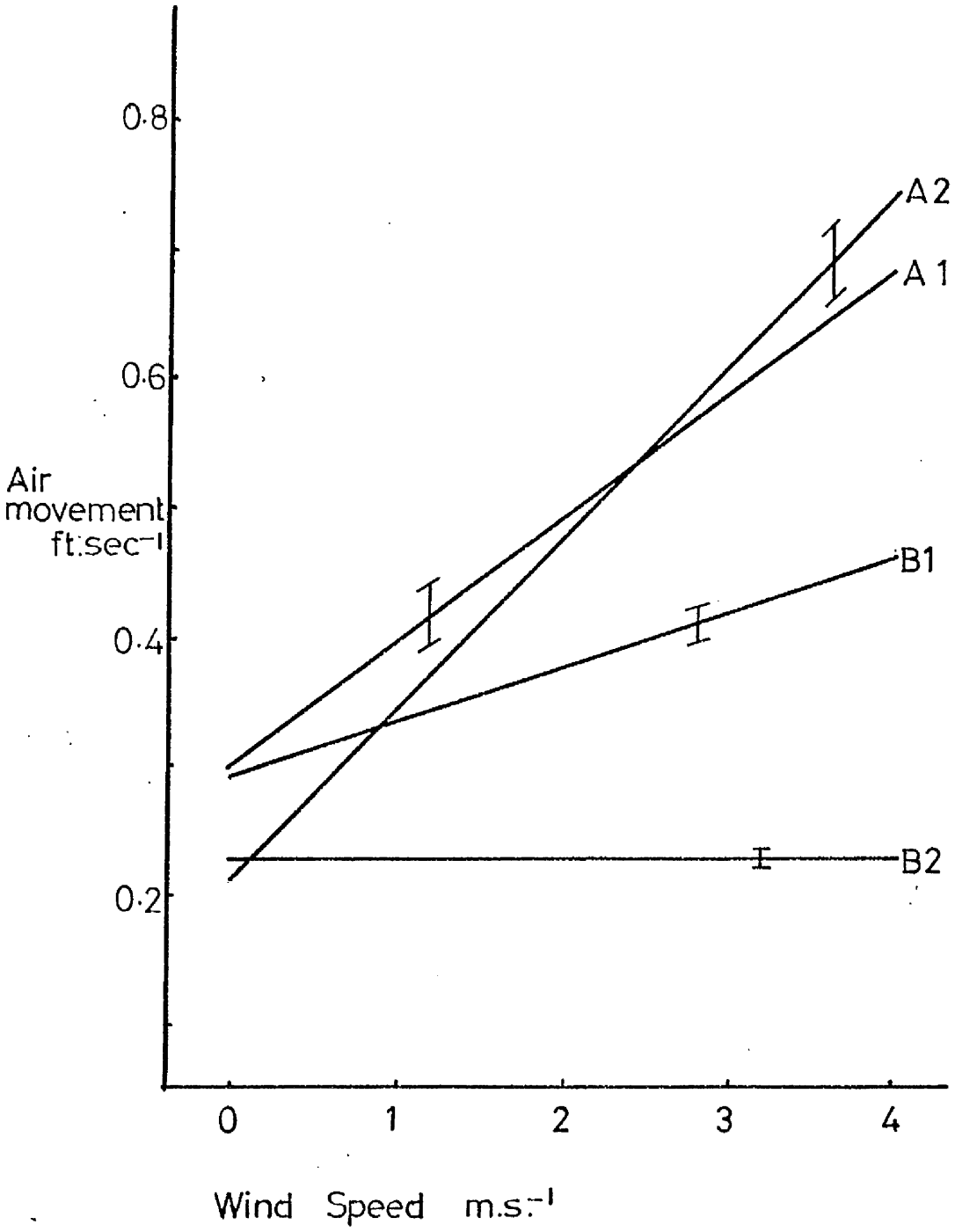
DISCUSSION

The effect of housing design and insulation on the internal environment of climatic calf housing is poorly documented. When a theoretical examination of the effect of insulation was made (Section 2a), it was postulated that if conduction of heat through the walls and roof of the building was the only form of heat loss from the buildings then there would be internal differences in temperature between the houses. This would result from the heat

Fig.2b.8.

Regression of Air Movement on Wind Speed

Series 4



produced by the housed animals, there being a greater retention of heat in the insulated building. It was also calculated by the same argument that temperature differences should exist between internal and external cells if conductive heat loss was the main source of heat loss. It was further stated that the magnitude of these temperature differences would be dependant on the ratio between conductive and convective heat loss.

The results have shown that consistent significant differences between houses were obtained in the internal measurements of temperature, relative humidity and air movement. Within each house there were small inconsistent non-significant differences between the temperatures recorded in internal and external cells. The mean temperature difference between an internal and external cell during the Spring '74 intake was 0.07°C, although on several occasions the external cells were warmer than the internal cells which is contrary to what would be expected. The constant 'a' in Table 2b.5 represents approximately the mean amount by which T_h was greater than T_o in the absence of any wind or sunlight; it showed surprisingly little difference between the houses. However, the four houses may be graded according to the degree to which T_h was greater than T_o and in this respect the order in which T_h was greater than T_o was B2>A2>A1>B1. It is also interesting to note that the value of 'a' was consistently higher for the Autumn crops than the Spring crops.

These results confirm the conclusions drawn in Section 2a suggesting that the major influence on internal temperature was the heat lost by convection and that by comparison the heat lost by conduction through the structure of the buildings was negligible.

There was only one occasion on which it appeared that the growth of the animals had any effect on internal temperature. During the

Spring '74 intake (T_h-T_o) increased in each of the four houses during the pre-weaning portion of the trial. The opening up of the four houses when the calves were weaned was identified as a drop in (T_h-T_o). Post-weaning there was again a gradual rise in (T_h-T_o) as the trial progressed and the animals grew. This result was expected from the fact that heat production is a function of the metabolic size of the animal; larger animals produce more heat than smaller animals. When the three subsequent calf intakes were examined there was no time dependancy of (T_h-T_o). Although during the latter three intakes the conditions in the A type houses were slightly different due to the lowering of the straw bale walls the management of the B1 house was identical for all four intakes. Thus if the lowering of the straw bale wall in the A houses was the reason for the absence of the time dependancy of (T_h-T_o) it was expected that the effect would still be recorded in the B1 house. As this was not the case an alternative explanation, other than the increased size of the animals producing more heat and thus raising (T_h-T_o) was sought. As was previously explained, it was considered that a gradual drying out of the new building structures may have resulted in the gradual increase in internal temperature. It is suggested that this drying process had completed by the time the second calf intake was introduced into the buildings.

Multiple regression analysis showed that internal house temperature was primarily determined according to a weighted average of T_o and T_{h-1}. The significant differences in the mean internal house temperature which were consistent between the four trials showed that the insulation of the buildings did prevent some heat loss. The effect of T_o decreased in order of increasing insulation and T_{h-1} increased in order of increasing insulation. In view of the influence

of (T_{h-1}) it is surprising that the increasing size of the animals and hence their greater heat production was not more evident. However as can be seen from Table 2b.5 the effect of T_o compared to $T_{(h-1)}$ was considerably greater in influencing the house temperature.

The overwhelming influence of T_o on internal temperature can be seen from the diurnal variation of internal temperature which closely followed the changes in external temperature Figure 2b.5. The mean slopes expressing the daily temperature range within the house as a percentage of daily temperature range outside were 94, 87, 73 and 40% for A1, B1, A2 and B2 respectively. The totally enclosed nature of the B2 appreciably reduced the internal temperature fluctuation compared with the effect of insulation in the A type housing. The reduced amplitude of the temperature variation in the insulated houses shows a two fold effect of insulation. Insulation has caused a greater retention of heat as shown by a higher minimum air temperature in the insulated houses. Thus the insulation had prevented heat leaving the building. The effect of radiant heat in raising the internal temperature is also reduced by insulation. The converse that radiation has a greater effect on internal temperature in the two uninsulated houses is shown in the coefficients of the radiation term shown in Table 2b.5. Thus insulation has had a profound effect on the heat entering the building.

The effect of wind in reducing the internal temperature was greater in the two insulated houses. This is in agreement with the conclusions drawn in Section 2a. This may be explained if Q_v in the insulated building represents a greater proportion of the total heat lost than Q_v for the uninsulated building; Q_c is higher in the uninsulated building and the total heat lost $Q = Q_c + Q_v$. It was

shown that internal air movement increased with increasing wind speed hence it may be concluded that the rates of air change increased with increasing wind speed. As Q_v is a function of the rates of air change per hour, then the house most affected by air change and hence wind speed will be that house in which Q_v represents the greater proportion of the total heat lost. It can thus be seen, as concluded in Section 2a, that as Q_v increases the temperature within the house decreases. Thus the temperature difference Δt between the internal and external faces of any structure is reduced. As Q_c is a function of Δt, then the heat lost by conduction decreases. It can thus be stated that in buildings in which convective heat loss accounts for a large proportion of the total heat lost insulation has a negligible affect on heat retention.

Humidity in the four houses was higher than external humidity. The increase in humidity above external was related to the degree of insulation and was higher in the more insulated building. There was no relationship between external wind speed and relative humidity in the houses. The very close diurnal relationship between external and internal humidity, although the latter was consistently at a higher level, demonstrates the dependence of the level of internal humidity on the humidity level of the incoming air.

An examination of the air composition in the four houses showed the highest oxygen decrement recorded, which may be considered equivalent to carbon dioxide increment occurred post-weaning when the calves weighed in excess of 100 kg live weight, and was 0.07%. This occurred in the B2 house. The highest recorded ammonia concentration, which was again recorded in the B2 house, was only 8 ppm. It is clear that excessive concentration of carbon dioxide and ammonia was never detected chemically in any of the houses.

CONCLUSION

Detailed hourly recordings of the environment within the four calf houses were made. Insulating the buildings resulted in a greater retention of heat which resulted in small significant differences in internal temperature between insulated and non-insulated buildings of the order of 1 to 2°C. The mean temperature in the warmest house was only 2.4°C above the outside mean air temperature. Insulation significantly reduced the diurnal range of temperature. In the house with the highest degree of insulation the internal temperature range was only 40% of the external range, whereas the maximum internal range in an uninsulated house was 94% of external. Insulating the houses also caused an increase in internal relative humidity.

The internal house conditions were most affected by the external environment. The size and hence the increased heat production of the animals did not affect the internal house temperature or relative humidity expressed relative to the external conditions.

Production Trials

Section 3

3a Nutritional Treatments

3b Metabolism Trial

3c Pre-weaning Trial

3d Calf Health

3e Calf Mortality

3f Post-weaning Trial

3g Conformation

3a Nutritional Treatments

INTRODUCTION

Within the objectives of the trial it was considered that there should be a parallel with present farming practice in the management of the calves. It would then be possible to demonstrate the successful, or otherwise, rearing of the calves in the four houses in terms of current farming practice.

At the extremes, two basic systems have developed for the rearing of calves for the first three to six months of life. Firstly, for veal production or for subsequent intensive systems of beef production, high level liquid diets are used. Secondly, there are systems which involve the early development of the rumen, offering a minimum quantity of liquid diet. Most other systems of artificial calf rearing are a compromise between those two basic methods. Present farming practice tends towards the latter of the two systems. However, not all calves are weaned onto dry food at the earliest opportunity of four to five weeks of age (Roy, 1976).

Three systems, (a) early weaning (b) milk feeding to 10-12 weeks (c) milk plus concentrate feeding to 10 weeks, were considered for the present trial.

(a) Early weaning with emphasis on concentrate feeding

(a) Early weaning with emphasis on concentrate feeding

It was considered that the calves should be reared on different levels of nutrition which would be achieved by feeding a range of levels of concentrates and/or milk replacer. In the early weaning system, calves are usually weaned on the basis of concentrate consumption. Concentrate dry matter consumption is depressed as the amount of milk replacer offered increases (Hodgson, 1971c). In the work of Hodgson, calves were weaned between 29 and 35 days from

arrival and between treatment differences in solid food intake, achieved as a result of offering milk replacer at between 6 and 20% of live weight, established at weaning, were maintained over the following 3 weeks, despite a five fold increase in the mean level of food intake over that period.

Leaver and Yarrow (1972) found that increasing the required concentrate consumption for weaning significantly increased the numbers of days to weaning. Also, that calves receiving 480 g/d of milk replacer took 29 days to reach a maintenance consumption of concentrates whilst calves receiving 320 g/d achieved the same consumption in 24 days, again demonstrating the reduction in concentrate consumption as a result of increased levels of milk replacer feeding.

It can thus be seen that if varying levels of milk replacer are to be used and weaning takes place when calves are consuming specified amounts of concentrates then large differences may exist in weaning time. The period, therefore, when comparisons can be made between animals on similar feeding systems is much diminished. This system does, however, entail a much reduced labour commitment. It must also be noted that early weaning results in a growth check at the time of weaning which in this instance is early on in the life of the calf.

(b) Milk replacer only feeding to 10 weeks of age

The feeding of milk replacer only to young calves has been perfected as a method for feeding veal calves. The system requires a high labour input and is usually carried out using custom built calf houses.

Labour is involved in feeding twice or three times daily and there is a much increased period of time for which calves have a greater susceptibility to disease as a result of the extended period of milk feeding (Leaver and Yarrow, 1972).

This system has the advantage that high live-weight gains may be achieved over an extended period without the check caused by weaning. Live-weight gains may also be achieved in excess of those obtained on a mixed ration in which ruminant digestion is favoured.

(c) Milk replacer and concentrate feeding to ten weeks of age.

This system incorporates the advantages derived from both the previous systems. As concentrate consumption is encouraged the time for which calves are fed milk replacer only is greatly reduced. Thus, the risk of nutritional disorders is reduced. Rumination is encouraged by the early consumption of concentrates, thus stimulating ruminant digestion. An extended period, during which live-weight gain will be increasing, may be achieved without the check caused by weaning. This latter point is important in the final analysis of the results.

All calves may be weaned at the same time, although concentrate consumption may be considerably different on the high and low levels of milk replacer. This is achieved as a result of all calves having a considerable appetite for concentrates by 10 to 12 weeks of age, thus consuming sufficient dry food for maintenance plus gain.

The system has disadvantages in that a high labour requirement will be required for milk feeding to ten weeks of age. Also between treatment live weight differences are likely to be large at weaning. Calves would require to be regrouped post weaning in order to form groups of comparable mean live weight.

As part of the aim of the present study was to examine the response of using calves, climatically housed, to different levels of nutrition the above system (c) was judged most appropriate. The use of both milk replacer and concentrate feeding would allow the manipulation of both these factors in developing different levels

of nutrition thus allowing an assessment of their relative importance. An examination was therefore made of methods and levels of milk replacer feeding which could be incorporated into the above system.

Level and Frequency of Milk Replacer Feeding

Experiments with whole milk (Owen, Plum and Harris, 1965) and with milk replacers (Burt, 1968; Randall and Swannack, 1975; Ackerman, Thomas, Theyne and Butcher, 1969) have shown little difference in the performance of calves given limited quantities of these diets either once or twice daily. The literature suggests that there is little to be gained from feeding calves twice daily compared with once daily (Randall and Swannack, 1975; Hardy, 1972). There is a suggestion however that once daily fed calves may be nutrient deprived in the period 18 to 24h post feeding (Fisher, 1972; Leibhols, 1975). As once daily milk replacer feeding is frequently used in farming practise and it would appear to place a greater stress on the young calf compared with twice daily feeding, it was therefore decided to use once daily milk replacer feeding.

The requirement for more energy for thermoregulation and consequently for maintenance under adverse environmental conditions has been noted (Blaxter, 1967; Johnson & Elliot, 1972b). It was thus considered pertinent in the present work to impose different levels of nutrition in a bid to overcome any adverse environment by the supply of higher levels of energy.

Calves on entering the unit would be given milk replacer. In order to obtain differences in level of nutrition from the earliest possible time different levels of milk replacer feeding would be required.

Current farming practise involves the offering of high fat (approximately 20% fat) milk replacer to calves. Excessive scouring,

probably associated with a decrease in pancreatic secretion has been associated with feeding milk replacers containing less than 5% fat (Roy and Stobo, 1974; Leaver and Yarrow, 1972).

A high fat experimental milk replacer was made available. The formulation and chemical analysis are shown in Table 3a.1. As can be seen, the fat level is 18%.

Table 3a.1

Milk Replacer Formulation

Milk Powders

a) Skim Milk Powder 60%. Spray dried using low heat treatment to retain a minimum non-casein nitrogen content of 19%. Pasteurised during manufacture.

b) Whey 19%; ex sweet Cheddar type, un-neutralised, pasteurised and spray dried.

Fats

a) Edible beef dripping Grade 2, 14%. Blended with liquid skim and whey, homogenised and spray dried, mean fat globule size 1.5 microns.

b) Lard 4% treated as above.

c) Emulsifier 1%. Soya bean lecithin incorporated with the fats and treated as above.

d) Other ingredients, Starch 2% progelatinised.

Supplements

Vitamins	Inclusion rate per ton of
A	60 million I.U.
D	6 million I.U.
E	20000 I.U.
B1	3g
B2	10g
Pantothenic acid	10g
Nictotinic acid	20g
B6	3g
B13	30mg
Ascorbic acid	250g

Minerals	
Mn	24.6g
fe	80.3g
Zn	22.8g
Cu	9.7g

Chemical Analysis

Moisture	3.6%
Protein (N x 6.38)	22.9%
Fat	18.3%
Starch	+ Ve
Ash	6.6%
Difference	48.6%
Metabolizable Energy	19.1 MJ/kg

Once daily fed calves may be additionally stressed by feeding cold compared with warm milk replacer (Randall and Swannack, 1975). Appleman and Owen (1975) found a greater incidence of scour in calves fed milk replacer at 3°C compared with at 33°C. It was not considered desirable to stress the calves by feeding cold milk replacer, so it was decided to offer the milk replacer warm.

As different levels of milk replacer were to be fed calves would either have to receive the same volume of liquid at different concentrations or different volumes at the same concentration. Stiles, Grieve, Butler and Willoughby (1974) concluded that the level of fluid intake was of greater importance in affecting calf scour than was dietary dry matter intake. Results of Leaver and Yarrow (1972) showed a higher incidence of scour in calves fed higher dry matter intakes (640g/day cf 320g/day). It is likely that the two factors are complementary in contributing to calf scour.

In the present experiment it was considered that feeding different volumes of a warm liquid may confer an advantage on the calves receiving the larger volume of warm liquid as these calves

would then be receiving a larger supply of heat. In order to overcome this it was decided that all calves should receive their allowance of milk replacer reconstituted in the same volume of warmed water. The heat increment of feeding would then not be affected by the volume of liquid fed.

It was not considered, at this stage, that any variation should be made in the formulation of the milk replacer. The present milk replacer provided 88.5 kJ DE/g DCP, equivalent to cows milk. Milk replacers of this form have been found not to interfere with digestion, however, increasing the energy content of the diet to 130 kJ DE/g DCP has been found to cause scour in young calves (Lodge and Lister, 1973). More suitable energy protein ratios than commonly used in liquid diets for calves may result in improved protein utilization.

Leaver and Yarrow (1972) fed calves on various levels of high and low fat milk replacers from 320 g/d to 640 g/d. In the former case, calves of between 32.5 and 49 kg received 90 and 60% respectively of the energy for maintenance from the milk replacer, the remainder being supplied by concentrates and hay. Calves were weaned at 32 days of age. Calves of 44.6 kg live weight have been reared successfully by feeding 0.34 kg of high fat milk substitute once daily, plus concentrates. In this instance the milk replacer supplied 70% of the energy required for maintenance. (Randall and Swannack, 1975). Hodgson (1971c) fed milk replacer at 76% of maintenance to calves of 43 kg live weight, together with concentrates. Thus the level of milk replacer feeding may be set below that which would be required to supply maintenance.

It was estimated that calves on the unit would be approximately 36 kg live weight on arrival with a requirement for maintenance of

7.83 MJ.DE/day (Roy 1970). Milk replacer would be required to supply the main source of energy over the first ten days until concentrate consumption became established. This level of energy may be supplied in total by 389g of milk replacer. The minimum liveweight for calves entering the unit was set at 36 kg, as the average live weight will be somewhat above this it would seem pertinent to incorporate some degree of safety in the level of milk replacer being fed. The feeding of 400g of milk replacer would supply maintenance for a 37kg calf.

Concentrate Feeding

At this point it was decided to make an examination of the concentrate intake likely to be achieved at various levels of milk replacer feeding. A commercial high palatibility calf weaning concentrate was made available, (B.O.C.M. calf wean pellets). The declared protein content was 16%.

Results of a Summer 1970 calf trial carried out at the Animal Husbandry Experimental Unit, Brickrow, were used (N.Roy, personal communication). Two systems of rearing were used in this experiment in which calves were fed milk replacer directly on arrival at the unit, or were gradually weaned onto milk replacer following an initial feeding of whole milk. The milk replacer was finally fed at two levels, namely 340 (12 ozs) and 567 (20 ozs) g/day. The concentrate consumption of calves on this trial is shown in Figure 3a.1.

The results of a second trial carried out at the Animal Husbandry Experimental Unit, Brickrow, are shown in Figure 3a.2. Milk replacer was fed to a maximum of 453g (16 oz) per day and a high digestibility calf concentrate was offered from the beginning of the first week. The concentrate intake represents the pooled results from three batches of calves reared on the same system.

Fig. 3a.1.

The Effect of Age and Level of Milk Replacer Feeding on Concentrate Consumption

Summer calf trial 1970

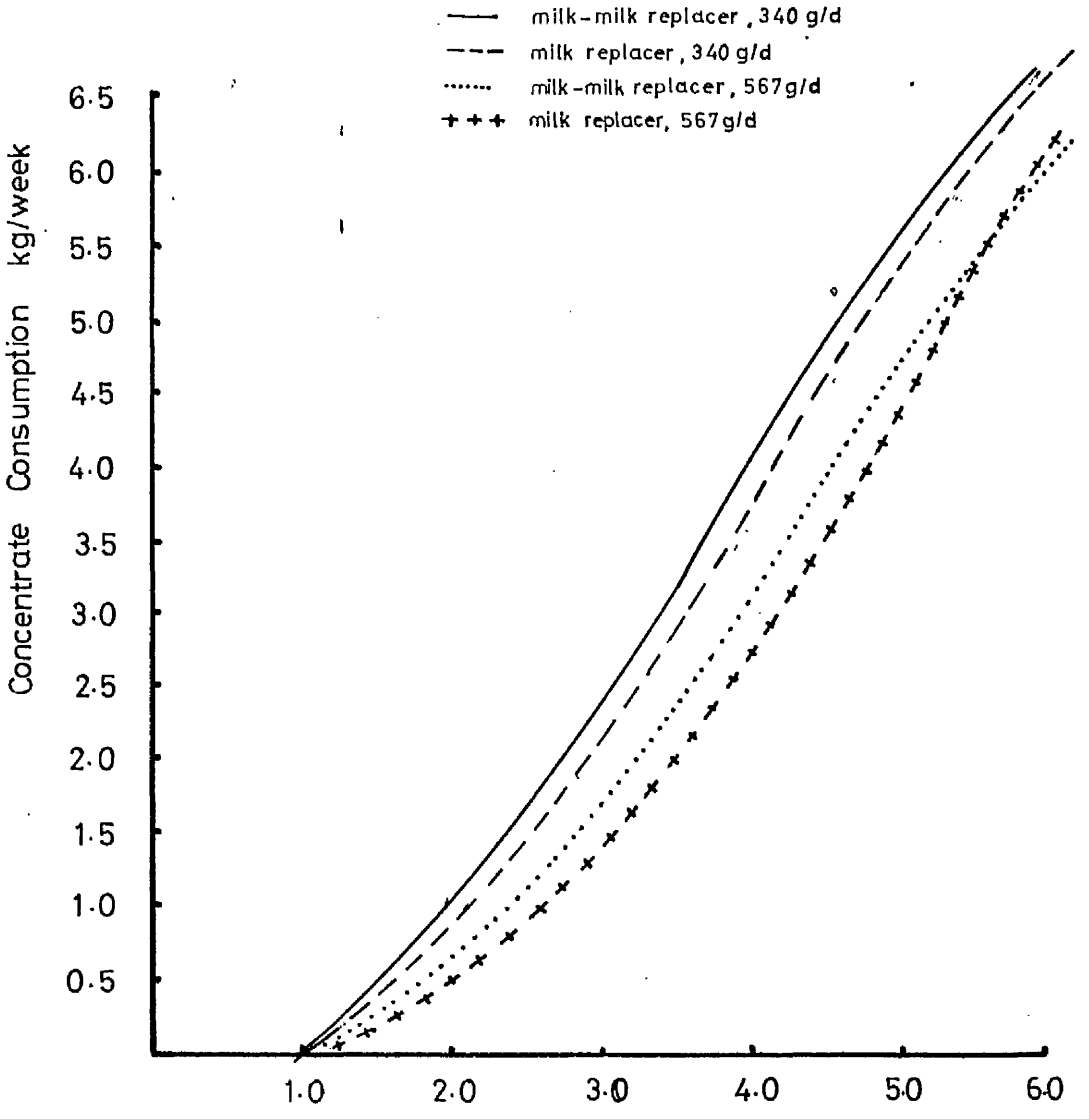
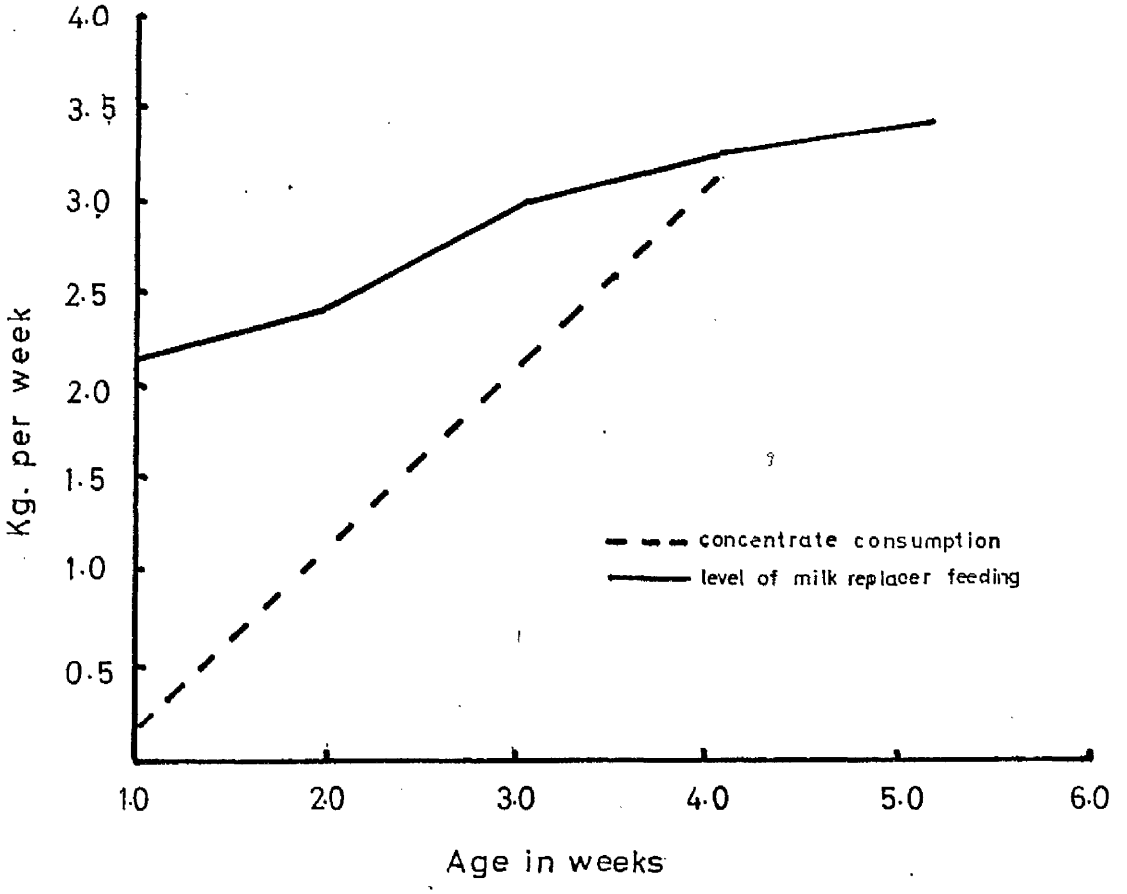


Fig. 3a.2.

The Effect of Age and Level of Milk Replacer Feeding on Concentrate Consumption

Calf trial 1973/74

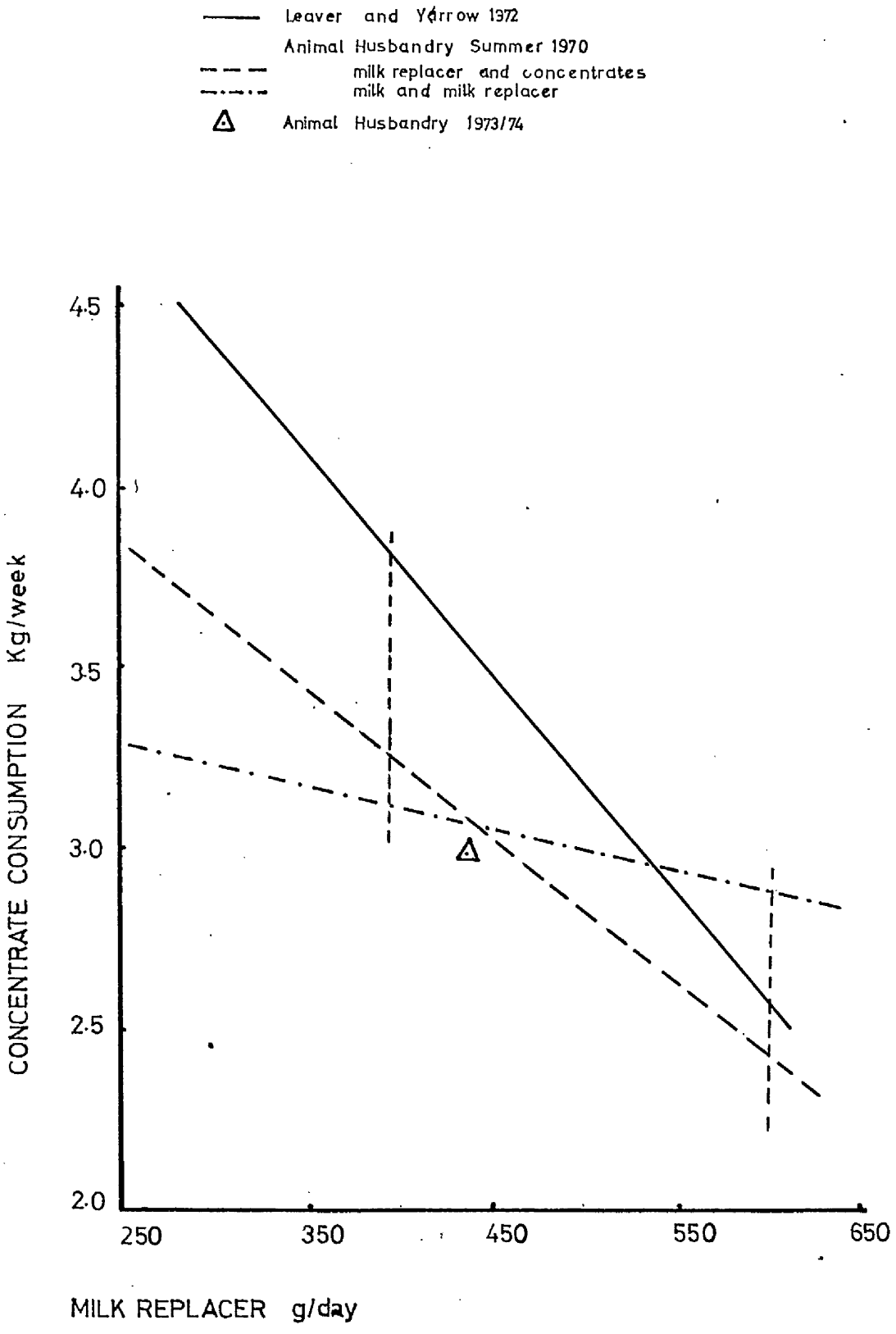


From Figures 3a.1 and 3a.2 the concentrate consumption was calculated for calves of four weeks of age being fed different levels of milk replacer. Results from Leaver and Yarrow (1972) were also used to calculate the concentrate intake of four-week-old calves being fed 320 and 480g of milk replacer per day. The information from the three different trials was then utilised to produce the graph of Figure 3a.3 showing concentrate intake at various levels of milk replacer intake in the four week-old-calf. The information was grouped according to its source and although the concentrate ration used by Leaver and Yarrow (1972) was not identical to that used at the Animal Husbandry Experimental Unit, the dry matter content of the ration was similar and it was considered that, for this purpose, it could be included. The concentrates used by Leaver and Yarrow were an unpelleted ration. This may account for the fact that at low intakes of concentrates, consumption was virtually the same in all experiments. However, at higher concentrate intakes the intake of the unpelleted ration was appreciably higher than the pelleted ration.

Calves receiving 640g of high fat milk replacer per day had significantly more scour days than calves receiving 320 or 480g of milk replacer (Leaver and Yarrow 1972). Radcliffe and White (1972) using a method whereby calves were fed a commercial milk replacer as a ten per cent suspension noted an appreciable increase in scour days and mortality in calves fed 70% more than those fed at the standard rate. The standard rates of feeding used for calves of less than 27 kg, between 27 and 34 kg and between 34 and 41 kg live weight were 280, 342 and 542g of milk replacer respectively, provided in two feeds per day. The same age ranges received, on the high level of feeding, 476, 581, 921g of milk replacer respectively in two feeds per day.

Fig. 3a.3.

Milk Replacer vs Concentrate Intake at four weeks of age



In order to achieve a difference in the levels of nutrition being received by the calves as early as possible it would be necessary to feed different levels of milk replacer. Differences in level of nutrition as a result of concentrate feeding could only be achieved later on when concentrate consumption was established.

Diet Formulation

From Figure 3a.3 and also from consideration of the number of grammes of milk replacer required to be fed per day to supply maintenance for a 36 kg calf (389g of milk replacer), 400g per day was suggested as the low level of milk replacer feeding. From Figure 3a.3 it was evident that to obtain a difference in appetite for concentrates other calves would need to be fed in excess of 540g of milk replacer per day. By feeding 600 grams of milk replacer per day, a significant difference could be achieved in concentrate intake at four weeks of age, thus allowing greater freedom in the choice of concentrate restriction. It was also felt that feeding 600g of milk replacer per day was the maximum which could safely be fed at one feed without incurring an excessive amount of scour. This level of feeding would allow as wide a comparison as possible between levels of milk replacer offered.

The levels of four hundred and six hundred grammes of milk replacer were accepted as being suitable for the trial. An examination was then made to predict the likely live weight gain of calves fed these levels of milk replacer and offered concentrates ad libitum. An examination was also made of the means whereby concentrate consumption could be restricted to impose a further difference in nutritional level later on in the trial.

The calculations of expected live-weight gain are given in Appendix 2.

First Approach. From the calculations made four treatments were envisaged:-

T1 = 600g milk replacer per day + concs ad libitum
T2 = 400g milk replacer per day + concs ad libitum
T3 = 400g milk replacer + restricted concs.
T4 = 600g milk replacer + restricted concs.

The levels of restriction able to be imposed were examined, initially at a level which would reduce the live-weight gain of the calves by about 0.25 kg/day. As calves receiving the low level of milk replacer would have the largest appetite for concentrates, it was considered that any concentrate restriction should be based on the consumption of these calves. The expected live weight gains of a 40 kg calf on the four treatments were:-

T1 = M + 0.48 kg/day
T2 = M + 0.23 kg/day
T3 = 0.99 x maintenance
T4 = M + 0.31 kg/day

It can be seen that three distinct levels of nutrition might be achieved, although the restriction of 0.25 kg of gain per day would seem to be an arbitrary figure. A second approach was examined.

Second Approach. The two levels of milk replacer considered, namely 600 and 400g/day supply:-

(600 x 0.95) x (21 x 0.98) kJ ME = 11.730 MJ.ME
(400 x 0.95) x (21 x 0.98) kJ ME = 7.820 MJ.ME

A difference of 3.91 MJ.ME exists between the two treatments. This represents an equivalent ME intake in terms of concentrate dry matter of:-

$\frac{3.91}{0.0114}$ = 343g of concentrates (concentrates = 11.4 MJ.ME/kg)

Calculations were again carried out to examine the likely live weight gains using a concentrate restriction of 343g of concentrates per day.

The calculations are shown in Appendix 2. From the calculations the treatments would be:-

Treatment 1 - a high high treatment, namely high milk replacer at 600g/day plus concentrates ad libitum

Treatment 2 - a low high treatment, low milk replacer at 400g/day plus concentrates ad libitum

Treatment 3 - a low low treatment, low milk replacer at 400g/day plus concentrates restricted by 343g/day

Treatment 4 - a high low treatment, high milk replacer at 600g/day plus concentrates restricted by 343g/day

Henceforth, the treatments will be represented by the initial letter of the treatment level, viz:-

T1	HH	High High
T2	LH	Low High
T3	LL	Low Low
T4	HL	High Low

From the calculations already carried out it can be seen that in terms of metabolizable energy, treatments 2 and 4, LH and HL, supply the same amount of energy but from different parts of the diet.

The expected live weight gains of a 40 kg calf on the four treatments were:-

T1,	HH	M + 0.48 kg/day
T2,	LH	M + 0.23 kg/day
T3,	LL	maintenance + 0.02 kg/day
T4,	HL	M + 0.33 kg/day

The difference in live weight gain between treatments 2 and 4 is a result of the difference in utilisation of the metabolizable energy for gain from concentrates and milk replacer, the latter being used with a higher efficiency for conversion to live-weight gain.

Summary

The requirements to be satisfied by the nutritional treatments may be summarised:-

a) As wide a difference between treatments as was considered practicable to allow the responses to different nutritional treatments and any environmental x nutrition interactions to be measured.

b) An extended period of uniform live-weight gain.

c) Some parallel with farming practise.

The adoption of a once daily milk replacer feeding system from which the calves are weaned at approximately ten weeks of age satisfies the latter two criteria. In order to satisfy criterion (a) the treatments should not be detrimental to the health of the calf. For this reason 600g/day was considered the maximum quantity of milk replacer which could be offered. Although T3 would incur feeding calves very close to maintenance, it was considered that this could be overcome by initially allowing some degree of concentrate consumption to supply maintenance. Differences in the level of nutrition would, however, be achieved immediately by the levels of milk replacer feeding. The level of concentrate restriction may then be gradually phased into the feeding treatments as the consumption of the LH reference calves increased. There should thus be no necessity to rear calves on a below maintenance ration.

The adoption of Approach 2 has an additional advantage in that it allows a comparison of the utilization of the metabolizable energy of the ration when it is supplied by different levels of milk replacer and concentrates.

The system to be adopted is in summary form:-

a) Once daily feeding of equal volumes of warm milk replacer.

b) Two levels of high fat milk replacer feeding (400 and 600g/day)

c) Concentrates to be offered ad libitum and restricted. The restricted calves to receive 343g of concentrates less than the controls.

d) All calves to be weaned at ten weeks of age.

Production Trials

Section 3b

Metabolism Trial

INTRODUCTION

The experiment carried out at the Animal Husbandry Experimental Unit, Brickrow, was a trial to examine the effects of different types of calf housing and different levels of nutrition on calf production. A review of the literature did not yield sufficient information to enable energy values to be accurately assigned to the milk replacer and concentrates as fed in the experiment.

It was decided to undertake a metabolism trial, in a manner which would closely represent the feeding in the main trial, in order to assess the metabolizable energy values of the milk replacer and concentrates as fed. It was considered that as hay feeding was kept to a minimum during the trial, then the value of the metabolizable energy of the hay could be estimated with sufficient accuracy from the literature; any deviation of this value from the actual value would be of little significance when the total hay consumption was considered. The contribution of the hay in the ration fed to the calves on the main trial is shown as MJ.ME consumed over the total trial period, Table 3b.1. For the purpose of this table energy values of 19.31, 12.5 and 6.28 MJ/ME kg obtained from the literature were assigned to the milk replacer, concentrates and hay respectively.

Table 3b.1

Total Energy Consumed (MJ.ME) from Milk Replacer Concentrates and Hay by Calves During the Four Trials

Ration	Spring'74	Autumn'74	Spring'75	Autumn'75
milk replacer	591	487	640	482
concentrates	577	528	629	524
hay	36	37	40	77
hay as % of milk + concentrates	3.1	3.6	3.2	7.6

It was realised that methane losses could not be measured during the trial, however, the expected loss of energy in the form of combustible gas in calves fed only milk was expected to be very small. (Blaxter, 1962). Very small methane losses, of the order of 0 - 0.2% of the gross energy were found in rapidly growing veal calves fed only milk replacer, (Van Es, Nijkamp, Van Weerden and Van Hellemond, 1969). For heifers older than five months, methane losses were stable and averaged 8 to 10% of the energy of the digested nutrients, equivalent to 2.8 to 7% of the gross energy of the diet (Demchenko, 1969).

The digestibility of the dry matter of milk is about 95% (Roy 1976). It is considered that there would be little fermentation loss and hence it was decided to consider the energy lost as methane from the milk replacer as nil. However, during the latter stages of the trial, this may not be the case. There is a lack of information on methane production from 12 week old milk replacer fed calves so the course taken was considered the most appropriate.

A value of 2.8% of the gross energy of the concentrates has been adopted as a value for the energy lost as methane production over the second period of the trial. This is the value obtained in 2 month old heifers of 85 kg live weight (Demchenko, 1969).

Feedstuffs express their characteristic metabolizable energy values only as components of nutritively complete rations (Forbes, 1933). Thus it was considered that the milk replacer and concentrate rations would exhibit their characteristic metabolizable energy values when fed as a mixed ration during the trial.

The rations fed during the main trial were all of high nutritive value (digestibility 85%). The minimal depression of digestibility on increasing feeding level from maintenance to 2 x maintenance occurs when rations of roughage with a digestibility of 85% are fed and is then less than 1 kJ/100 kJ. food energy.

Depression in digestibility = 0.119 (100 - digestibility at maintenance). Hence the level of feeding will not have any significant effect on the characteristic metabolizable energy values as displayed by the constituents of the ration (Blaxter, 1961). It was therefore considered valid to apply the feeding values obtained during the metabolism trial to the production trial.

MATERIAL AND METHODS

Metabolism Trial Apparatus

Metabolism Crate. Following the decision to undertake the metabolism trial various methods of faecal and urine collection were considered. The minimum intake of food in the first period of the trial would be 300g of milk replacer per day. The apparent digestibility and dry matter of the milk replacer would be expected to be in the region of 94% and 96.4% respectively (Roy, 1976). Thus a calf consuming 300g of milk replacer would be expected to excrete approximately 17g DM per day. Thus it was decided as a result of the small daily dry matter collection envisaged that the method of collection should not allow any loss or cross contamination of the faeces and urine.

A method whereby faeces and urine were collected separately beneath the animal was considered. As only bull calves would be used this method was considered feasible. It was, however, rejected on the grounds that the allowed movement, front to back, would have needed to be so small, due to the short horizontal distance between the prepuce and anus of the young calf that it would have caused unnecessary discomfort to the calf.

It was also decided that, as a result of the expected low dry matter excretion during the first trial period, the receptacle for

the collection would need to be as light as possible, it being preferred to collect and store faeces in the same bag. Any error therefore in the weight of each receptacle would not appreciably interfere with the weight of faeces.

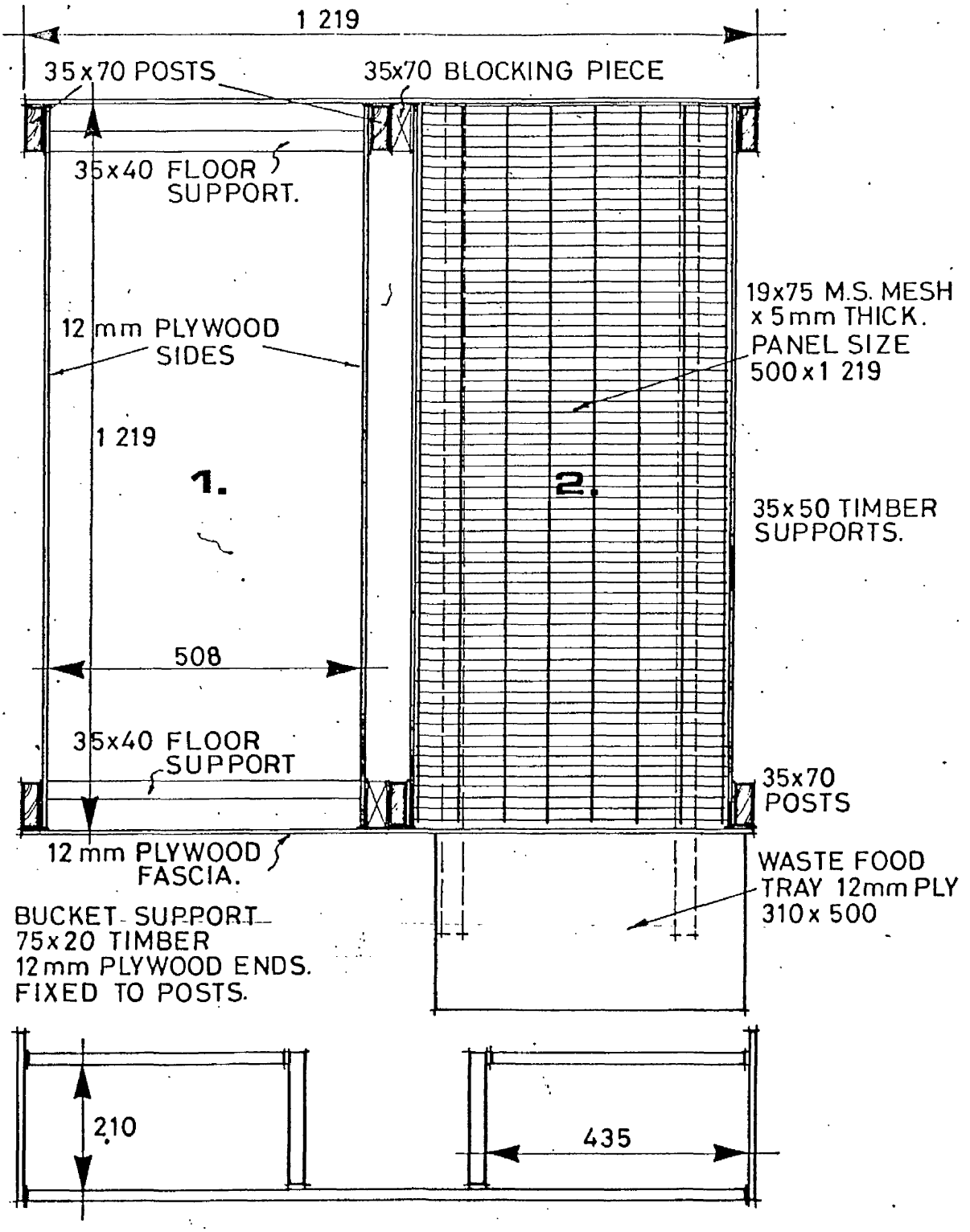
Following this examination of the possible alternatives it was considered that the most appropriate solution would incorporate faecal collection via a light bag attached to the animal and urine collection either via a harness attached to and covering the prepuce or via collection through the floor of the crate.

As the young calf spends a larger percentage of its time lying compared with the adult ruminant then any facet of the trial which interfered with this behavioural trait, could affect the results obtained. It was decided that the minimum amount of harness and apparatus should be attached to the calf in order to allow it to lie in comfort and hence it was judged best to collect the urine through the floor of the crate and not by a further harness. The confinement of the calf would need to be such that it was unable to interfere with the dung collection apparatus. It was decided that the total floor area of the crate could be used for urine collection, thus allowing maximum lateral movement for the calf.

Several existing calf crates were available (WSAC Farm Buildings Dept. Calf Housing 300) and these were modified to produce the metabolism crate as shown, Figures 3b.1, 3b.2 and 3b.3.

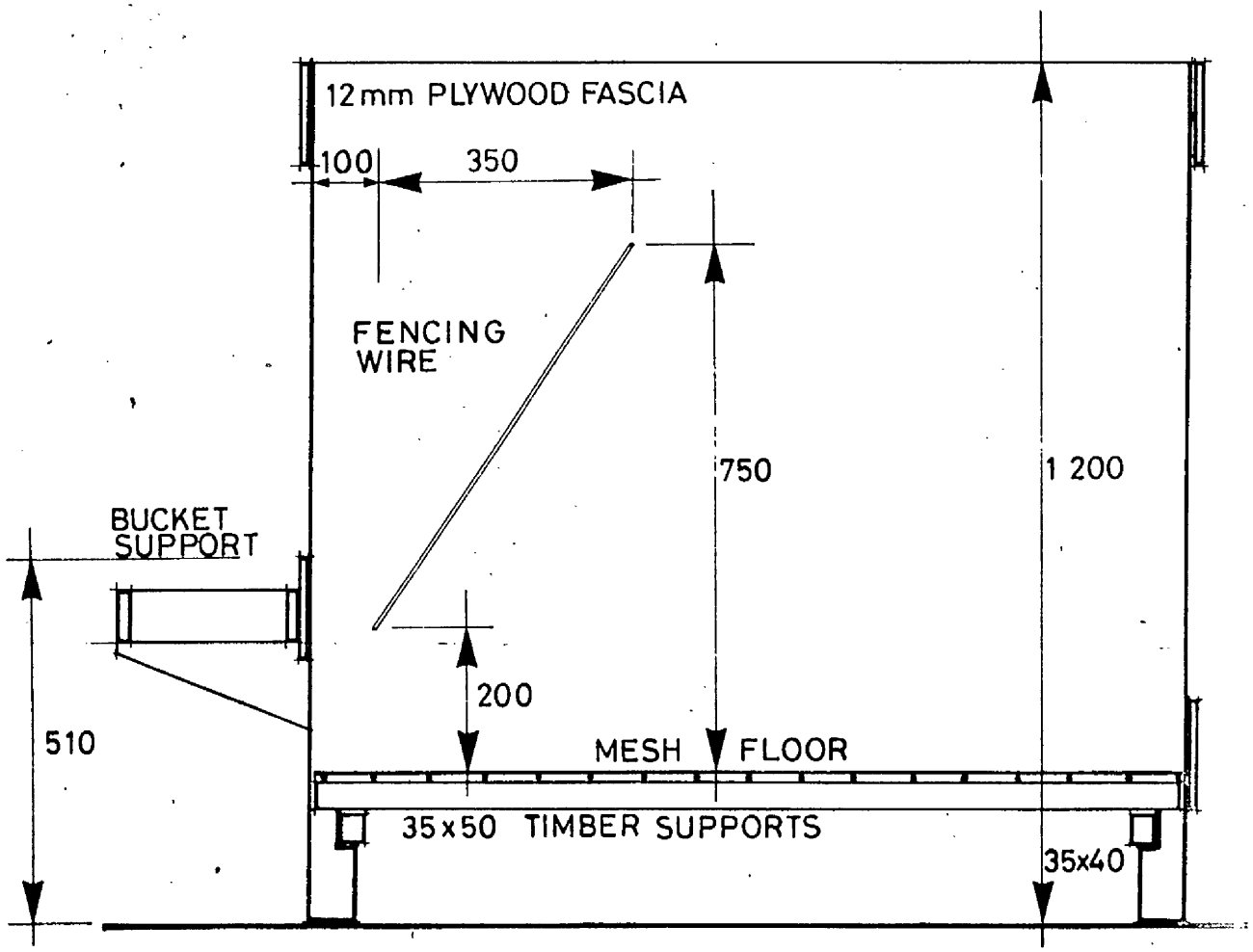
It was decided to use as open a front as possible so that each calf could see its companions. Webster (1976) has commented that social environment may effect calf performance. The calves were tethered by way of a leather collar, attached by a swivel link and shackel, via chain to two runners, one on each side of the crate.

Fig. 3b.1.



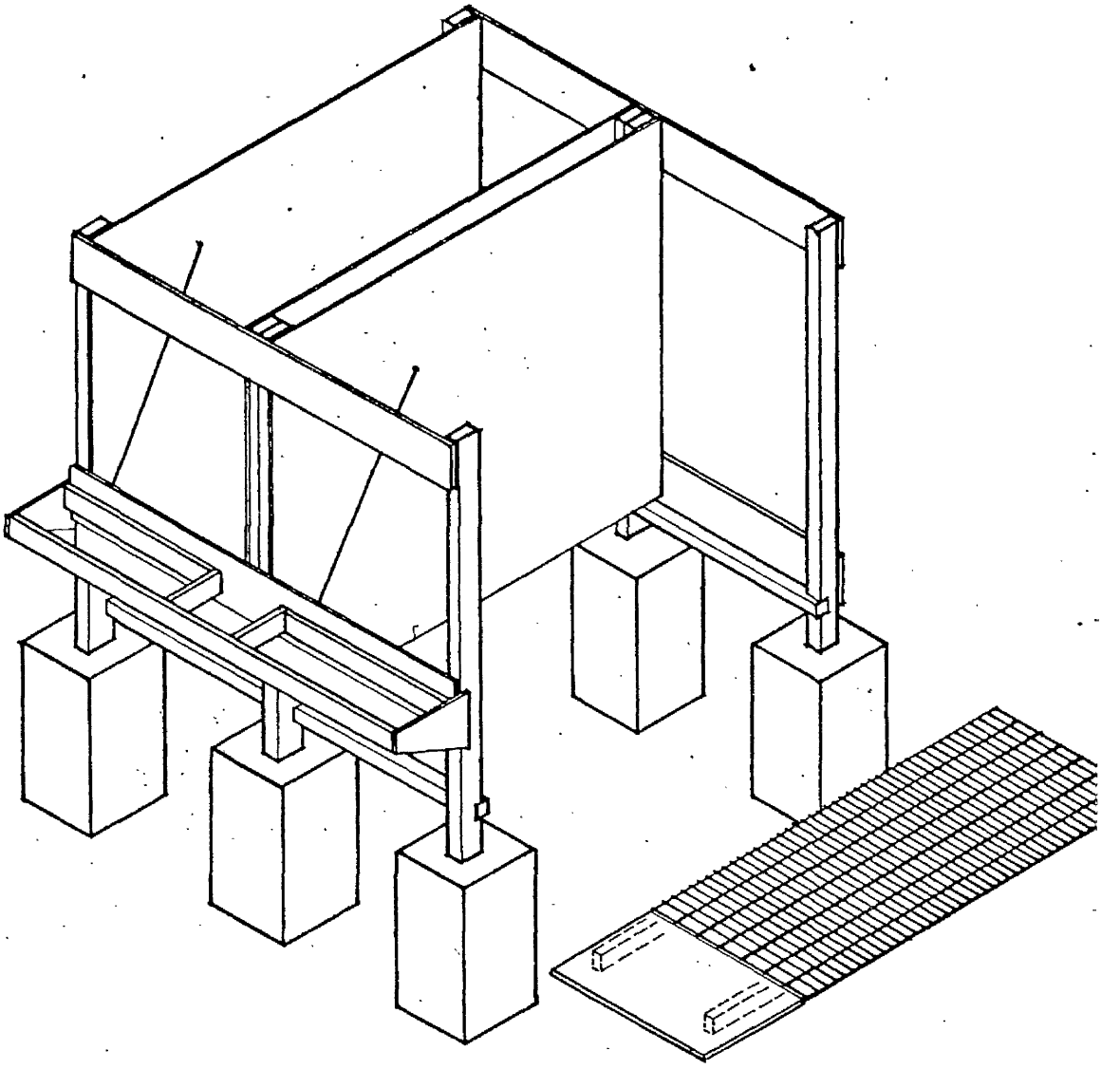
PLAN OF 2 CRATES

Fig. 3b.2.



SECTION THROUGH CRATE

Fig. 3b.3.



PICTORIAL VIEW

The runners were angled so that the calf could lower its head and step forward to drink but on raising its head, was drawn back into the crate.

The existing front design of the crate was discarded and replaced by the front shown, allowing freer access to the head of the calf, the original front panel was then available for use as the rear of the crate. By discarding the original feedgate a completely open rear section was obtained with a step, as shown, preventing the calf from stepping off the back, together with ample access to the rear of the calf. A complete new floor was constructed of weld mesh incorporating a spill tray at the front.

Faecal Bag Harness and Urine Collection. A harness presently being used in conjunction with young calves was loaned by Dr.J.H.B.Roy, N.I.R.D., Reading. The basic design of the harness was modified by using nylon webbing throughout, unlike the leather and hessian structure of the original. Fully adjustable buckles were used, which allowed a greater freedom of adjustment of the harness.

Urine was collected by allowing the calf to urinate through the floor of the crate. A polythene sheet suspended beneath the crate channeled the urine into a polythene funnel which was secured in a narrow necked 5 litre container.

Performance of the Apparatus

Metabolism Crate. Throughout the period of the trial the crates were seen to functio well. Calves were housed in the crates from 5 days to 10 weeks of age, during which time average live weight increased from 40.75 kg to 67.7 kg. It is considered that the crates would have housed animals up to 80 kg live weight.

Some difficulty was experienced in moving the calves in and out of the crates, even though a custom built ramp was used at the rear.

The difficulty could have been overcome by placing the handler on a platform at the side of the crate allowing easier access to the side of the animal.

It is considered that the two slides which carried the yolk could have been moved approximately 15 cm. back from the front of the crate, as there was a tendency for the calves to stand out over the front of the crates during feeding.

There was a tendency for the calves to gnaw the front of their crates. This was prevented by soaking the wood in creosote.

Faecal Bag Harness. Over the first two periods of the trial the harness and method of attachment of the bag functioned well.

On only a very few occasions were faeces lost from the bag. This occurred mainly with the very small calves when the bag caught under a hind hoof. This was remedied by slightly shortening the bag. Care had to be taken that the bag was not pulled too tight at the tail head as in several instances over a period of time it was found to cut into the skin of the calf.

A certain amount of chaffing was noted immediately in front of the hind legs, caused by the rear section of the harness. This was not of a severe nature and was cured by the application of a cream.

Due to the material of the harness, which was nylon, it was easily washed and sterilised between each period of use. This process did not cause any deterioration of the material.

The harness and bag functioned well in calves up to an average live weight of 56.75 kg. maximum 65 kg. On the diets as fed, the maximum weight of faeces collected on any one occasion was 1100g. On a subsequent occasion, when the same calves reached an average of 67.7 kg maximum 76 kg live weight the bag failed to function and the trial was terminated. The failure lay in the pocket of the bag being

unable to hold the weight of faeces voided. This might have been overcome by using a larger bag or more frequent collections.

It is suggested that if cattle of a size in excess of 70 kg are to be used, then an alternative harness in which greater support is given to the collection bag should be adopted.

ANIMALS AND MANAGEMENT

A total of twelve Friesian calves were purchased directly from farmers possessing accredited herds. The average weight of the calves on arrival at the unit was 40.75 $\pm$ 4.35 kg and all calves were between four and twelve days of age.

On arrival all calves received 2 ml of a multi vitamin injection* plus 2 ml of an escherichia coli, Salmonellae dublin and typhimurium and Pasteurella septica vaccine**. The calves were then weighed and immediately placed in the metabolism crates. All calves were fed 1.25 l. of a 10% glucose solution. No other food was given until the following day.

All calves were weighed at three and four day intervals whilst they remained on the unit.

Nutrition

Period 1. The milk feeding treatments had been allocated, in order, to the metabolism crates for ease of management. Random allocation of calves to the crates ensured that all calves were allocated randomly to the levels of feeding.

On the day following their arrival each calf was placed on a programme which would enable it to consume the required amount of milk replacer on a once daily system before the commencement of the first trial period.

* Zylphon Vitamin Injection, Bayer Leverkusen, Germany. Vit. A, D3 and E.

** Bovivac-Plus, Hoechst Pharmaceuticals.

The final levels to be fed were 300g and 600g of milk replacer reconstituted in 2.5 l of warm water fed once daily. Henceforth, these two treatments will be designated Low and High milk replacer respectively.

The programme to allow this level of feeding consisted of a period of between twelve and fourteen days during which the required amount of milk/replacer powder was initially fed half twice daily (2 x 150g; 2 x 300g) reconstituted in 1.25 l of warm water at each feed. When it was considered that the calf could digest the required amount of reconstituted milk powder, it was finally offered as one feed per day. All calves, excepting numbers one and six, consumed the required level of food fed once daily three days before the beginning of the first trial period.

The three days prior to the first trial period were used as a preliminary period during which feed intake remained constant. During this period, the calves were fitted with the harnesses to be used for faecal collection for the remainder of the trial.

The first trial consisted of a period of ten days during which calves received milk replacer reconstituted at the high or low level of 600g and 300g of milk replacer in 2.5 l of warm water once daily. During this period no other feed was offered to the calves.

Total faecal and urine collections were made for the duration of the trial.

The calves were weighed at the beginning of the trial period, twice during the trial period and at the end of the trial.

Period 2. Following the first ten day trial period the calves were offered concentrates. The concentrate ration used was a commercial calf pellet ration* and was initially offered ad libitum

* B.O.C.M. Quicklottes calf rearing ration.

to all calves. The pellets were offered immediately following the final calf weighing on the last day of trial period 1. All calves were allowed ad libitum access to concentrates for a period of ten days. Milk replacer was still fed to the calves at the levels established during period 1.

Following the preliminary ten day period of ad libitum feeding, an estimate was made of the average concentrate intake on days eight, nine and ten of the preliminary period.

According to the level of concentrate intake achieved during the preliminary period, the calves were allocated to a high or low concentrate ration, the difference in level of concentrates within each pair being fixed at 300g/d of concentrates.

As the trial was being performed in order to determine the metabolizable energy value of the concentrates, it was not considered necessary to impose exactly the same concentrate restriction as that used during the main trial, there being no advantage in equating the concentrate and milk energy differences in the present instance. The figure of 300g/d difference was arbitrarily chosen as being a value likely to yield measurable differences in faecal output. The high level of concentrate feeding was fixed at a level which it could safely be assumed the calves would consume without any refusals for the duration of the second trial period. In some instances, this value was above the average consumption value obtained for days eight, nine and ten of the preliminary period. Table 3b.2 shows the three day average consumption of the calves before they were allocated to the treatments shown in Table 3b.3.

Table 3b.2

Three Day Concentrate Consumption (g) Prior to Allocation to High and Low Concentrate Feeding

Low Milk 300g/day			High Milk 600g/day		
Calf No.	Live Weight (kg)	3d-Av conc. intake (g)	Calf No.	Live Weight (kg)	3d-Av conc. intake (g)
1	43.75	891	2	60.50	600
3	43.50	556	4	47.75	214
5	46.25	900	6	47.75	741
7	43.50	700	9	49.00	333
10	43.00	573	11	55.50	620
8	died during Trial 1		12	53.25	583

Table 3b.3

Feed Allocation During the Second Trial Period

Low Milk Pairs				High Milk Pairs			
Calf No.	Low Concs (g)	Calf No.	High Concs (g)	Calf No.	Low Concs (g)	Calf No.	High Concs (g)
1	700	5	1000	12	300	11	600
10	500	7	800	2	500	6	800
	-		500	4	200	9	400

After the concentrate allocation had been made the calves underwent a four day preliminary period during which no feed adjustments were made.

Trial Period 2 started at the culmination of the second four day preliminary period and consisted of a ten day period during which milk replacer was fed at the same level as in Period 1 and concentrate intake was that allocated at the beginning of the second preliminary period. Separate total faecal and urine collections were made over

the 2nd trial period.

The concentrate ration was fed twice daily one third at 9 a.m. and two thirds at 4 p.m. This was done in an attempt to appease the appetite of the calves which in some instances were on a severe level of restriction. Any concentrate or milk refusal was noted.

The calves were weighed a total of three times during the experiment.

The metabolism trial was terminated at the completion of trial period 2.

Faecal and Urine Collection

Faecal Collections. As previously indicated, the faeces were collected in polythene bags attached to the harness and were removed for storage twice daily. After removal the bag and faeces were immediately weighed, 2 ml of toluene were added and the bag sealed.

Urine Collection. The urine was collected in a polythene container. In order that the urine was immediately acidified 10 ml of dilute sulphuric acid was placed in the container before any urine was collected.

The volume of urine collected was measured once every 24 hours, 10% by volume of the total collection was then transferred to a Winchester for storage.

Storage of faeces and urine

Total faecal collections were made. Following collection the sealed bags were transferred to a chill room, where they were stored at between 1^{o} and 2^{o}C for the duration of the trial. This method, it was considered, would not result in any nitrogen or energy loss (Fuller and Cadenhead, 1969).

Following the completion of the trial, all faecal samples were removed from the chill room. The bags were reweighed and a 10% sample by weight was taken of each 12h collection. The samples were obtained by coring through the bulk of the faeces at various positions in the stool. A representative sample weighing 10% of the total collection was thus obtained for each calf.

This sample was then transferred to the laboratory where a known volume of water was added to form an approximate 5% slurry. The slurry was vigorously stirred and samples taken for dry matter determination in triplicate. Half of the remaining slurry was removed for deep freezing and subsequent nitrogen determination, the remainder was oven dried at 105°C and stored for energy determination at a later date.

A 500 ml aliquot was taken of the composite urine sample, the aliquot was stored in a chill room at 1°C until required for nitrogen and energy determinations.

Faeces and Urine Energy Determinations

Faeces. Energy determinations were carried out on the dried faecal samples. The samples were first milled for one minute in a Moulinex grinder. Triplicate samples of the milled dried faeces were pelleted and weighed. At the same time duplicate samples were taken and dry matter determinations carried out. Dry matter determinations were made by drying for 24 hours at 105°C. Energy determinations were carried out on the weighed pellets using a Gallenkamp Adiabatic Bomb Calorimeter. Determinations were carried out until two energy determinations agreed to within 2% of each other. Acid corrections were made on all determinations.

Urine. The composite urine samples were removed from the cold store and 10 ml pipetted into a tared polytetrafluoroethelyne (P.T.F.E)

bag held upright in a card container. Triplicate samples were taken. The samples were then placed in an oven and dried at 37°C under vacuum over silica gel for a total of three days until the samples were dry.

Energy determinations were carried out on the dried samples by attaching the P.T.F.E. bags with cotton to the fuse wire of a Gallenkamp Adiabatic Bomb Calorimeter. Energy determinations were made until two determinations agreed to within 2% of the total energy value. Energy determinations were made of the P.T.F.E. bags and the total energy of urine and bag was corrected by subtracting the energy values of the individual bags.

Nitrogen Determination

Faeces. Nitrogen determinations were carried out on samples of thawed slurry. Slurry samples were initially homogenized by passage for one minute through a homogenizer (Alexander, 1969). Triplicate samples, by volume, were withdrawn from the slurry. Two of these samples were used for accurate dry matter determinations and the third analysed in triplicate for nitrogen content. Nitrogen was determined by a method attributed to Mitchell (1972), modified by Alexander (personal communication). The nitrogen content of the dry matter was determined by reference to the dry matter of the slurry.

Urine. Nitrogen content of the urine was determined by a similar method to that used for faecal nitrogen determination. A 1 to 10 dilution of the urine sample was necessary in order to comply with the method of determination.

RESULTS

Chemical Composition of the Milk Replacer and Concentrates

The chemical composition of the milk replacer is shown in Table 3b.4. Two samples were analysed, one from a single bag and one comprising aliquots from several bags.

Table 3b.4
Milk Replacer Composition

	Sample	
	1 Bag	Bulked
% Moisture	3.0	3.6
% Crude Protein in Sample	22.6	22.9
% Ash	6.78	6.58
% Fat	18.0	18.3
Starch	+ve	+ve
% Whey Powder	0.5	0.5
% Total Carbohydrate by difference	49.6	48.6

From the declared milk replacer composition the energy value of the ration, using energy values of the constituents from Watt and Merrill (1963), was calculated. Calculated in this manner the gross energy value of the milk replacer was 19.31 MJ/kg. The analysis of the concentrates is shown in Table 3b.5.

Table 3b.5
Chemical Analysis of the Concentrate Ration

	Sample	
	1 Bag	Bulked
% Moisture	10.2	9.7
% Crude Protein in Sample	19.00	19.05
% Crude Protein in Dry Matter	21.15	21.10
% Crude Fibre in Dry Matter	7.3	8.1

The values for moisture content of 3.6 and 9.7% for milk replacer and concentrates respectively agree with those obtained at a later date when the two samples were pelleted for energy determination. Gross energy values by Bomb Calorimetry, for the milk replacer and concentrates were found to be 19.670 ± 0.013 and 15.374 ± 0.114 MJ/kg respectively.

Period 1 Milk Replacer Only Feeding

Average values for the apparent digestibility of the milk replacer during period 1 when fed at the high level of 600g/d or the low level of 300g/d were 95.05 ± 1.54 and 93.97 ± 1.96 per cent respectively. A comparison of the two samples showed there to be no significant difference between these two values. The mean value of all calves of 94.51% has therefore been chosen as the digestibility of the milk replacer during period 1.

The figures for total energy intake (MJ per day) during the balance trial and the partition of energy loss in faeces and in urine are shown in Table 3b.6 for the high and low levels of milk replacer.

Table 3b.6

Partition of Energy Loss During Period 1

Level of Feeding Milk Replacer	Daily Gross Energy Intake MJ/day	No. of Calves	Energy Loss in Faeces MJ/d SE	Energy Loss in Urine(a) MJ/d SE	Total Energy Loss(b) MJ/d SE	a/b x 100
600g/day	11.80	4	0.60 ±0.22	0.15 ±0.02	0.75 ±0.22	21
300g/day	5.90	4	0.40 ±0.16	0.14 ±0.03	0.54 ±0.18	26

The figures for energy loss showed there to be no statistically significant difference between the energy lost in the urine as a percentage of the total energy excreted on the high or low levels of milk replacer feeding. The major portion of the energy lost occurred in the faeces and accounted for 78.7 and 73.8% of the total energy excreted on the high and low level of milk replacer respectively.

The metabolizable energy of the milk replacer was calculated directly from the terms stated in the ARC Technical Review No. 2. The Nutrient Requirements of Farm Livestock Ruminants viz:-

$$\text{Metabolizable Energy} = \text{Gross Energy} - \{\text{Heat of combustion of faeces} + \text{heat of combustion of fermentation gases} + \text{heat of combustion of urine}\}$$

As previously stated, methane production whilst the calves were on milk feeding only was considered as zero. Average values for the metabolizable energy of the milk replacer were 17.87 $\pm$ 0.63 and 18.41 $\pm$ 0.38 MJ.ME/kg on the low and high levels of feeding respectively. These two values were not significantly different, thus a pooled value of 18.14 MJ.ME/kg milk replacer (18.82 MJ.ME/kg DM) has been adopted as the metabolizable energy of the milk replacer when fed to calves of an approximate average live weight of 40 kg at levels of feeding equivalent to 0.69M and 1.38M (energy required for maintenance by a 40 kg calf = 8.52 MJ.ME/day hence 11.8 and 5.9 MJ.ME/day supply $^{11.8}/_{8.52}$ and $^{5.9}/_{8.52}$ respectively) (Roy 1976).

Nitrogen intake during period 1 on the high and low level of milk replacer feeding was 21.36 and 10.68g of nitrogen per day respectively. Nitrogen intake, faecal nitrogen and urinary nitrogen, expressed as g per day, obtained for the calves during period 1 is shown in Table 3b.7. Metabolic faecal nitrogen shown, has been expressed as 4.1 g/kg dry matter intake according to Raven (1972) and also as 2.5 g/kg dry matter intake according to the Nutrient

Requirements of Farm Livestock No. 2 Ruminants. Endogenous Urinary nitrogen has been calculated as 0.20 g/d/$W^{0.73}$ (Nutrient Requirements of Farm Livestock No. 2. Ruminants Technical Reviews and Summaries, Agricultural Research Council, London, 1965).

Table 3b.7

The Partition of Nitrogen Excretion During Period 1

Nitrogen intake g/day	Nitrogen in faeces g/day	Metabolic 4.1g/kg DM	Faecal N 2.5g/kg DM	Urinary N g/day	Endogenous Urinary N g/day	N Retention g/day
21.36	1.025	2.370	1.445	10.310	3.784	10.49
10.68	1.072	1.185	0.7225	8.674	3.174	1.17
21.36	2.278	2.370	1.445	9.111	3.380	10.45
10.68	0.837	1.185	0.7225	11.313	3.270	-1.23
10.68	0.871	1.185	0.7225	9.653	3.146	0.395
10.68	1.510	1.185	0.7225	15.339	3.664	-
21.36	2.209	2.370	1.445	8.111	3.472	11.52
10.68	1.643	1.185	0.7225	9.775	3.136	-4.9
21.36	2.518	2.370	1.445	6.772	3.558	12.55
21.36	2.375	2.370	1.445	6.907	3.504	12.55

From Table 3b.7 if a figure of 4.1 g/kg DM is assumed as the metabolic faecal nitrogen then in 60% of the calves the calculated metabolic faecal nitrogen exceeds the actual nitrogen excreted in the faeces. As has previously been stated, calves on the low level of milk replacer were being fed sub-maintenance. It is to be expected therefore that a certain amount of lipolysis or proteolysis may occur in order to supply the energy requirements of the calves. In some of the calves receiving the low level of milk replacer urinary nitrogen excretion was elevated. It is suggested therefore that in the absence of a sufficient supply of dietary energy the body energy reserves of the calves in the form of fat were insufficient to supply the energy requirements of the calf. In this situation proteolysis has occurred as a means of increasing the available energy. Using a value for metabolic faecal nitrogen of

2.5 k/kg dry matter intake, the calculated true digestibility of the protein on both levels of feeding was 96.04% ± 1.78. This figure is in good agreement with the figure of 100% suggested by Roy (1970), for the true digestibility of protein of good quality milk substitute powder. This therefore is further evidence for the adoption of 2.5 g/kg dry matter intake as the value for metabolic faecal nitrogen in these particular calves. The biological value of the protein on the high and low milk replacer was 76.53 ± 7.05 and 35.83 ± 9.37 respectively, the latter figure again reflecting the protein catabolism in the calves fed sub-maintenance.

Period 2. Milk Replacer Plus Concentrate Feeding

Digestibility. The digestibility of the two milk replacer and concentrate diets offered during period 2 was determined by regression analysis and treatment effects were examined by a comparison of regression lines (Snedecor and Cochran 1972). The daily dry matter intake and the daily dry matter retention (dry matter intake - faecal dry matter) for the eleven calves during period 2 is shown in Figure 3b.4. The equations which best fit the two lines are represented by the formulae:-

Low milk replacer, $y = 0.703x + 0.0871$ (1)

High milk replacer, $y = 0.629x + 0.2182$ (2)

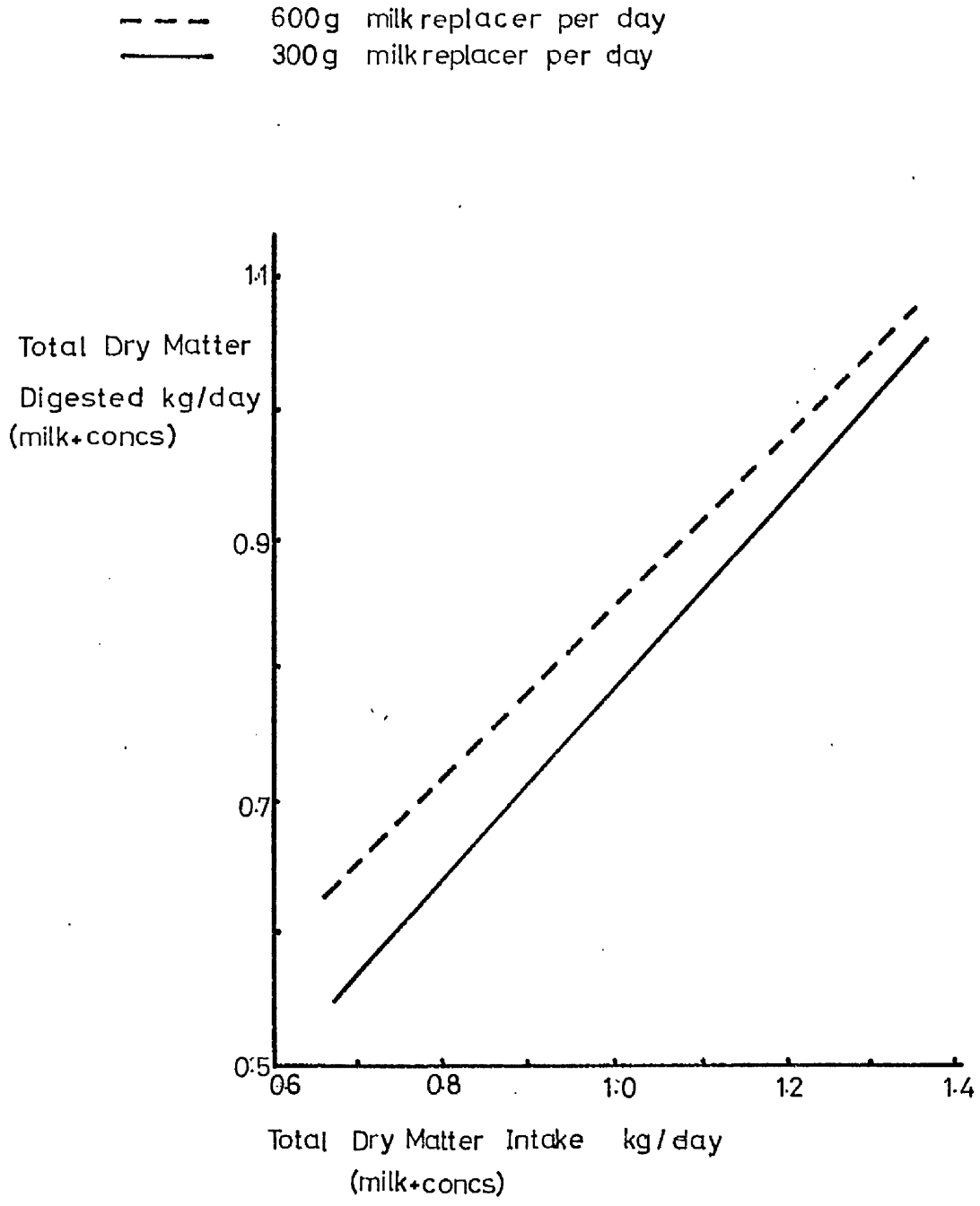
where y = the dry matter digested per day

and x = the dry matter intake per day

The gradients of the two lines shown in Figure 3b.4 represent the digestibility of the ration with increased level of concentrate feeding. There was no significant difference between the gradients of the two lines shown in equations (1) and (2) hence the digestibility of the ration was unaffected by the level of concentrate feeding.

Fig. 3b. 4.

Ration Digestibility



A significant difference was found ($P < 0.01$) in the elevation of the two lines. The increased elevation of the line representing the high milk replacer diet shows that at any given dry matter intake the high milk replacer diet was more digestible, at 1 kg DM intake 0.79 and 0.85g of DM were digested on the low and high milk replacer diets respectively. This was due to the higher digestibility of the milk replacer in the diet compared with the digestibility of the concentrates.

By substituting into equations (1) and (2) dry matter intakes equivalent to 300 and 600g of milk replacer respectively, the dry matter retention equivalent to these levels of milk replacer feeding may be calculated. Values obtained in this manner are shown in Table 3b.8.

Table 3b.8

Calculated Digestibility of the Milk Replacer in a Diet of Milk Replacer and Concentrates

Level of milk replacer feeding/ day	Dry matter intake g/day	Calculated dry matter retention g/day	Apparent Digestibility
300	289.2	290.4	>100
600	578.4	582.0	>100

The dry matter retained thus equates well to dry matter intake if the digestibility of the milk replacer is 100 per cent.

The pooled regression coefficient for the concentrate digestibility on both levels of milk replacer feeding was 0.66.

The true digestibilities of the milk replacer obtained during period 1 for the high and low levels of milk replacer feeding (95.0% and 93.9% digestible respectively), was used, in conjunction with the dry matter intake equivalent to 600 and 300g of milk replacer to

calculate the apparent dry matter retained from the concentrates alone. This calculation was made for all calves individually. The apparent dry matter retained from the concentrates was then plotted against the daily concentrate dry matter intake and is shown in Figure 3b.5. In this instance the digestibility of the concentrates from regression analysis was calculated to be 70%. As can be seen, the values for apparent concentrate digestibility lie on the same straight line and do not differ according to whether the diet contained 300 or 600g of milk replacer per day. There was no significant difference between the digestibility of the concentrates when fed in conjunction with either 300 or 600g of milk replacer per day.

Metabolizable Energy. The gross energy intake of the calves was calculated from the sum of the gross energy of the milk replacer plus the gross energy of the concentrates. Methane energy was calculated as 2.8% of the gross energy consumed from the concentrates.

Metabolisable Energy was calculated from:-

Metabolizable Energy = Gross energy - {Energy lost in faeces + energy lost in urine + energy lost via methane production}

The metabolizable energy retained was calculated in this manner for the eleven individual calves and was corrected to a daily ME intake value. Daily ME intake was then plotted against daily concentrate intake and regression analyses were carried out for the two sets of data referring to the rations fed containing 300 and 600g of milk replacer per day respectively. The two lines constructed from the data are shown in Figure 3b.6. The slope of the lines represents the ME content of the concentration. Equations for the two lines were:-

Fig. 3b.5.

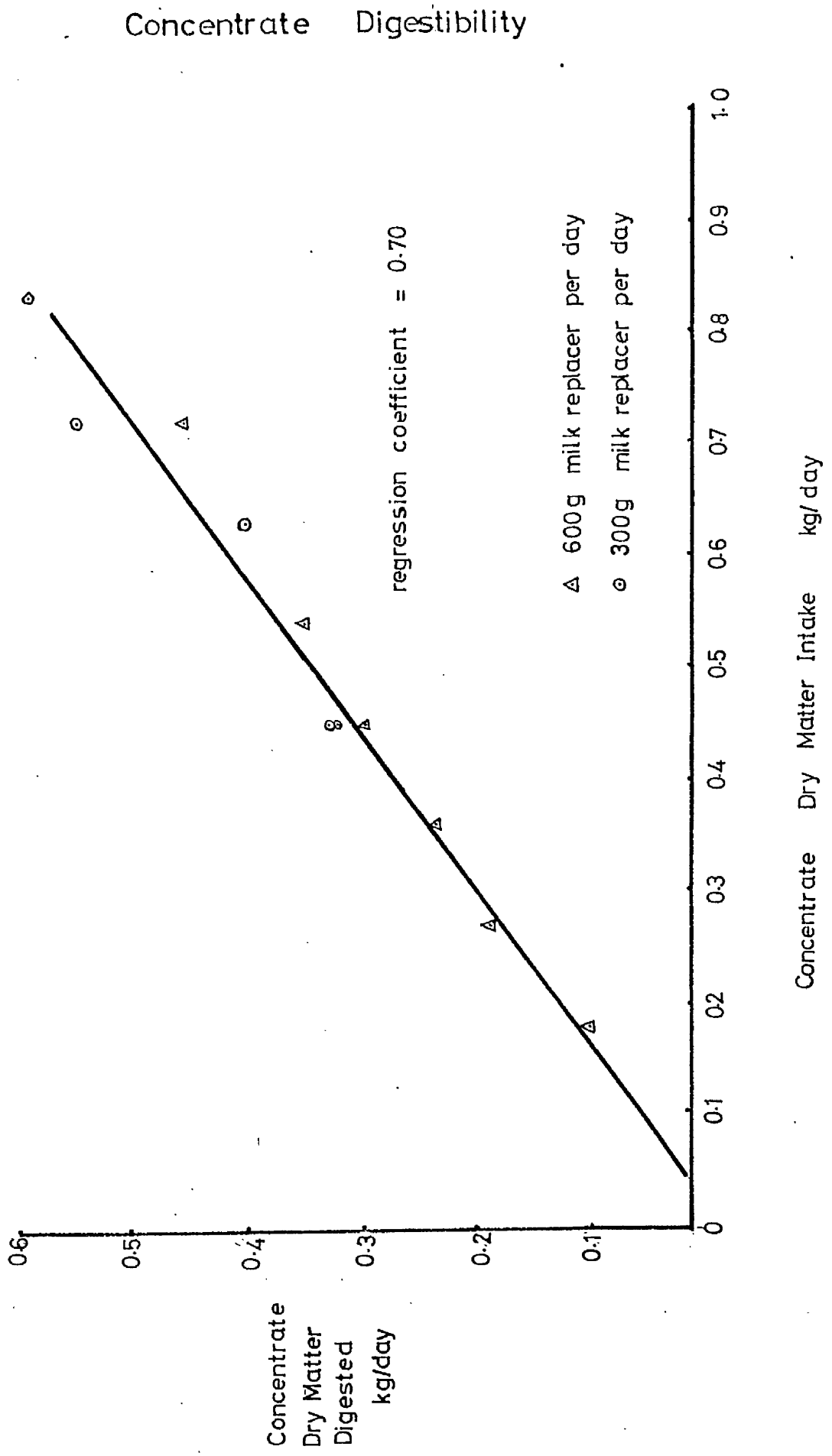
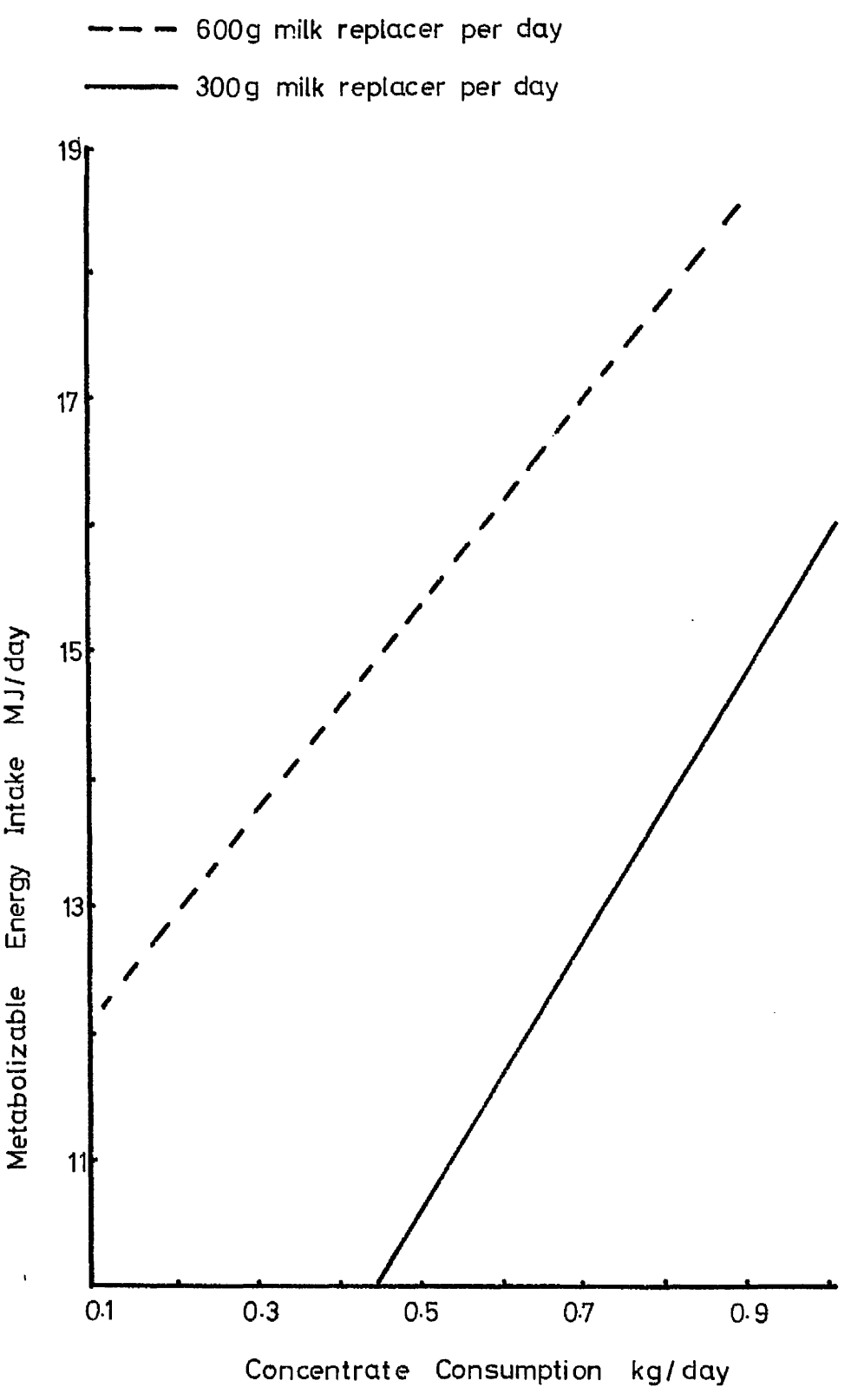

Concentrate Digestibility
regression coefficient = 0.70
△ 600g milk replacer per day
⊙ 300g milk replacer per day
Concentrate Dry Matter Digested kg/day
Concentrate Dry Matter Intake kg/day
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Fig. 3b.6.

Daily Metabolizable Energy Intake versus Daily Concentrate Intake



For the diet containing 300g milk replacer

$$y = 10.16x + 5467.4$$

For the diet containing 600g milk replacer

$$y = 8.76x + 11248.78$$

Thus the metabolizable energy of the concentrates = 10.16 and 8.76 MJ/kg of concentrates as fed together with 300 and 600g of milk replacer per day respectively. No significant difference was found between the two metabolizable energy values for the concentrates when fed in conjunction with the two levels of milk replacer.

Extrapolation to zero concentrate intake yielded the value for the total metabolizable energy intake of the two levels of milk replacer feeding. Hence:

Metabolizable energy from 300g of milk replacer = 5467.4 kJ/day = 18.22 MJ/kg of milk replacer

Metabolizable energy from 600g of milk replacer = 11248.78 kJ/day = 18.74 MJ/kg of milk replacer

Thus the metabolizable energy of the milk on the high and low level of milk replacer feeding = 18.9 and 19.4 MJ/kg DM respectively.

The validity of using linear regression analysis in the analysis of the above data was tested by fitting a quadratic regression equation to the two sets of data. In neither case were the quadratic components significant compared with the linear components which were highly significant. Thus over the range of feeding levels used in the experiment the use of linear regression analysis was most appropriate (Draper and Smith, 1966).

Nitrogen Digestibility. Using the previously accepted value of 2.5g/kg DM intake as the value for metabolic faecal nitrogen, total nitrogen intake per day during Period 2 was plotted against total

faecal nitrogen minus metabolic faecal nitrogen. Separate regression analyses were carried out on the data pertaining to the two diets and the lines of best fit are shown in Figure 3b.7. The equations of the two lines are:-

Low (300g) milk replacer diet $y = 0.213x - 2.214$

High (600g) milk replacer diet $y = 0.282x - 6.764$

where x = total nitrogen intake g/day

y = (faecal nitrogen - metabolic faecal nitrogen)

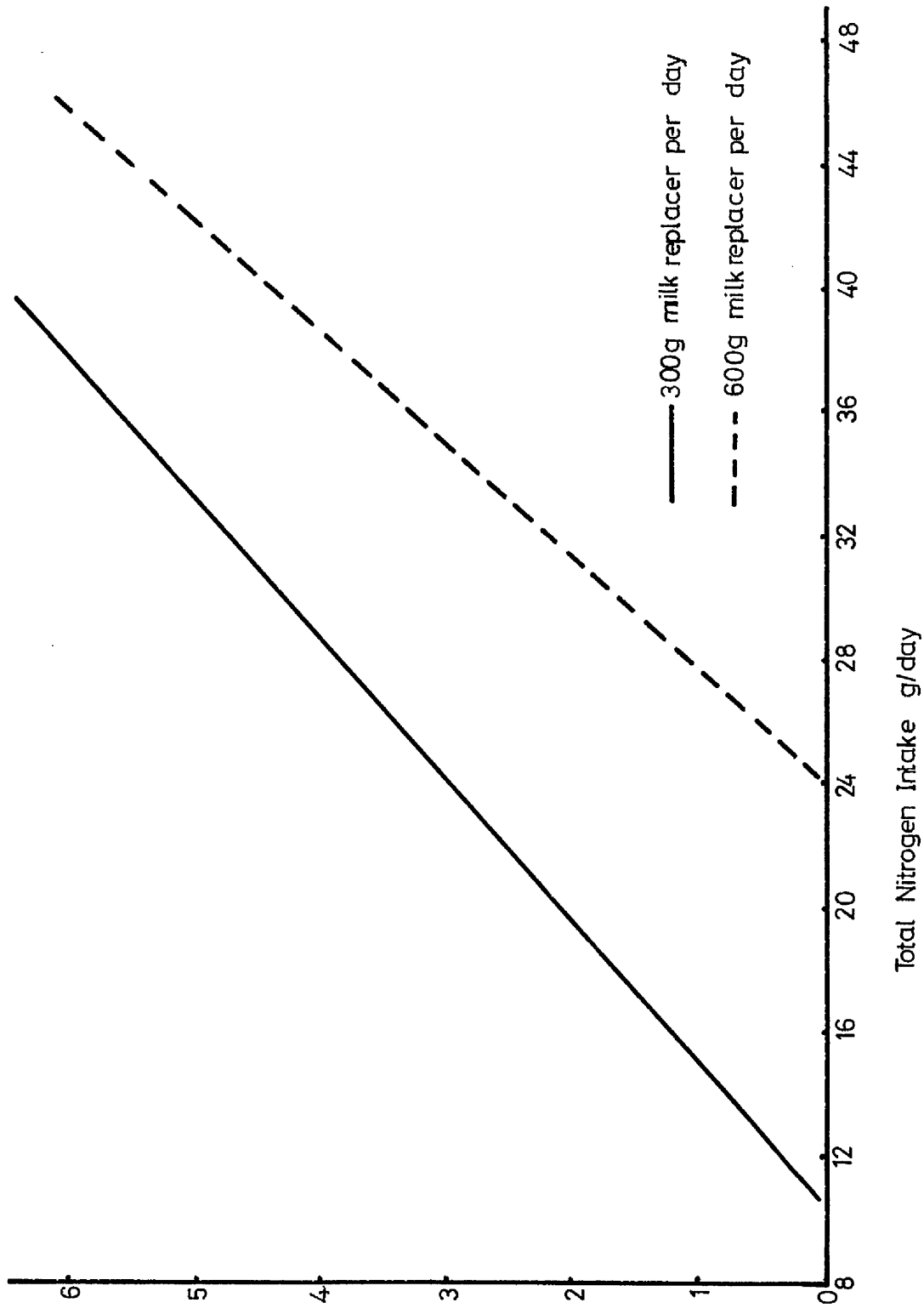
There was no significant difference between the two coefficients of x hence the pooled regression coefficient of 0.252 was adopted. The intercept when $y = 0$, i.e. when faecal nitrogen excretion due to the diet = 0, = 10.39 and 21.98g of nitrogen/day for calves being fed the low and high levels of milk replacer diets respectively. These figures correspond well with the nitrogen intakes on the low and high level of milk replacer of 10.62 and 21.25g respectively. These figures would suggest that the nitrogen supplied by the milk replacer is approaching 100% digestible.

The increase in nitrogen intake and increase in nitrogen excretion is then supplied by the concentrates. The increase in nitrogen excretion of feed origin per unit increase in nitrogen intake is then represented by the pooled regression coefficient = 0.25. Hence the retention per unit of nitrogen intake = (1 - 0.25) = 0.75. Hence the nitrogen content of the concentrates is 75% digestible.

Energy for Maintenance and Production. In calculating the maintenance requirement and energy content of the gain, account was first taken of the change in weight of the gut contents during the two periods of the trial. Gut fill during milk feeding only, Period 1, was considered as 4.1% of live weight (Kesler, Raining

Fig. 3b.7.

Faecal Nitrogen versus Nitrogen Intake



& Knodt, 1969). During Period 2 gut fill was calculated from the equation due to Stobo, Roy and Gaston (1966):-

$$y = 0.20x_1 - 3.33x_2 + 0.40x_3 + 2.90$$

where y = the weight of gut contents (kg)

x_1 = the live weight (kg)

x_2 = the daily concentrate intake (kg)

x_3 = the daily hay intake (kg)

During both Periods 1 and 2, food intake was constant over the whole of each period, thus, increase in gut fill likely only occurred as a result of the increase in metabolic size. Therefore, the live weight component was the only functional component in the equation. During Period 1, the gut fill correction factor ranged from 0, in calves which maintained or lost weight, to 0.184 kg. Actual live weight gain was obtained by subtracting the correction factor from the apparent live-weight gain. During Period 2, when concentrates had been offered for a total of 24 days, the gut fill correction factor ranged from 0.3 to 1.65 kg.

The mean live weight of the calves, together with the mean daily live-weight gain recorded over the two ten-day trial periods, is shown in Table 3b.9.

Table 3b.9

Mean Live Weight and Daily Live Weight Gain of the Calves Over the Two Ten-Day Trial Periods

	Period 1		Period 2	
Calf No.	Mean Live Weight kg	Mean Daily Live Weight Gain kg/day	Mean Live Weight kg	Mean Daily Live Weight Gain kg/day
1	40.56	-0.02	49.18	0.20
2	50.43	0.34	66.75	0.40
3	39.87	0.01	47.43	0.15
4	43.43	0.62	52.81	0.28
5	41.50	0.04	53.0	0.35
6	38.43	0.27	55.81	0.53
7	39.43	0.06	50.50	0.45
8	48.31	-0.09	-	-
9	44.93	0.35	57.05	0.58
10	39.25	0.33	47.31	0.20
11	46.06	0.32	62.56	0.83
12	45.50	0.41	58.37	0.35

In order to calculate the metabolizable energy requirements of the calves for maintenance and live-weight gain it was considered that in a graph of the form:-

$$y = mx + c$$

where y = metabolizable energy intake and x = live weight gain then the intercept on the y axis when x = zero would yield the maintenance requirement of the calf. However, if animals of differing live weights are considered, as in combining the results from Periods 1 and 2 the maintenance requirement so calculated cannot be referred to a specific live weight. It was considered that this problem could be overcome by converting ME intake to ME intake per unit of metabolic weight. This could then be plotted against daily live weight gain. The data in this form is shown in

Figure 3b.8. Regression analysis was carried out on the data and the equation representing the line of best fit is given by:-

$$y = 0.664\ x + 0.457$$

where y = daily metabolisable energy intake per unit metabolic weight ($W^{0.75}$) and x = daily live weight gain

The standard deviation of the regression coefficient 'm' was calculated to be 0.086, hence m = 0.664 ± 0.086. The intercept on the y axis when x = 0 = 0.457. This figure represents the daily ME requirement for maintenance per unit of metabolic weight. In order to calculate the energy requirement per unit live weight gain the coefficient 0.664 was multiplied by the average metabolic weight of the calves:-

Metabolisable energy per kg live-weight gain = 0.664 x 18.62 = 12.36 MJ.

A second method of calculation of the energy required per unit live-weight gain was also considered using the average metabolic weight of the calves (18.62 kg), the average daily ME intake (11.28 MJ) and the average daily live-weight gain (0.206 kg/day). From the previously calculated value for maintenance of 0.457 MJ $W^{0.75}$ then the maintenance requirement of a calf of metabolic weight of 18.62 kg equals:

maintenance requirement = 0.457 x 18.62 = 8.50 MJ/day

The Average daily metabolisable energy intake = 11.28 MJ Hence energy for gain equals:

11.28 - 8.50 = 2.77 MJ

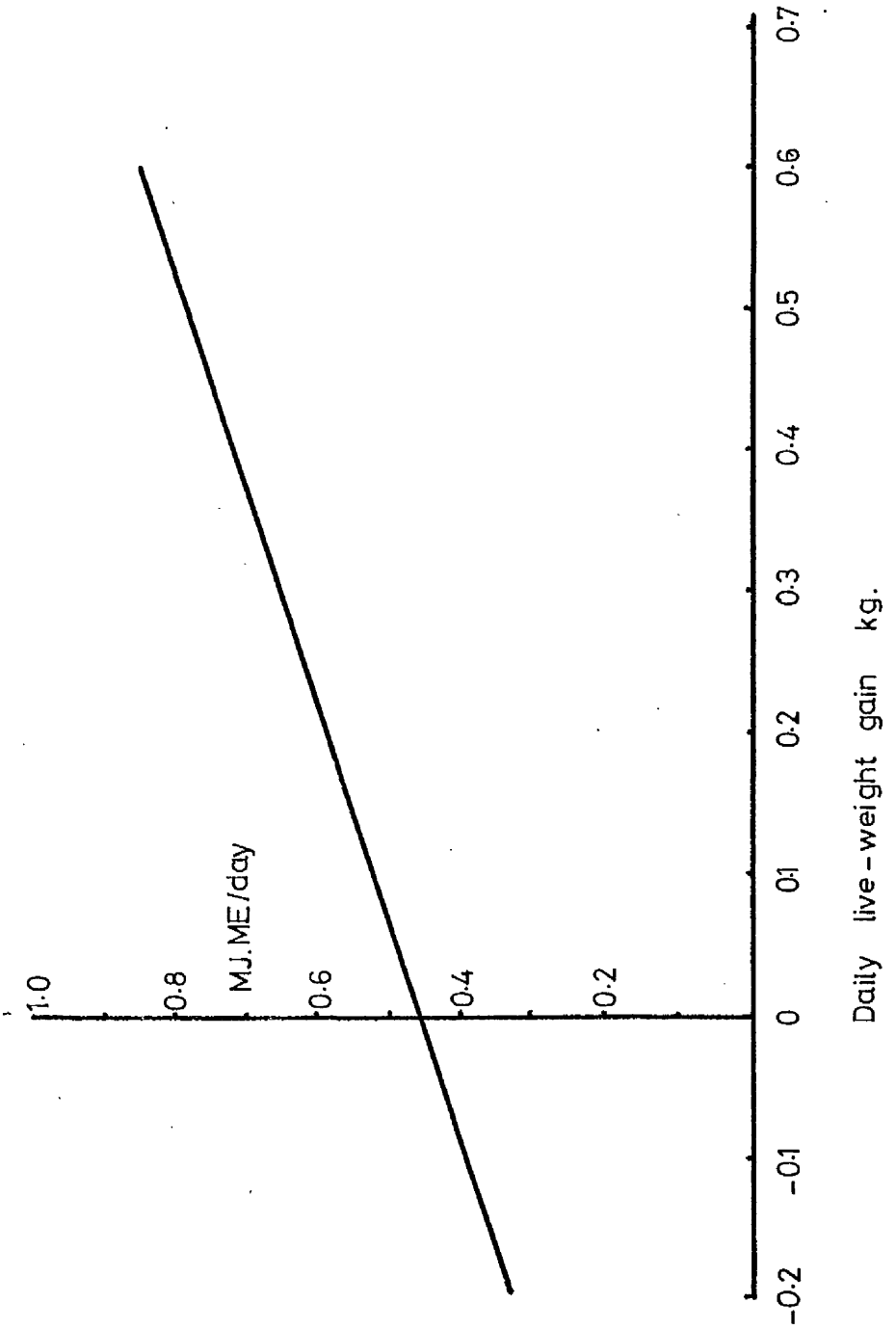
This energy supports a gain of 0.206 kg/day

hence the metabolisable energy per unit live-weight gain =

$$\frac{2.77}{0.206} = 13.47 \text{MJ}$$

Fig.3b.8.

Daily Energy Intake MJ.ME/$W^{0.75}$ versus
Daily Live-weight Gain in kg.



It can be seen that the metabolisable energy required for unit gain obtained by regression (12.36 MJ/kg) is not appreciably different from that obtained by using the mean energy intake (13.47 MJ/kg). Care should be exercised in using a technique as above in order to determine the energy content of the gain. If the maturity of the animals used in the analysis is highly variable, then the energy content of the gain will be variable and hence the combining of the data in one analysis will lead to errors. In the above analysis the age of the animals did not vary to any great extent even when the difference in age between Periods 1 and 2 was considered. The range in live weights of animals used in the analysis was from 39 to 66 kg. It is considered that the adoption of single values for the energy for maintenance and production in the above calves would not lead to serious errors. Calculation of the point when live-weight gain equals zero in this instance is considered appropriate as the live-weight gains of the calves ranged from - 0.2 kg/day to 0.7 kg/day. No extrapolation was, therefore, made out with the range of the values.

DISCUSSION

Chemical analysis of the milk replacer showed no difference which would significantly offset the results between a sample obtained from a single bag of powder or from a bulk sample. This was to be expected, as assurance had been given that the milk powder for the trial would be manufactured in one batch. Small insignificant differences were found in the composition of the concentrates, but the differences obtained were unlikely to have any effect on the energy level and nitrogen content of the diet or upon its digestibility.

The average digestibility of the milk replacer during Trial Period 1, of 94.51% of the dry matter ingested, agrees with values of approximately 97% for milk substitute diets based on butter fat. (J.H.B. Roy, 1970). Raven (1972) obtained values of 95.1% and 97.1% for the digestibility of the organic matter of 20% tallow and 20% butterfat milk replacer diets respectively. Thus the digestibility of the milk dry matter is in good agreement with literature values and from the results it would appear that there is no effect on the digestibility of the milk replacer by feeding 300 or 600g of milk in one feed reconstituted at 11.5 and 23.0% dry matter.

Evidence has already been propounded for the use of 2.5 g/kg dry matter intake as the value for metabolic faecal nitrogen. The value of 96.04 and 100% for the true digestibility of the protein of the milk replacer during Periods 1 and 2 respectively is in good accord with the figure given by Roy (1970).

The biological value of the protein of the milk replacer used by Raven (1967) was, for milk replacers of the same level of protein as that used in the trial, between 73 and 80%. Thus the biological value of 76.5 obtained in this work, for the high level of milk replacer feeding agrees well with these values. The value of 35.83% obtained when feeding 300g of milk replacer per day represents the high loss of nitrogen in the urine caused by protein catabolism as a result of the calves being fed sub-maintenance.

The excess nitrogen lost per day from calves on the low level of feeding is shown in Table 3b.10. The figures have been calculated from a theoretical biological value of the protein consumed of 76%. Expected urinary excretion was calculated and was then subtracted from actual excretion, giving the excess excretion.

Table 3b.10

Urinary Nitrogen Excretion of Calves Fed Sub-Maintenance

Actual Urinary N g/day	Calculated Urinary N g/day	Excess Urinary N g/day	Live Weight Gain kg/day	Live Weight kg
8.674	5.626	3.048	-0.1	39.87
11.313	5.806	5.507	-0.2	41.50
9.653	5.674	3.979	0.00	39.43
9.775	5.589	4.186	-0.1	39.25

Thus in this particular instance approximately 4.2g of excess urinary nitrogen were produced by a loss in weight of 0.1 kg/day in a 40 kg calf.

From the results of Period 2, Figure 3b.4 substituting in equations (1) and (2) gives digestibility of the concentrates, when fed in conjunction with the high and low levels of milk replacer of 63 and 70% respectively, with a pooled value of 66%. From Figure 3b.5 when the digestibility of the milk replacer is allotted a value of approximately 94% concentrate digestibility from regression equals 70%. From the results it cannot be categorically stated whether the digestibility of the concentrates in the mixed ration is 66 or 70% or whether the value for the digestibility of the milk replacer is 100 or 94% during the second period of the trial. The fact that in Figure 3b.5 when concentrate dry matter digested equals 0, concentrate intake = 23g, is sufficiently close and within experimental error, to suggest that dry matter digested equals zero when intake equals zero. This is further evidence that the value of the digestibility of the milk replacer used to construct the graph in Figure 3b.5 is close to the digestibility of the milk replacer when fed in conjunction with concentrates. Thus the inclusion of concentrates in the diet has not affected milk replacer digestibility.

By regression the metabolisable energy of the milk replacer was calculated to be 19.17 MJ/kg DM. This figure agrees precisely with that of 19.2 MJ/kg DM obtained by Webster, Gordon and Smith (1976) for the metabolisable energy of Volac milk powder. In producing Figure 3b.6 the value of using linear regression has already been discussed. As the information best fits a straight line it can be stated that over the levels of feeding used the metabolisable energy of the concentrates is not affected by the level of feeding. It can also be stated that the level of milk feeding does not affect the metabolisable energy of the concentrates. (ME of concentrates 10.16 and 8.76 MJ/kg concentrates as fed together with 300 and 600g of milk replacer). Hence these values may be accepted as the individual values of the metabolisable energy of the milk substitute powder and the concentrates when fed in a mixed ration to young calves. The pooled value of 9.37 MJ ME/kg of concentrates is approximately 15% lower than the ME value for an equivalent cattle cake of approximately 11 MJ ME/kg (M.A.F.F. Technical Bulletin 33).

If this figure is considered in conjunction with the value of 70% for the digestibility of the concentrates, then if concentrate digestibility were raised to 80% i.e. that expected for a highly digestible ration (Roy, 1970), a 14% increase in ME would be obtained giving close agreement with the literature values.

It is suggested that the low value for the metabolisable energy of the concentrates fed during this experiment is due to the initial low digestibility of the concentrate ration. The low digestibility is thought to be the result of the short period of time for which concentrates had been consumed. At the culmination of Period 2 calves had access to concentrates for a total of 24 days.

In order to examine the effect of the length of time for which concentrates were fed on concentrate digestibility the pattern of the daily faecal excretion during Period 2 was examined for each of the calves. As the level of feeding of each calf was the same throughout the trial any changes in dry matter excretion are caused by changes in the digestibility of the diet. The data on faecal excretion was in the form of the weight of faeces excreted over a 12-hour period. Due to the variability of the weight of faeces voided on consecutive days by each calf, it was not possible to obtain a reliable estimate of the daily trend in faecal excretion. In order to overcome this total faecal excretions over the first three and last three days and over the first five and last five days were compared. In neither of the two comparisons were any differences in faecal excretion found. These results would suggest that over the ten-day trial period the digestibility of the diet did not change. This evidence however is not conclusive. It was not possible to estimate the change in dry matter content of the faeces over the period of the trial as the dry matter determination was only made on a bulked faecal sample from each calf. Thus although the total excretion did not change over the period of the trial it is possible that later in the trial the calves were consuming more water which was offered ad libitum. Thus the faeces collected later in the trial may have had a lower dry matter content.

During the second trial period the nitrogen content of the diet did not differ to any great extent in the high concentrate low milk replacer diet or the low concentrate high milk replacer diet. The crude protein contents of the dry matter of the milk replacer and the concentrates were similar (23 and 21% respectively).

Dry matter intake plotted against faecal nitrogen is shown in Figure 3b.9. Regression analyses were carried out on the two sets of data from Periods 1 and 2 and the regression equations of faecal nitrogen as a function of dry matter intake for the two periods are given by:-

Period 1 $y = 0.0040x + 0.0314$

Period 2 $y = 0.0097x - 2.9562$

where y = faecal nitrogen g/day

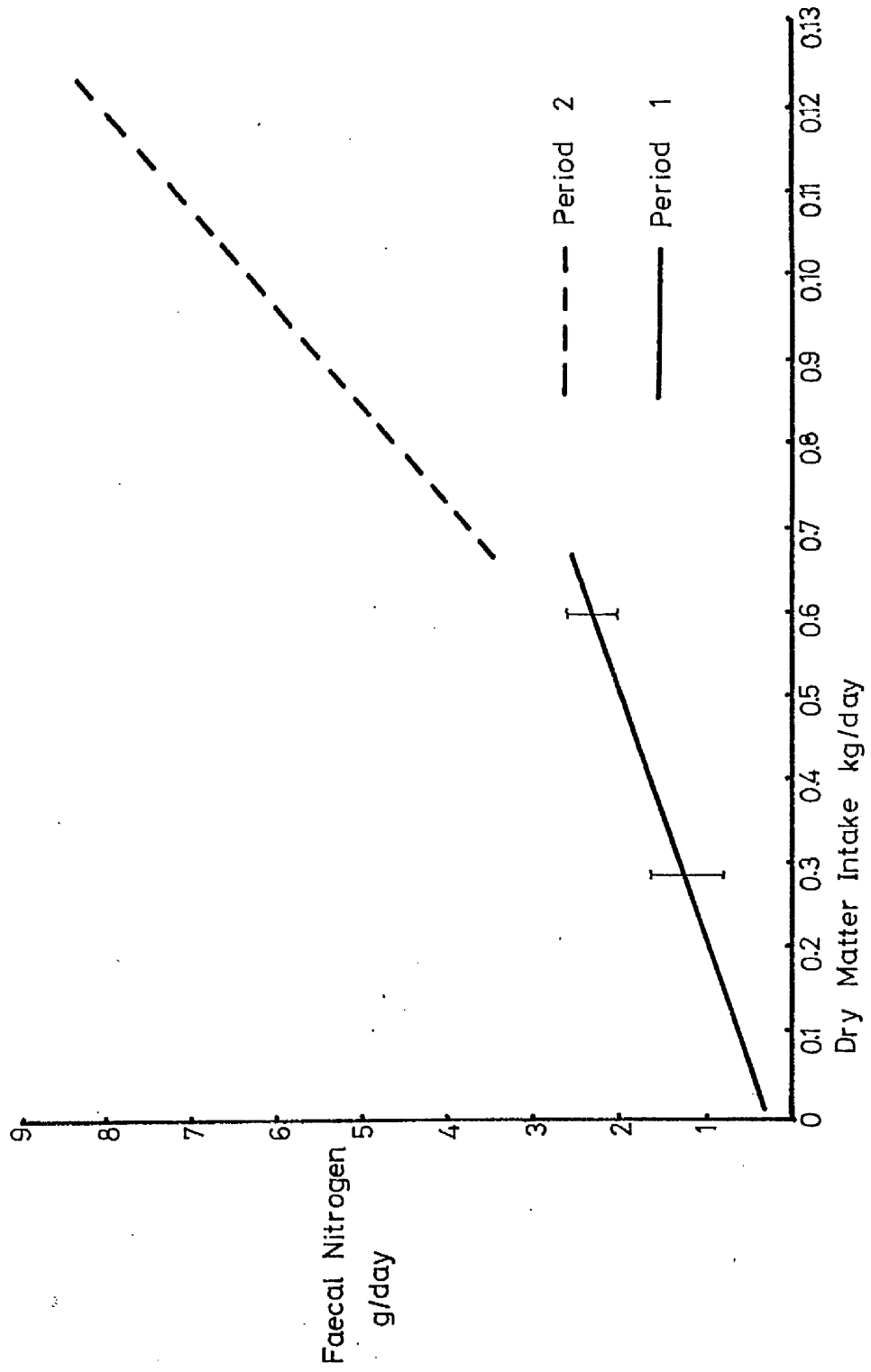
and x = dry matter intake kg/day

The two functions of x were significantly different ($P < 0.001$). It should be noted that the line representing Period 1 is obtained from only two levels of dry matter intake (equivalent to 600 and 300g of milk replacer per day). The bar lines on the graph represent the spread of the points obtained from the six calves on each level of feeding.

The two functions of x represent the increase in faecal nitrogen per unit increase in dry matter intake. As can be seen there is an increase of 142% $\left(\frac{0.0097 - 0.0040}{0.0040} \times 100\%\right)$, in nitrogen excretion per unit of dry matter intake between Periods 1 and 2. Although the protein of the concentrates is less digestible than that of the milk replacer (75% cf 96% respectively), it is not considered that this reduction could account for the increase in nitrogen excretion between Periods 1 and 2. Thus during Period 2 there is an increased nitrogen excretion which cannot be accounted for by a change in the nitrogen content or digestibility in the diet. The increased faecal nitrogen may be the result of an increased level of metabolic faecal nitrogen. It is suggested that this may be accounted for as a result of the

Fig. 3b.9.

Dry Matter Intake g/day versus
Faecal Nitrogen g/day



overall digestibility of the diets during Periods 1 and 2 being quite different. During Period 1 the digestibility of the dry matter was 94%, hence the amount of dry matter reaching the lower gut was negligible and only 6% of intake, thus the effect of dry matter sloughing off the surface of the gut was only felt over a small portion of the digestive tract, presumably as far as the end of the large intestine. In this instance it does not seem appropriate to base metabolic faecal nitrogen on dry matter intake. During Period 2 the digestibility of the total ration was 81%, there was, therefore, a significantly higher amount of dry matter (19% of the intake) passing through the total length of the gut. It would seem pertinent therefore when calculating metabolic faecal nitrogen, that if dry matter intake is to be the governing factor, a different function of dry matter intake should be used which takes account of the digestibility of the diet.

The graph of faecal nitrogen excretion versus dry matter excreted is shown in Figure 3b.10. It is realised that in this instance the two variables plotted are not completely independent. Regression analyses were carried out on the data from Periods 1 and 2 and the regression equations describing the lines of best fit are given by:

Period 1 $y = 0.065x + 1.359$

Period 2 $y = 0.043x + 115.081$

where y = nitrogen excretion g/day

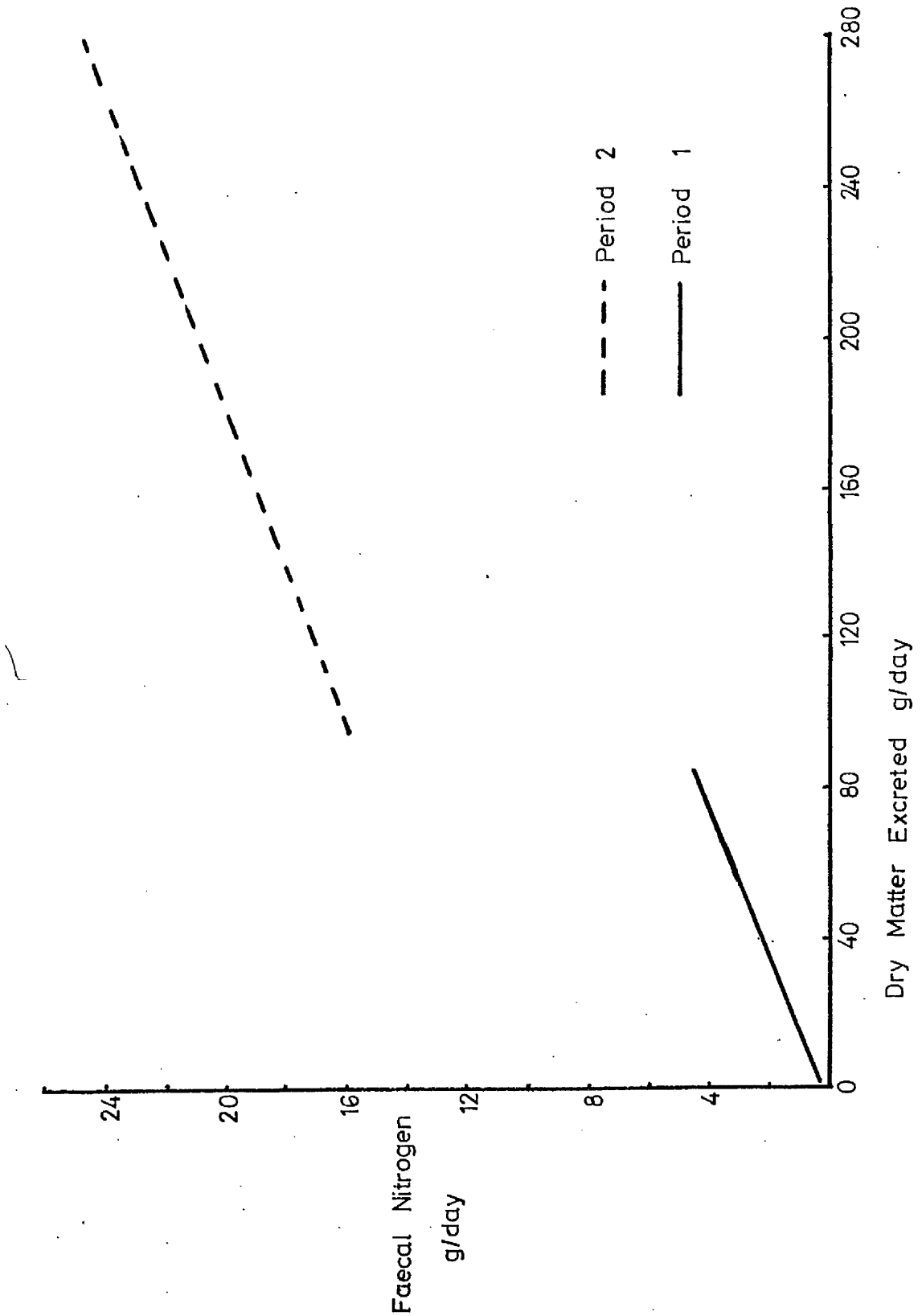
and x = dry matter excreted g/day

No significant difference was found between the two functions of x.

As the two functions 0.065 and 0.043 do not differ significantly ($P > 0.05$) the statement can be made that nitrogen excretion, when considered as a function of the dry matter excreted, was directly

Fig. 3b.10.

Dry Matter Excreted g/day versus
Faecal Nitrogen g/day



related to dry matter excretion irrespective of whether the dry matter intake was from milk or concentrates. Dry matter excretion is directly related to the digestibility of the diet. Hence, it is suggested that metabolic faecal nitrogen be considered as being related directly to dry matter intake and inversely to the digestibility of the diet.

The value of 0.46 $MJ/kg^{0.75}$ for maintenance requirement of the calves agrees well with other values of 0.39 to 0.45 $MJ/kg^{0.75}$ per day for calves (Holmes and Davey, 1976). The figure is also in good agreement with the values of 0.42 and 0.46 $MJ/kg^{0.75}$ per day for milk fed calves published by Johnson and Elliot (1972 a & b). The latter figure produced by Johnson and Elliot was from calves reared in an open sided shed whilst the former was from calves reared in a metabolism room. Calves in this experiment were a maximum of 24 days old. It could be expected therefore that the maintenance requirement would be greater than that obtained in the present work, whereas the converse has been found. It is thus suggested that, in view of the current published figures, the requirement for maintenance obtained in this work is slightly high.

The values of 13.47 and 12.36 MJ.ME/kg live weight gain obtained in the present experiment are in agreement with the figures quoted by Holmes and Davey (1976) of 11.2 and 13.8 MJ.ME/kg live weight gain for calves on low and high levels of feeding respectively. These values are in good agreement with the value obtained by Roy (1970) of 12.34 MJ.ME/kg live weight gain although in this instance the level of feeding was not stated.

CONCLUSION

The results of the trial show that there was no appreciable affect on the apparent digestibility of the milk replacer when it was fed at levels of 300 or 600g/day or whether it was fed alone or in a mixed diet with concentrates. The apparent digestibility of the milk replacer when fed alone was 94.51% and by extrapolation when fed in conjunction with concentrates 100%. The metabolizable energy content of the milk replacer was 19.17 MJ.ME/kg DM. The true digestibility of the protein in the milk replacer was 96.04% and its biological value was 76.5.

There was no affect of the level of concentrate feeding on the apparent digestibility of the concentrates. Concentrate digestibility was between 66 and 70% and the metabolizable energy content of the concentrate was 9.37 MJ/kg. It is suggested that the low values obtained for the digestibility and metabolizable energy content of the concentrates were due to the undeveloped dry matter digestion of the calves, which had only been consuming concentrates for a total of 24 days. The nitrogen content of the concentrates was 75% digestible.

It is considered that, in determining metabolic faecal nitrogen in young calves, the value of metabolic faecal nitrogen should depend to some degree on the digestibility of the diet.

The energy requirements of the calves, which averaged 53 kg in weight over the duration of the trial, were for maintenance and production 0.456 MJ.ME/$kg^{0.75}$ and 12.36 to 13.47 MJ.ME/kg live weight gain respectively.

Production Trials

Section 3e

Pre-weaning Trial

MATERIALS AND METHODS

In accord with good calf rearing practice a batch rearing system has been employed with the four calf intakes. The chronological order of events over the period February 1974 to February 1976 is shown in Figure 3c.1. Between each intake there was a period of approximately four weeks, during which time the unit was completely cleared of stock and all the houses were steam cleaned. This procedure was adopted in order to break any disease pattern which could have developed when the unit was occupied by stock.

Purchase of Calves and Treatment on Arrival

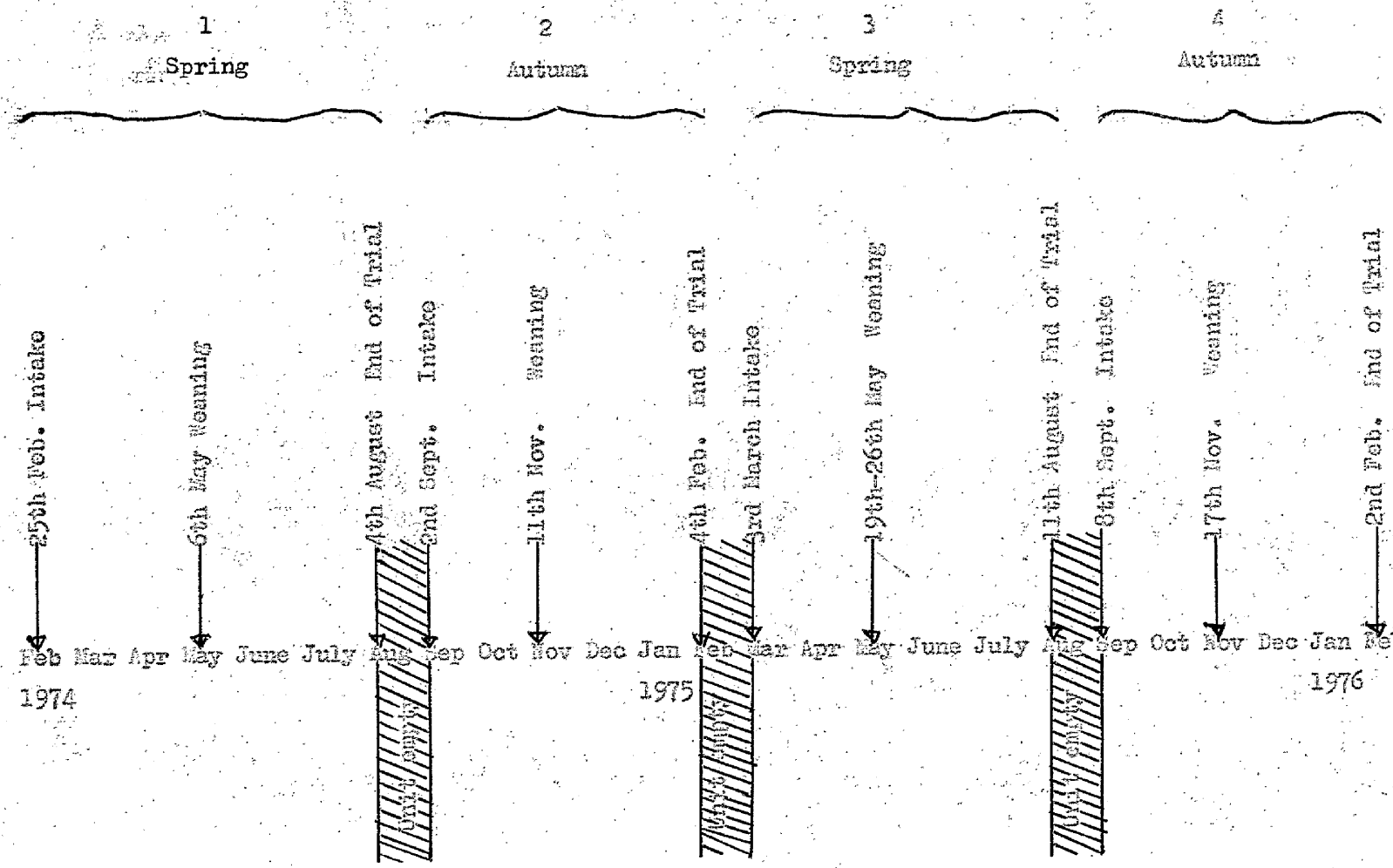
Calves for the trial were purchased from farms in Central and North Ayrshire. Only bull calves from accredited herds were used and all were of the Friesian, Friesian x Ayrshire or Friesian x Friesian-Ayrshire breed. It was requested that all calves should have received colostrum within the first six hours after birth.

At purchase all calves were examined for signs of scour or wet navel. Calves were rejected should either of these two factors be apparent. Calves of under 36.3 kg live weight (80 lbs) at the time of purchase were rejected as it was considered that these calves were likely to be weaker and less able to thrive. (Martig, Rose, Nicolet and Stock 1976). All calves were between four and ten days of age at purchase and were collected and transported to the unit in batches of between 20 and 30 in number. Each intake of one hundred and twenty-eight calves was collected over a twelve day period. There was thus a maximum difference of 18 days in the ages of the calves on the unit at any one time.

On arrival at the unit, all calves were weighed and their navels treated with antiseptic spray. All calves received 2ml of the following concentrated multivitamin injection:-

Figure 3c.1

Chronological Order of Events During the Four Trials



	Units per ml.
Vitamin A	300,000 i.u.
Vitamin D3	100,000 i.u.
Vitamin E	50 mg

(Zyliphon Bayer Leverkusen, Germany).

Calves were then allocated to house and to nutritional treatment. Where possible no two calves from the same source were allocated to the same house or nutritional treatment. Each animal was then allowed approximately one hour of undisturbed rest before being offered 1.25 litre of 10% glucose solution warmed to blood heat. No other form of food was offered to the calves on their day of entry onto the unit.

Any calf, on arrival, that was seen to be scouring was immediately isolated and treated. Blood immunoglobulin levels of all calves were measured on the day following their entry onto the unit. With prior knowledge of the age of the calf this procedure was adopted in order to identify calves which had not received colostrum. Animals comprising the Spring '75 intake were vaccinated against Salmonellosis (Mollavax, Burroughs Wellcome and Co.) at five days after admission and the Autumn '75 intake received 2 ml of an Escherichia coli; Salmonella dublin, Salmonella typhimurium and Pasteurella septica vaccine (Bovivac-Plus Hoechst Pharmaceuticals).

Time to Weaning and Feeding Management

Within the period of five months, during which individual calves were resident on the unit, two distinct rearing periods were discernible, pre-weaning and post-weaning. It is well known that calves are more prone to digestive upsets and disease hazards whilst receiving liquid diets (Loever and Yarrow, 1972a; Martig, Rosa, Nicolet and Steck, 1976), and also that when weaned, calves undergo a check in growth rate (Loever and Yarrow, 1972b; Wicken, White, Lewis and Radcliff, 1972).

The period of time over which individual feed data could be compiled was governed by the length of time for which calves could be individually housed. N.C.C.M. calf crates were used to individually house calves in the 'A' type houses and steel mesh crates were constructed within the cubicle divisions in the 'B' type houses. The size of the crates were suitable for housing calves up to twelve weeks of age.

Calves were weaned at twelve weeks of age. The advantages gained by the extended period up to weaning were:-

a) a maximum period over which individual feed records could be made.

b) an extended period without the growth check due to weaning.

c) an extended period on milk feeding during which time high live weight gains could be attained.

The management of the calves was on the basis of a once daily feeding system. The final milk feeding levels for the Spring '74 intake were fixed at 600 and 400g of milk replacer per day. It was considered that equal volumes of the warmed liquid should be fed to both the high and low milk treatments to prevent any differential heating effect as a result of different volumes of warmed liquid. The milk replacer was finally reconstituted in 2.5 l. of warm water, warmed to approximately 38°C, giving final values of 23.1 and 11.6% dry matter for the high and low level of milk replacer feeding respectively. The reconstituted low level milk replacer was approximately equal to the dry matter concentration of cows' milk (Roy 1970). As an attempt was being made to impose a degree of nutritional stress to the nutrient restricted calves, with a view to examining environment x nutrition interactions, it was considered in the light of the results from the first trial to increase the level of restriction on

the low level of milk replacer feeding. Thus for the Autumn '74 and two 1975 trials the levels of milk replacer feeding were set at 600 and 300g of milk replacer per day.

Initially an attempt was made to adhere to a programme whereby the milk replacer offered was geared to achieve once daily feeding when the calves had been on the unit for a total of seven days. This rationale was changed for later intakes and adjustments were made to the levels of feeding according to the health and performance of the calf. The feeding programme used for the four calf intakes is shown in Figure 3c.2. Although Figure 3c.2 shows set feeding levels on specific days, all calves progressed through each level and remained on any level for at least the period shown. Any changes were made by retaining calves on a specific level of feeding for longer periods of time or by cutting back on the concentration of milk replacer.

Concentrates were offered to all calves, according to experimental treatment, within the first two weeks of the calves having arrived on the unit. During the Spring '74 intake concentrates were offered to all calves up to an intake of 200g/day. Those calves which were to receive the restricted level of concentrates were held at 200g/day until the corresponding calves on concentrates ad libitum reached an intake equivalent to 200g plus the restricted amount. During Spring '74 this amounted to a total consumption of 543g of concentrates. The allowance to be offered to the restricted calves was then based on the consumption of four calves on the ad libitum treatment from two adjacent pens. An average of the consumption of these four calves on three consecutive days was taken in an attempt to take account of daily fluctuations in intake. Thus account was taken of 12 separate daily intakes in the calculation of each restricted level of feeding.

Figure 3a.2

Feeding Programme for the Introduction of Once Daily Milk Replacer Feeding

(indicating volume of liquid, conc. of DM and frequency of feeding)

	Level of MR	Vol & Conc	1.25 lt water glucose 10% soln	1 2	3 4 5 6	7 8 9 10 11 onwards
Spring 74	Low	vol		1.25	1.87	2.5
		conc		107g	107g	160g
			1 feed	2xdly	2xdly	1xdly
	High	vol		1.25	1.87	2.5
		conc		160g	160g	240g
			"	2xdly	2xdly	1xdly
Autumn 74	Low	vol		1.25	1.87	2.5
		conc		80g	80g	120g
			"	2xdly	2xdly	1xdly
	High	vol		1.25	1.87	2.1
		conc		80g	160g	240g
			"	2xdly	2xdly	1xdly
Spring 75	Low	vol		1.25	1.87	1.87 2.5
		conc		80g	80g	120g 120g
			"	2xdly	2xdly	1xdly 1xdly
	High	vol		1.25 1.25	1.87	1.87 2.5
		conc		80g 160g	80g	240g 240g
			"	2xdly 2xdly	2xdly	1xdly 1xdly
Autumn 75	Low	vol		1.25 1.25	1.25	1.87 2.5
		conc		40g 80g	80g	120g 120g
			"	2xdly 2xdly	2xdly	1xdly 1xdly
				glucose +midday		
	High	Vol		1.25 1.25	1.25	1.87 2.5
		conc		40g 80g	160g	240g 120g
			"	2xdly 2xdly	2xdly	1xdly 1xdly
				glucose +midday		

Volume is given in litres

Concentration of milk replacer in grammes per litre

In the three subsequent trials concentrates were offered to the restricted calves up to a maximum of 100g/day before a restriction was imposed. This was an attempt to impose the level of restriction earlier in the trial. As the low milk replacer treatment was reduced to 300g/day during the Autumn '74 and the two '75 intakes, the concentrate restriction equivalent in ME terms to the level of milk replacer restriction was increased to 514g of concentrates per day. Thus the total concentrate consumption required by the LN calves before the level of restriction was attained by the LL and HL groups was 614g/day (514 + 100g/day).

Hay was also offered within the first two weeks; a maximum allowance of 500g/day was offered to all calves.

Water was offered to calves on once daily milk feeding. Initially calves were restricted to 2.5 l of cold water per day, this was changed to water ad libitum within one week of the calves starting once daily milk feeding.

Other Aspects of Management

Prior to weaning, all calves were bedded with fresh straw each day. In these experiments no account was taken of the effect of bedding on the micro climate of the calf. Post weaning, calves housed in the A type houses were bedded on straw and those in the B type houses were bedded on wood shavings.

Dehorning took place when horn buds were discernible and was carried out using an electric or gas hot iron. Calves were usually dehorned between five and six weeks of age.

All calves were castrated by the Burdizzo method following weaning. The calves were not castrated earlier in order to achieve a uniform rate of gain over the pre-weaning period, without the check caused by castration (Mullen, 1964).

Calves were weighed on the day of arrival and then weekly on the Monday morning of each week. The calves were weighed to the nearest kilogram, using a weigh crush placed on a portable dial scale (R.Paterson Fully Automatic Industrial Dial Scale (700 Series)) capable of weighing 250 kg in 500g units. The weighing of the batch of calves took approximately 2½ hours. In order to minimise any effects due to differences in gut fill, between subsequent weighings of the same calf, all calves were weighed in the same order each week. Thus, individual calves were weighed at approximately the same time of day each week. Any differences as a result of the amount of concentrate consumed before weighing and in excretion of faeces were therefore minimised.

Veterinary Hygiene and Disease Prevention

A programme of veterinary treatment and hygiene was adopted in order to standardise, over the period of each trial, the routine treatment of individual calves.

At the commencement of each trial consideration was given to precautions which could be taken to minimise the risk of the spread of disease throughout the unit. As previously explained, each house could accommodate 32 calves and each cell within a house, eight calves.

The batch rearing system used has the advantage of isolating each batch from subsequent intakes. When all the pens in each cell had been filled no calf was subsequently moved before weaning into any other house or cell in the unit. Thus in the event of any mortality, calves were not regrouped in order to form complete cells.

In order to further isolate individual cells, foot baths were provided at each cell. The boots of personnel were dipped on entering and leaving each cell and each cell was thus maintained as an isolated unit as far as was possible.

Each calf was allocated its own buckets for the duration of a trial. Milk buckets were washed daily and concentrate buckets twice weekly.

Routine veterinary treatment included:-

Treatment of Incoming Animals:

1. Dressing all navels with tetracycline spray
2. Giving all calves a multivitamin injection
3. Rectal swabbing all calves
4. Obtaining serum samples for immunoglobulin and total protein determination.
5. Obtaining blood samples, from each calf, for haemoglobin estimation.

Week 2:

1. Obtaining serum samples for immunoglobulin level determination

Week 7:

1. Obtaining serum samples for immunoglobulin level and total protein estimation.

Scouring calves were treated initially by reducing the quantity of milk replacer being fed. If scour persisted the affected calf was treated orally with one of several antibiotic treatments. The treatments used were administered according to the manufacturers' recommendations and treatment usually lasted between three and four days. In the exceptional circumstances of a persistently scouring calf, the animal was removed from the trial and transferred out with the unit.

In calves which persistently scoured and in which dehydration was suspected fluid replacement therapy was used. Initially some subcutaneous administration of isotonic saline was used, latterly the calves were frequently given an oral dose of isotonic glucose saline solution.

Calves suspected of suffering from pneumonia were injected with 5 ml of a penicillin, streptomycin* mixture on the first day and 3 ml on each of the two consecutive days.

On several occasions, when it was suspected that calves were unable to maintain homeothermy as a result of malady, supplementary heating was supplied by an infra-red lamp suspended over the calf. It was not considered that this action would materially affect the environment of the cell in which the heating was supplied.

Any calf which died was immediately removed for post mortem examination. The calf's bedding was also removed and the pen and area thoroughly disinfected.

During the Autumn '74 and Spring '75 intakes the technique of Stiles, Grieve, Butler and Willoughby (1974) was used in a modified form to monitor the health of the calves. See section on Calf Health (Section 3d).

Statistical Analysis

The effects of level of nutrition, housing environment and interactions between nutrition and housing environment were examined by analysis of variance for each of the individual calf crops. A sample analysis is shown in the Appendix 3. In the design of the experiment there was no replication of the houses or of the building site, thus there was no estimate of the error associated with each calf crop. Thus no statistical examination has been made of the differences between calf crops. However any trends associated with seasonal (crop) effects have been indicated.

Performance of the calves from arrival to weaning was calculated using the difference between final and initial weights to determine

* Streptovin. Glaxo Laboratories Ltd., Greeford, England.

the live-weight gain to weaning. Daily live-weight gain was calculated for individual calves by dividing the pre-weaning gain in live weight by the length of time the calf was resident pre-weaning on the unit. The determination of daily live-weight gain was initially made by regressing weekly individual calf live weights against time. No significant reduction in the standard error of this parameter was achieved by using such regression analysis compared with using the difference between the final and initial weight as representing the total live weight gain. It was considered that the reduction in the increased accuracy expected to be gained from using weekly weighings and regression analysis might be accounted for by the variable nature of the live-weight gain experienced by all the calves during each of the four intakes. Of all the calves reared on the unit approximately 60% lost weight or did not have uniform rates of gain over the duration of the trial. The simpler, final minus initial weight achieved an equal amount of precision as the regression technique and was used because of its simplicity. Multiple regression analysis together with correlation analysis was used to give an analysis of variance of the growth variates with all combinations of arrival date, arrival weight, breed and age on arrival as covariates. Inspection of the results suggested the use of the breed covariate was justified in the phase to weaning and the use of the covariates, arrival weight and breed for the period from weaning to the end of the trial. This latter combination was also appropriate for the total period presumably because the period post-weaning over-shadowed the pre-weaning period. The inclusion of the breed covariate in the analysis of the growth variates did not alter the interpretation of the results pertaining to the pre-weaning period. The inclusion of date of

arrival as a covariate accounted for the effects associated with the cells within a house and showed the cell effect to be due to the cells being filled with calves in a set order i.e. calves in the No. 1 cells were resident on the unit longer and were older at weaning than calves in the No. 4 cells.

The effects of housing environment on feed intake and the interactions between milk replacer and concentrates intake were also examined by an analysis of variance technique. The analysis of variance table was of a similar form to that used in examining the effects of housing and level of nutrition on calf performance as shown in Appendix 3.

The partitioning of energy intake into that required for maintenance and gain was determined according to the equation of Forbes and Robinson (1969) where:-

$$I = a\,W^{0.75} + bG + C$$

where I = ME intake

$W^{0.75}$ = mean metabolic live weight $\left(\frac{\text{Final + Initial wt}}{2}\right)^{0.75}$

and G = mean daily live weight gain

The constants 'a' and 'b' represent the factors for maintenance and gain respectively. In the analysis ME intake (I) was considered the independent variable, mean metabolic live weight ($W^{0.75}$) and mean daily live weight gain (G) as the dependent variable.

RESULTS

Weight Records

During the purchase of the calves a minimum weight of 36.3kg (80 lb) live weight was aimed for, although lighter calves were accepted. Initial weights of the calves on arrival do not therefore represent the average weights of calves born during any period of the

year but merely the weight range of animals starting the trial, Table 3c.1.

Table 3c.1

Mean Live Weight on Arrival (kg)

Live weight	Spring'74	Autumn'74	Spring'75	Autumn'75
mean	40.06	41.45	40.55	39.62
min	33.00	34.00	33.00	32.00
max.	57.00	56.00	68.00	49.00

As can be seen, the average live weight and range of initial live weights was very similar for the four calf crops. The average age of calves on arrival together with the breed covariate are shown in Table 3c.2.

Table 3c.2

Mean Age of Calves on Arrival (Days) Together with the Breed Covariate

Age on arrival	Spring'74	Autumn'74	Spring'75	Autumn'75
mean	6.61	6.06	6.12	6.47
min	3.00	1.00	3.00	4.00
max	11.00	13.00	13.00	10.00
Breed covariate	0.76	1.34	1.05	1.16

The random allocation of calves to the houses and nutritional treatments resulted in no significant differences between the age, live weight or breed of any group of calves on any one particular treatment. The breed covariate was calculated by allotting the values of 0, 1 and 2 to the Friesian x Ayrshire, Friesian x Friesian x Ayrshire and Friesian calves respectively. A high value of the breed covariate denotes a higher percentage of Friesian in the population. There were slight differences in the genetic stock of

the four crops as shown by the difference in the mean breed covariates. Three of the pre-weaning trials lasted a total of 70 days each. During the Spring'75 trial calves in the numbers 1 and 2 cells were on trial an average of 77 days and calves in the 3 and 4 cells an average of 70 days.

The mean pre-weaning daily live-weight gain of all calves on each of the four calf crops is shown in Table 3c.3. Whilst the mean value includes data from calves receiving restricted levels of nutrition it does give an indication, from the results of calves on the ad libitum treatments, of the ability of the calves to increase in body weight. Mean daily live-weight gain is also shown for the four nutritional treatments for each calf crop. The better overall performance of the Spring'74 crop is likely due to the higher levels of nutrition fed. Calves receiving the low levels of milk replacer received 400g of milk replacer per day compared with 300g/day on the other three intakes. The analogous concentrate restriction was also correspondingly lower for the latter intakes. Evidence for this may be derived from the fact that calves on the three restricted treatments (LL, LH, HL) tended to have higher live weight gains compared with calves on the corresponding treatments in the other three crops.

Within each of the four calf crops, calves on the HH treatment had the ability to express their maximum performance. A comparison of the HH treatment of each of the four intakes shows no effect of season on the performance of the calves (Spring average = 0.565 kg/day, Autumn average = 0.560 kg/day). There is a suggestion that under restrictive feeding conditions Spring born calves perform slightly better than those born during the Autumn. However, a comparison equivalent to that made with the HH treatments cannot be made due to the higher level of feeding offered to the Spring'74 LL and LH groups.

Table 3c.3

Overall and Nutritional Treatment Mean Daily Live Weight Gain from Arrival to Weaning of Calves During Each of the Four Intakes

	Mean	Standard Error	LL	LH	HL	HH	Standard Error	Significant Difference $P < 0.01$
Spring'74	0.506	0.084	0.425	0.520	0.524	0.556	0.015	LL < LH, HL < HH
Autumn'74	0.471	0.068	0.307	0.473	0.522	0.527	0.012	LL < LH < HL ? ND < HH
Spring'75	0.475	0.096	0.303	0.517	0.506	0.574	0.017	LL < HL, LH < HH
Autumn'75	0.466	0.092	0.334	0.449	0.486	0.593	0.016	LL < LH, HL < HH

Although the differences between the restricted treatments during the Autumn '74 and the Spring and Autumn'75 calf crops were the same, as the level of feeding was based on the ad libitum consumption of one group of calves, the absolute levels of feeding were not equivalent for the three calf intakes. A similar argument is also pertinent to the levels of feeding of calves in each of the four houses during any particular intake.

During three of the four calf intakes, no significant effect of housing was found on the daily live-weight gain of the calves. During the Autumn'74 intake, significant differences were recorded ($P < 0.01$) in the mean daily live weight gain of calves in each of the four houses. The mean daily live weight gain of all calves in each of the four houses is shown in Table 3c.4. It should be noted that any differences in performance may be the result of differences in environment or level of nutrition.

Table 3c.4

The Mean Daily Live Weight Gain (kg/day) of All Calves, Grouped According to Calf House

	A1	A2	B1	B2	P	Treatment Differences
Spring'74	0.521	0.499	0.512	0.493	N.S.	
Autumn'74	0.490	0.497	0.464	0.433	<0.01	A2>B1>B2 A1>B2
Spring'75	0.480	0.503	0.458	0.459	N.S.	
Autumn'75	0.459	0.469	0.431	0.502	N.S.	
Unweighted mean	0.487	0.492	0.466	0.471		

As can be seen during the Autumn '74 crop calves in the A2 house performed significantly better than calves in the B1 and B2 houses. An examination of the mean performance of all calves over the four intakes shows that animals in the A2 houses tended to have the highest daily live-weight gain although the differences between the four mean

values were very small.

The mean daily live-weight gain of calves in each of the four houses presented in Table 3c.4 contains data from calves receiving ad libitum and restricted feeding treatments. Although when presented in this manner the mean values are representative of the performance of all calves in the four houses, an examination of the performance of calves on the ad libitum treatments is required in order to assess the potential of the houses in promoting optimal performance. The daily live-weight gain of the calves receiving the two ad libitum concentrate treatments, grouped according to housing environment is shown in Table 3c.5.

Table 3c.5

Daily Live-Weight Gain of Calves on the Two Ad Libitum Concentrate Treatments Grouped According to Housing Environment

HH treatment	A1	A2	B1	B2
Spring'74	0.553	0.604	0.546	0.521
Autumn'74	0.608	0.619	0.570	0.528
Spring'75	0.571	0.598	0.571	0.557
Autumn'75	0.494	0.563	0.535	0.781
Unweighted mean	0.556	0.596	0.555	0.596
LH treatment				
Spring'74	0.540	0.497	0.513	0.532
Autumn'74	0.507	0.482	0.473	0.428
Spring'75	0.523	0.545	0.497	0.504
Autumn'75	0.463	0.498	0.406	0.429
Unweighted mean	0.508	0.505	0.472	0.473

The data presented in Table 3c.5 derived from the two ad libitum concentrate treatments does not yield any further evidence as to the effect of housing on the performance of the calves. The fact that the calves in the A2 house performed best during five of the eight comparisons is in agreement with the slightly better performance

recorded when the mean daily live-weight gains of the four treatment groups were examined in Table 3c.4. It was not valid to compare the performance of calves from different houses which received the LL and HL treatments as the levels of feeding offered to these restricted calves were not the same in each of the four houses.

Feed Intake

In all the four trials the total feed intake of each calf was obtained by summating its daily intakes. Differences in the amount of feed consumed by calves on different nutritional or housing treatments were analysed using the individual calf data.

Milk Replacer. The mean daily intake of milk replacer by calves on the high and low levels of milk replacer feeding, for each of the four intakes, is shown in Table 3c.6.

Table 3c.6

Mean Individual Daily Milk Replacer Intake (g/day)

Calf Crop	Standard Levels of feeding g/day		Total Consumption g/head	Average days on trial	Mean daily intake g
Spring'74	High	600	36640	65	563
	Low	400	24415	65	375
Autumn'74	High	600	36770	65	565
	Low	300	18500	65	285
Spring'75	High	600	42610	74	576
	Low	300	22034	74	297
Autumn'75	High	600	36579	66	554
	Low	300	18408	66	278

The actual mean daily amount of milk replacer consumed by the calves was approximately 95% of the set standards. This was partly due to the reduced levels of milk feeding which were used to introduce calves to the feeding treatments. Scouring calves were also fed

reduced concentrations and volumes of milk replacer. The reduction of mean daily milk replacer intake compared with the set feeding levels was therefore a combination of the effects due to reduced feeding on arrival and the reduced feeding of scouring calves.

During each of the four intakes there was a significant difference ($P < 0.001$) between the two levels of milk replacer consumed. There was no significant effect of housing or level of concentrate feeding on the amount of milk replacer consumed on either of the two milk replacer levels. During each of the four intakes there was a significant interaction ($P < 0.001$) between cells and houses on the amount of milk replacer consumed. This was probably due to the fact that severe outbreaks of scour were often confined to individual cells, thus single cells of calves received reduced levels of milk replacer. It was not possible from the data to confirm whether this was the reason for the house x cell interaction.

Concentrates. The concentrates were offered to all calves within 14 days of the animals having arrived on the unit. Total consumption of concentrates by individual calves was calculated from the individual daily intakes. In order to estimate the daily concentrate consumption ten days was allowed for the time when concentrates were not offered at the beginning of the trials. The concentrate consumption of calves on each of the four nutritional treatments is shown in Table 3c.7 for each of the four calf intakes.

During the Spring'74 intake the average concentrate restriction imposed on the two low concentrate groups compared with the HI groups was 370g/day. This is in good agreement with the theoretical restriction of 343g/day. During the Autumn'74 and the two 1975 trials the theoretical restriction was 514g/day. The restrictions attained

Table 3a.7

Total and Daily Concentrate Consumption (g) of Individual Calves on Each of the Four Treatments during Each of the Four Calf Trials

	Days on Treatment	T1 Treatment		T2 Treatment		T3 Treatment		T4 Treatment		Standard error of total intake means	Differences between total intakes P < 0.05
		Total Intake g	Daily Intake g	Total Intake g	Daily Intake g	Total Intake g	Daily Intake g	Total Intake g	Daily Intake g		
Spring'74	55	35510.2	645.6	36473.7	663.2	56364.1	1024.8	46143.6	838.9	1774.4	T1,T2<T3<T4
Autumn'74	55	39830.0	724.2	37160.3	312.0	54260.0	986.5	45560.1	828.2	1393.9	T1,T2<T4<T3
Spring'75	64	39677.6	619.9	41755.2	652.6	74440.1	1163.3	54869.1	857.7	2232.9	T1,T2<T4<T3
Autumn'75	56	27107.2	424.5	26233.7	410.8	52642.2	823.5	45823.6	716.1	2307.5	T2,T1<T4,T3

during the Autumn'74, Spring'75 and Autumn'75 trials were 460, 527 and 405g of concentrates per day. The poorer agreement of the theoretical and actual restriction obtained during the Autumn'75 trial was due to the overall low consumption of concentrates by calves on the LH treatment during this trial. As calves on the HL and HH treatments received an allowance of 100g/day of concentrates until the LH calves were consuming in excess of 600g/day, there was an extended period during the Autumn'75 trial when the LH calves were consuming less than 600g/day and the two restricted groups were receiving 100g of concentrates per day. On the two occasions when the actual restrictions were greater than the theoretical this was most probably due to feed refusals by sick calves on the two restricted treatments.

During the Spring and Autumn'74 and the Spring'75 calf crops the concentrate consumption of calves on the LH treatment was significantly greater ($P < 0.01$) than that of calves on the HH treatment, differences between treatments during the three intakes were 186, 156 and 306g/day respectively. During the Autumn'75 crop calves on the LH treatment consumed on average 106g/day more concentrates than calves on the HH treatment, although the two levels of consumption were not significantly different.

Differences in the levels of concentrates consumed by calves in each of the four houses were examined by comparing the mean intakes of all calves in each house. Total concentrate intakes and mean daily intakes of the calves in each of the four houses during each of the four trials are shown in Table 3c.8. The mean daily concentrate consumption of calves on the two ad libitum concentrate treatments for each of the four intakes, is shown in Table 3c.9.

Table 3c.8

Total and Daily Concentrate Consumption of Calves in Each of the Four Houses During Each of the Four Calf Trials

		House A1		House A2		House B1		House B2		Standard error of total intake means	Significant Differences $P < 0.05$
	Days on Treatment	Total Intake g	Daily Intake g	Total Intake g	Daily Intake g	Total Intake g	Daily Intake g	Total Intake g	Daily Intake g		
Spring'74	55	43806.9	796.5	44565.3	810.3	48053.4	873.8	38061.1	692.0	1774.4	B2 A1,A2,B1
Autumn'74	55	21420.0	389.5	49970.0	908.5	43260.0	786.5	42270.0	768.5	1842.0	$P < 0.01$ A1 B2,B1 A2
Spring'75	64	55010.0	859.5	61380.0	959.0	47015.0	734.6	47308.1	739.2	2332.0	N.S.
Autumn'75	56	44813.8	800.2	42993.8	767.7	36212.5	646.6	27911.9	498.4	2307.5	$P < 0.01$ B2 B1,A2,A1

Table 3c.9

Mean Daily Concentrate Consumption of Calves Receiving the Two Ad Libitum Concentrate Treatments

	Days on Treatment	House A1		House A2		House B1		House B2	
		LH	HH	LH	HH	LH	HH	LH	HH
Spring '74	55	1053.4	791.1	954.9	1026.2	1212.8	786.8	878.1	769.8
Autumn '74	55	532.4	435.5	1232.5	1001.3	1082.0	995.1	1093.3	888.4
Spring '75	64	1240.6	896.5	1216.3	842.8	1095.8	892.2	1100.3	795.3
Autumn '75	56	1009.9	1086.1	1143.5	828.4	844.8	849.7	761.9	509.2

There were no significant differences in concentrate consumption within nutritional treatments between houses. However it is pertinent to compare the ad libitum concentrate intakes on the two levels of milk replacer feeding in order to further elucidate the house differences in concentrate intake shown in Table 3c.8. The effect of housing on the ad libitum concentrate intake of calves is summarised in Table 3c.10. Significant differences obtained using total house consumptions are shown together with the trends in daily consumption of calves on the two ad libitum concentrate intake treatments.

Table 3c.10
The Effect of Housing on Concentrate Intake of Calves Allowed Ad Libitum Access to Concentrates

	Significant differences obtained using total concentrate consumption ←—— inc. consumption	Treatment	Trend in Daily Concentrate Intake ≐ denotes difference of less than 10g/day —→ increasing consumption
Spring '74	B2<A1, A2, B1	LH	B2 A2 A1 B1
		HH	B1 ≐ B2 A1 A2
Autumn '74	A1 < B2, B1 < A2	LH	A1 B1 ≐ B2 A2
		HH	A1 B2 B1 ≐ A2
Spring '75	N.S.	LH	B1 ≐ B2 A2 A1
	B1, B2, A1, A2	HH	B2 A2 B1 ≐ A1
Autumn '75	B2 < B1, A2, A1	LH	B2 B1 A1 A2
		HH	B2 A2 B1 A1

It can be seen from Table 3c.10 that the trend in daily concentrate consumption of the LH calves closely follows the trend in total consumption when significant differences in consumption were found. The trend in consumption of the HH calves does not follow as consistently the trend in total consumption as do the LH calves. As the two restricted concentrate groups were based on the consumption of the LH groups then small differences between houses in concentrate consumption of the LH calves may achieve significance by virtue of the replication of the difference on the two restricted treatments. Thus the differences in concentrate consumption found in different houses mainly represent differences achieved by calves on the LH treatment. On two occasions during the four calf crops the total consumption of concentrates by calves in the B3 house was significantly less than calves in either of the other three houses. This occurred during the Spring'74 and Autumn '75 intakes, hence there is no evidence to suggest that the reduction in intake was a seasonal effect. There was no other identifiable effect of housing on concentrate intake.

The total concentrate consumption of all calves during each of the four intakes is shown in Table 3c.11, together with the estimated mean daily intakes.

Table 3c.11

Total and Mean Daily Concentrate Consumption of all Calves on Each of the Four Intakes

Spring'74			Autumn'74			Spring'75			Autumn'75		
Days on Trial	Total £	Daily £	Days on Trial	Total £	Daily £	Days on Trial	Total £	Daily £	Days on Trial	Total £	Daily £
55	43622	793	55	39230	713	64	52678	823	56	37982	678

As can be seen there was a tendency for calves of the two Spring intakes to consume approximately 100g/day more concentrates than calves of the

two Autumn crops. As has previously been explained, differences between crops were not tested for significance. This difference would amount to a total increase in consumption in excess of 5kg per head of concentrate by calves during the Spring intakes compared with the Autumn intakes.

Hay. Good quality fresh hay was available to all calves from 14 days after the calves arrived on the unit. The maximum allowance was 500g per head per day. The figures quoted for hay consumption do not, therefore, represent the ad libitum hay intakes of the calves. On no occasion were differences found in total hay consumption between the four nutritional treatments. During the Autumn'74 and the two intakes of 1975 calves on the low milk replacer treatment consumed more hay than calves on the high milk replacer treatment. However, the amounts consumed were not significantly different. The total amounts of hay consumed by calves on the ad libitum and restricted concentrate feeding treatments are shown in Table 3c.12.

Table 3c.12

Total Hay Consumption in g of Calves on the Two Concentrate Feeding Treatments

Spring'74		Autumn'74		Spring'75		Autumn'75	
ad lib	restricted	ad lib	restricted	ad lib	restricted	ad lib	restricted
5434.8	6117.9	4940.0	6730.0	5332.0	6488.3	9418.4	14371.1
N.S.		$P < 0.001$		$P < 0.05$		$P < 0.001$	

During all four intakes the hay consumption of calves on the restricted level of concentrate feeding was greater than that of calves receiving concentrates ad libitum. The three occasions when the differences achieved significance are shown in Table 3c.12.

Total amounts of hay consumed in each of the four houses were similar in each of the Spring'75 and Autumn'75 calf crops. The total

hay consumed per head by the calves in each of the four houses during the four calf crops is shown in Table 3c.13.

Table 3c.13

Total Hay Consumed Per Head by Calves in Each of the Four Houses During the Four Calf Crops

	Total Consumption g.				Treatment Differences
	House A1	House A2	House B1	House B2	
Spring'74	6464.7	7325.0	5317.2	3998.7	$P < 0.01$ A1, A2 > B2
Autumn'74	2840.0	5730.0	8590.0	6170.0	$P < 0.001$ B1>A2>A1 B1>B2>A1
Spring'75	6578.1	7757.8	2890.6	6414.1	N.S.
Autumn'75	13039.0	11750.0	11742.0	11047.0	N.S.

There was no discernible trend in the roughage consumption of the calves in each of the four houses throughout the duration of the four calf crops.

Metabolizable Energy Intake

The metabolizable energy values of the milk replacer and concentrates were determined during the metabolism trial. During the metabolism trial and over the levels of feeding employed there was no suggestion that the metabolizable energy content of the milk replacer was affected by concentrate feeding *per se* or by the level of concentrates fed. Similarly there was no suggestion that the amount of milk replacer fed had any effect on its metabolizable energy content. Thus over the period of the four trials the milk replacer was allotted a value of 19.17 MJ.ME per kg DM.

From the results of the metabolism trial the metabolizable energy content of the concentrates was found to be 9.37 MJ/kg. It was suggested that this low value was a result of the low concentrate digestibility attained by the calves during the short period of time

for which concentrates were fed during the metabolism trial. As concentrate consumption was increasing exponentially during the early part of the main calf trial it was considered inappropriate to allocate the low value of the metabolizable energy of the concentrates obtained during the metabolism trial to the concentrate consumption of the calves throughout the main trial. The digestibility of the concentrates by the calves during the metabolism trial was 70%. If the digestibility had been 80% as expected from Roy (1970) then the ME content of the concentrates would be:

$$\frac{9.37}{70} \times 80 = 10.70 \text{ MJ.ME/kg}$$

The value of 10.70 MJ.ME/kg agrees well with that of an equivalent cattle cake (12.5 MJ.ME/kg DM @ 90% DM. M.A.F.F. Bulletin 33). Hence a value of 11 MJ.ME/kg was adopted as the metabolizable energy content of the concentrates as fed.

The metabolizable energy content of the hay fed to the calves was taken as the mean value of the 23 samples taken during the period of the trial. The ME content of the hay was calculated from:-

$$\text{MJ.ME/kg DM} = 0.235 \times \begin{pmatrix}\text{digestible organic matter} \\ \text{in the dry matter \%}\end{pmatrix} - 4.45$$

(R.F.Alexander - personal communication)

The mean ME content of the hay obtained in this manner was 7.78±1.02 MJ.ME/kg DM. The mean dry matter content of the hays was 80.72% = 6.28 MJ.ME/kg hay as fed.

The values of total milk, concentrates and hay intakes of individual calves were used in conjunction with the metabolizable energy values of the milk concentrates and hay of 18.14, 11.0 and 6.3 MJ.ME/kg fed respectively to calculate the total and daily metabolizable energy consumption of all the calves for the duration of each of the four calf trials. The mean daily metabolizable energy

consumptions of calves on each of the four nutritional treatments are shown in Table 3c.14 for each of the four calf crops.

Table 3c.14

Mean Daily Metabolizable Energy Intakes of Calves on Each of the Four Nutritional Treatments

	Daily ME intake MJ.ME/day				Standard error	Treatment Differences P < 0.001
	LL	LH	HL	HH		
Spring'74	13.77	17.05	17.24	18.76	0.331	LL < LH, HL < HH
Autumn'74	10.78	14.85	15.73	18.56	0.233	LL < LH, HL < HH
Spring'75	11.97	17.42	18.21	19.26	0.373	LL < LH, HL, HH
Autumn'75	11.29	15.11	16.12	18.73	0.385	N.S.

Although significant differences between the four nutritional treatments were only found in the first three calf crops there were significant differences in the daily ME intake ($P < 0.001$) between the high and low milk feeding treatments and between the high and low concentrate feeding treatments with each of the four calf crops. The lack of significance between the four individual treatments during the Autumn'75 crop may have been due to the changes in level of feeding of calves of ill health thus giving a higher within treatment variation as evidenced by the higher standard error.

As can be seen the four nutritional treatments have resulted in different levels of energy intake by the calves during each trial. During each of the four trials calves on the HH treatment had the highest energy intake and calves on the LL treatment the lowest energy intake. During the four calf crops calves on the HL treatment had higher intakes of metabolizable energy than calves on the LH treatment, although the differences were not significant. Although in the design of the four nutritional treatments calves on the LH and HL treatments were to

receive the same daily energy allowance the calves on the HL treatment likely received more energy from the increased hay intake noted in calves fed the restricted level of concentrates. The total differences in hay consumption between the ad libitum and concentrate restricted groups were 0.683, 1.790, 1.156 and 4.953 kg for the Spring'74, Autumn'74, Spring'75 and Autumn'75 groups respectively. These differences in hay consumption represent increases of 0.065, 0.173, 0.113 and 0.55 MJ.ME/day respectively for each of the four calf crops in chronological order. It can be seen therefore that differences in hay intake cannot completely account for the differences in the daily ME intake between the HL and LH treatments. Differences between treatments would have resulted from the treatment of scouring calves, however, as more scour was found in calves receiving the high level of milk replacer then reductions were made in the amounts of food offered to the HL and HH calves on more occasions than were made in the amounts offered to LL and LH treatment calves. On the basis of this argument the ME intake of the HL calves would be expected to be below that of the LH calves. The reasons for the small difference between the energy intakes of the HL and LH calves when hay consumption was accounted for are difficult to fully explain. However, small differences in metabolizable energy intake between treatments may have resulted from the small discrepancy in the metabolizable energy values of the milk replacer and concentrates used in formulating the nutritional treatments and the actual values obtained from the metabolism trial.

During the Spring'74 intake calves on the low level of milk replacer feeding received 400g of milk replacer per day compared with calves in the other three intakes which received 300g of milk replacer per day on the low level of milk feeding. By subtracting 1.814 MJ.ME from the daily ME intake of the Spring'74 LH calves (milk replacer 18.14 MJ.ME/kg $\therefore$ 100g = 1.814 MJ.ME) then the energy intakes of the calves receiving

the LH and HH treatments may be compared for each of the four calf crops, Table 3c.14. During the two Spring intakes calves in the LH and HH groups consumed 1.34 and 0.35 MJ.ME per head per day respectively more than the calves on the same two treatments during the Autumn intakes.

The mean daily metabolisable energy intakes of calves in each of the four houses during each of the four intakes is shown in Table 3c.15.

Table 3c.15

Mean Daily Metabolisable Energy Intakes of Calves in Each of the Four Houses

	Daily ME intake MJ.ME/day				Standard error	Treatment Differences
	A1	A2	B1	B2		
Spring'74	16.77	16.88	17.51	15.66	0.33	* B2 < A1 A2 B1
Autumn'74	11.70	16.68	15.96	15.57	0.23	** A1 < A2 B1 B2
Spring'75	17.16	17.75	16.12	15.84	0.37	N.S.
Autumn'75	16.61	16.19	15.12	13.31	0.39	N.S.
Unweighted mean	* 16.84	16.87	16.17	15.09		

* The Autumn'74 result was ignored in the calculation of the mean.

The result pertaining to the A1 house during the Autumn'74 intake was anomalous due to the very low concentrate intake of six of the LH reference calves, thus the concentrate restricted treatments were severely restricted, consequently the mean daily ME intake does not justify comparison with the other three houses. As has previously been stated, the mean intakes of the calves in the four houses presented as in Table 3c.15 is biased by the consumption of the LH calves as two of the other treatments were based on the concentrate consumption of these calves. The values are comparable however as the level of restriction used was the same in each of the four houses and the level of restriction in concentrate intake was achieved approximately at the

same time in each of the four houses, hence there were no differences between houses in the feed intake of calves before the treatments were established. (Spring'74; 25, 26, 23 and 26 days to establishment of treatments in A1, A2, B1 and B2 houses respectively).

During the four calf crops, calves in the B2 houses had a lower daily metabolizable energy intake per head than calves in any of the other three houses. This difference was only significant ($P < 0.05$) during the Spring'74 intake. There was no trend over the four intakes between the other three houses, although from the means of the four intakes there was a suggestion that the daily ME intake per head per day of calves in the A type houses was very similar but slightly above

Energy for Maintenance and Live-Weight Gain

Energy for Maintenance and Live-Weight Gain

The expected live-weight gains of calves on the four levels of nutrition and in each of the four houses were calculated for comparison with the actual rates of gain obtained up to weaning. The energy intake of the calves was taken as the mean daily metabolizable energy intake of each treatment group over the total period up to weaning. The mean daily live-weight gain was calculated from the day the calves arrived on the unit until weaned as was the daily metabolizable energy intake. The mean live weight of each treatment group was converted to the metabolic live weight ($W^{0.75}$) and the daily maintenance requirement calculated as 0.42 MJ.ME/$kg^{0.75}$. The expected live-weight gain was then computed from the energy available in excess of maintenance. The values of 11.2 and 13.8 MJ.ME/kg live-weight gain (Holmes and Davey, 1976) for calves on low and high levels of feeding respectively plus the mean of these two values were examined in the context of the present trial. The results of the four calf crops are summarised in Tables

3c.16 to 3c.19. It can be seen that, from the figures of the actual as percentages of the expected gain, the figure of 11.2 MJ.ME/kg live weight was more relevant to the calves on the lower rates of gain and the figure of 13.8 MJ.ME/kg live-weight gain was more relevant to the calves achieving high rates of gain. The final column of Tables 3c.16 to 3c.19 shows the metabolisable energy required per kg of live-weight gain during each of the four intakes when a value of 0.42 MJ.ME/$kg^{0.75}$ was allowed for the maintenance requirement of the calves. The mean live weights, daily live-weight gains and daily energy intakes were used for this computation.

The relationship between the live-weight gain of the calves on the four nutritional treatments and the mean metabolisable energy intake in MJ.ME per day in excess of maintenance is shown in Figure 3c.3 for the four crops of calves. There is little to suggest that anything other than linear regression should be used to describe the data. In plotting this graph the assumption was made that the maintenance requirement of the calves did not differ during the four intakes and was unaffected by the level of feeding. These same assumptions were made in calculating the data for Figure 3c.4 which shows live-weight gain and the energy required per unit of live-weight gain. If the energy required per unit live-weight gain was a constant then the data should form a line parallel with the daily live-weight gain axis, bisecting the energy axis at the energy requirement per unit gain. The points x and y represent the energy requirement of the gain of the Friesian calves used by Holmes and Davey (1976). These calves were fed in two groups and gained 0.30 and 0.60 kg/day respectively. The points x and y represent the energy requirements per unit of live-weight gain at these two rates of gain. In this presentation the two

Table 3c.16

Calculation of Expected Daily Live Weight Gains of Calves of the Spring'74 Intake

Treatment	Mean L.Wt kg	Mean Metabolic Wt. $kg^{0.75}$	Maintenance Requirement MJ/day	Energy Intake MJ/day	Energy in Excess of Maintenance MJ/day	Expected L.W.G. kg/day at 11.2MJ/kg (1)	Expected L.W.G. kg/day at 12.5MJ/kg (2)	Expected L.W.G. kg/day at 13.8MJ/kg (3)	Actual L.W.G. kg/day	Actual / Expected (1) %	Actual / Expected (2) %	Actual / Expected (3) %	MJ.ME/kg actual L.W.G.
LL	53.58	19.80	8.32	13.77	5.45	0.49	0.436	0.395	0.425	86.7	97.5	107.6	12.82
LH	57.25	20.81	8.74	15.11	6.37	0.569	0.510	0.462	0.520	91.4	102.0	112.6	12.25
HL	57.98	21.01	8.82	16.12	7.30	0.652	0.584	0.529	0.524	80.4	89.7	99.1	13.93
HH	58.26	21.09	8.86	18.73	9.87	0.881	0.790	0.715	0.556	63.1	70.4	77.8	17.75
A1	56.16	20.51	8.61	16.77	8.16	0.729	0.652	0.591	0.521	71.5	79.9	88.2	15.66
A2	57.34	20.84	8.75	16.88	8.13	0.726	0.650	0.589	0.499	68.7	76.8	84.7	16.29
B1	57.59	20.91	8.78	17.51	8.64	0.771	0.698	0.626	0.512	66.4	73.4	81.8	16.88
B2	55.99	20.47	8.59	15.66	7.07	0.631	0.565	0.512	0.493	78.1	87.3	96.3	14.34

Table 3c.17

Calculation of Expected Daily Live Weight Gains of Calves of the Autumn'74 Intake

Treatment	Mean L.Wt kg	Mean Metabolic Wt. $W^{0.75}$	Maintenance Requirement MJ/day	Energy Intake MJ/day	Energy in Excess of Maintenance MJ/day	Expected L.W.G. kg/day at 11.2MJ/kg (1)	Expected L.W.G. kg/day at 12.5MJ/kg (2)	Expected L.W.G. kg/day at 13.8MJ/kg (3)	Actual L.W.G. kg/day	Actual Expected (1) %	Actual Expected (2) %	Actual Expected (3) %	MJ.ME/kg actual L.W.G.
LL	52.07	19.38	8.14	10.78	2.64	0.236	0.211	0.191	0.307	130.1	145.5	160.7	8.59
LH	56.39	20.58	8.64	14.85	6.21	0.554	0.496	0.450	0.473	85.4	95.4	105.1	13.13
HL	58.19	21.07	8.85	15.73	6.88	0.614	0.550	0.499	0.522	85.0	94.9	104.6	13.18
HH	59.48	21.42	8.99	18.56	9.57	0.854	0.765	0.693	0.527	61.7	68.9	76.0	18.16
A1	57.51	20.88	8.77	11.70	2.93	0.262	0.234	0.212	0.490	187.0	209.4	231.1	5.98
A2	56.93	20.73	8.71	16.68	7.97	0.712	0.638	0.578	0.497	69.8	77.9	86.0	16.04
B1	57.84	20.97	8.81	15.96	7.15	0.638	0.572	0.518	0.464	72.7	81.1	89.6	15.41
B2	55.66	20.38	8.56	15.57	7.01	0.626	0.561	0.508	0.433	69.2	77.2	85.2	16.19

Table 3c.18

Calculation of Expected Daily Live Weight Gains of Calves of the Spring'75 Intake

Treatment	Mean L.Wt kg	Mean Metabolic Wt $W^{0.75}$	Maintenance Requirement MJ/day	Energy Intake MJ/day	Energy in Excess of Maintenance MJ/day	Expected L.W.G. kg/day at 11.2MJ/kg (1)	Expected L.W.G. kg/day at 12.5MJ/kg (2)	Expected L.W.G. kg/day at 13.8MJ/kg (3)	Actual L.W.G. kg/day	Actual / Expected (1) %	Actual / Expected (2) %	Actual / Expected (3) %	MJ.ME/kg actual L.W.G.
LL	51.99	19.36	8.13	11.97	3.84	0.343	0.307	0.278	0.303	88.3	98.7	109.0	12.67
LH	59.16	21.33	8.96	17.42	8.46	0.755	0.677	0.613	0.517	68.5	76.4	84.3	16.36
HL	59.46	21.41	8.99	18.21	9.22	0.823	0.737	0.668	0.506	61.5	68.7	75.7	18.22
HH	61.48	21.96	9.22	19.26	10.04	0.896	0.803	0.728	0.574	64.1	71.5	78.8	17.49
A1	58.13	21.05	8.84	17.16	8.32	0.743	0.666	0.603	0.480	64.6	72.1	79.6	17.33
A2	58.52	21.16	8.89	17.75	8.86	0.791	0.709	0.642	0.503	63.6	70.9	78.3	17.61
B1	57.11	20.77	8.72	16.12	7.40	0.661	0.592	0.536	0.458	69.3	77.4	85.4	16.16
B2	58.35	21.11	8.87	15.84	6.97	0.622	0.558	0.505	0.459	73.8	82.3	90.9	15.19

Table 3c.19

Calculation of Expected Daily Live Weight Gains of Calves of the Autumn'75 Intake

Treatment	Mean L.Wt kg	Mean Metabolic $W^{0.75}$	Maintenance Requirement MJ/day	Energy Intake MJ/day	Energy in Excess of Maintenance MJ/day	Expected L.W.G. kg/day at 11.2MJ/kg (1)	Expected L.W.G. kg/day at 12.5MJ/kg (2)	Expected L.W.G. kg/day at 13.8MJ/kg (3)	Actual L.W.G. kg/day	Actual / Expected (1) %	Actual / Expected (2) %	Actual / Expected (3) %	MJ.ME/kg actual L.W.G.
LL	51.02	19.09	8.02	11.29	3.72	0.292	0.262	0.270	0.334	114.4	127.5	123.7	11.14
LH	53.38	19.89	8.35	15.11	6.76	0.604	0.540	0.490	0.449	74.3	83.1	91.6	15.06
HL	55.54	20.34	8.54	16.12	7.58	0.677	0.606	0.549	0.486	71.8	80.2	88.5	15.59
HH	59.51	21.43	9.00	18.73	9.73	0.869	0.778	0.705	0.593	68.2	76.2	84.1	16.41
A1	55.31	20.28	8.52	16.61	8.09	0.722	0.647	0.586	0.459	63.6	70.9	78.3	17.63
A2	54.57	20.08	8.43	16.19	7.76	0.693	0.620	0.562	0.469	67.7	75.6	83.5	16.55
B1	53.84	19.88	8.35	15.12	6.77	0.604	0.542	0.491	0.431	71.4	79.5	87.8	15.71
B2	56.19	20.52	8.62	13.31	4.69	0.419	0.375	0.340	0.502	83.5	133.9	147.6	9.34

Fig. 3c.3.

Daily live-weight gain versus Metabolizable energy. MJ.ME per day in excess of maintenance.

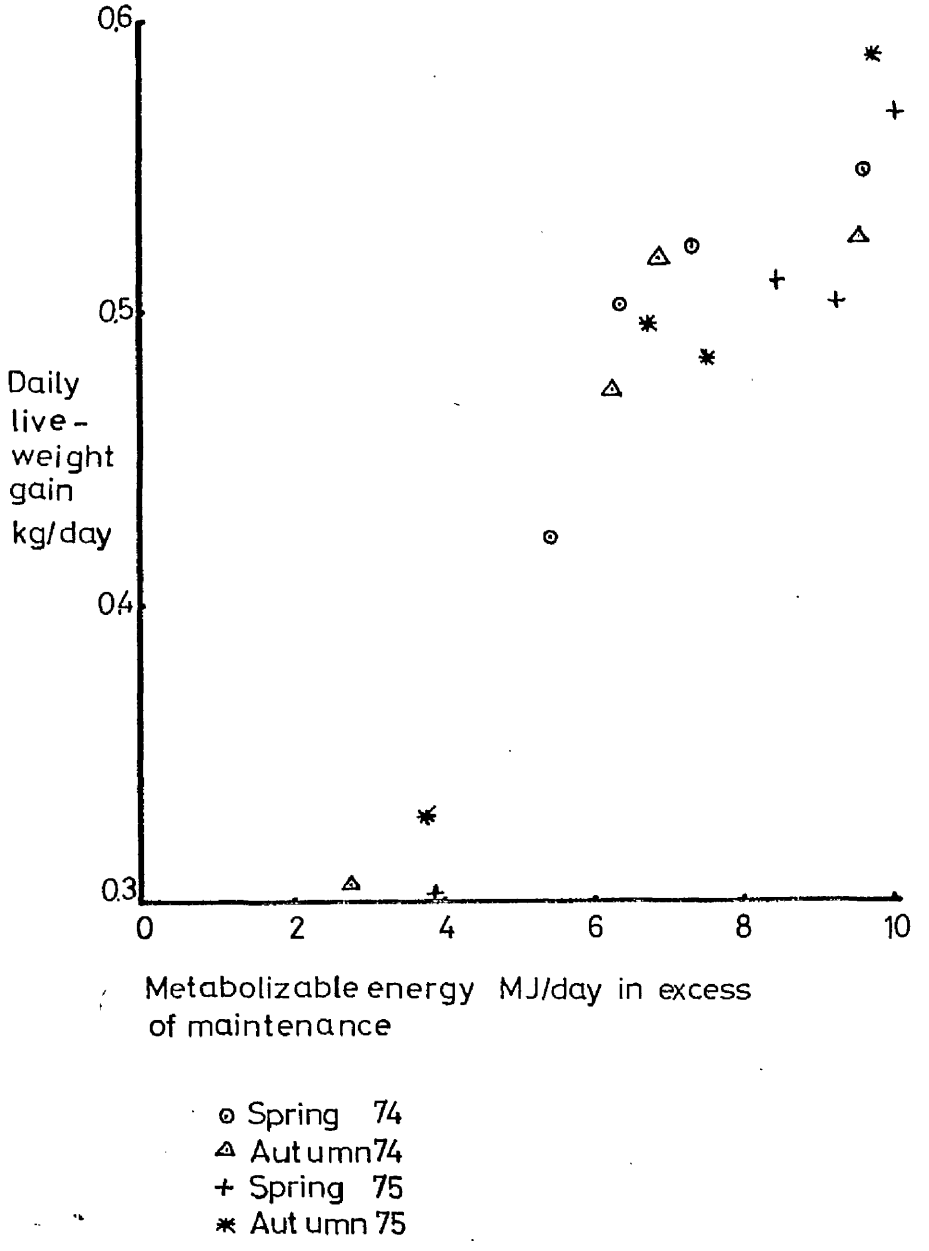
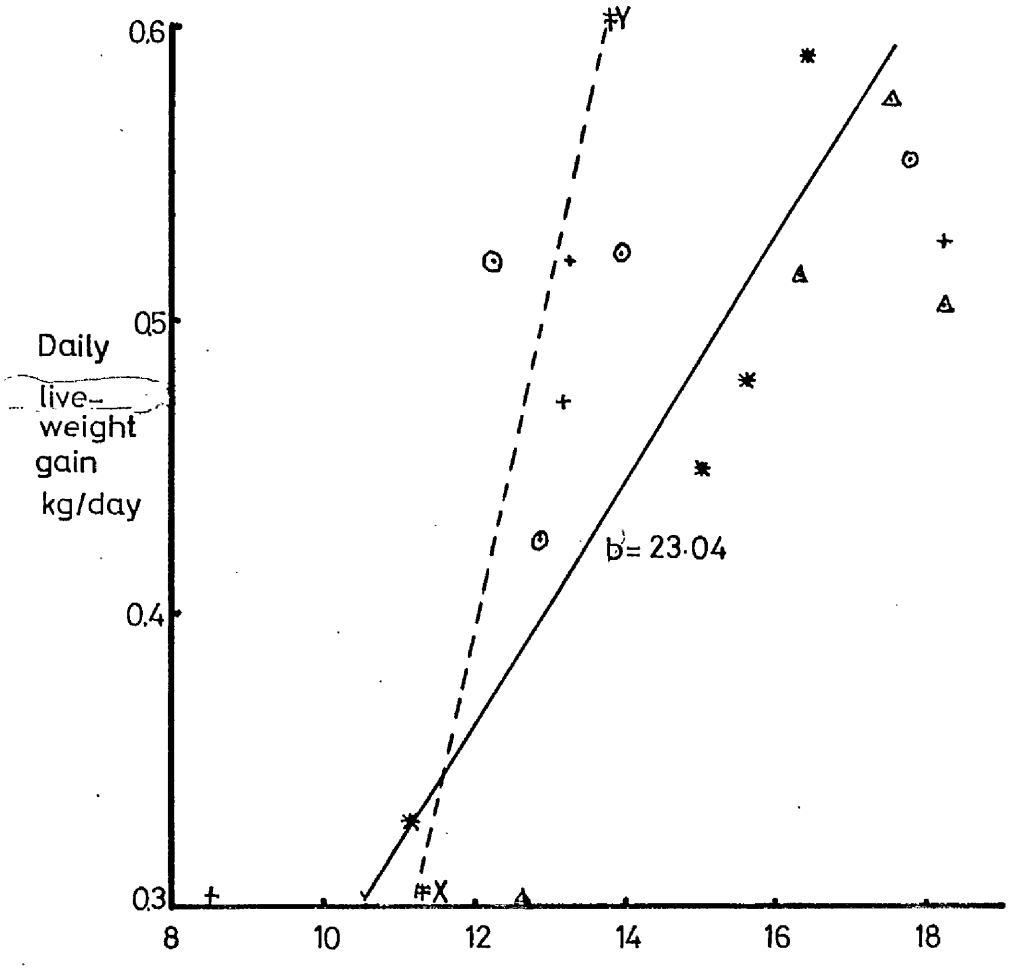


Fig. 3c.4.

Daily live-weight gain versus Metabolizable Energy required per unit live-weight gain, in excess of maintenance.



points x and y have been joined by a straight line and the slope of this line represents the increase in energy requirement per unit live-weight gain as the daily rate of gain of the calves increased. At this stage it cannot be categorically stated that the relationship is linear. The statistically determined line of best fit of the data from the present trial is also shown. It should be emphasised that it has been assumed that the maintenance requirements of the calves did not differ during each of the four intakes and on each of the levels of nutrition. The equation representing the line of best fit for the data is given by:-

$$y = 23.044\ x + 3.577$$

where x = Metabolisable Energy MJ/kg live-weight gain

y = daily live-weight gain, kg

Due to the assumptions made regarding the maintenance requirement of the calves this information should be viewed with caution. It does however indicate that the energy requirement of the calf for live-weight gain increased as the daily live-weight gain of the calves increased.

Examination of Tables 3c.16 to 3c.19 also shows that during three of the four intakes the metabolisable energy required per kilogram of gain by calves in the B2 house was less than for calves in the other three houses. However, during the Autumn'74 intake the metabolizable energy requirement per kilogram of gain was highest for the calves in the B2 house. The tables show that during two of the four intakes the live-weight gain of calves in the B2 house was lower than calves in the other three houses and on a third occasion it was second to lowest. If, as previously stated, the metabolisable energy requirement for live-weight gain is dependent on the rate of gain then it cannot be stated

that the results shown in Tables 3c.16 to 3c.19 demonstrate increased efficiency of metabolizable energy utilization for gain attributable to the B2 type house.

A second approach was used in order to determine the metabolizable energy requirements of the calves for maintenance and live-weight gain. Multiple linear regression analyses were carried out. Metabolizable energy intake (MJ.ME/day) was regressed against daily live-weight gain and against initial live weight. Initial live weight was chosen as it was independent of energy intake. It was considered that as the data was being fitted to the equation:

$$I = a\,W^{0.75} + bG$$

where I = the mean daily ME intake

$W^{0.75}$ = the metabolic live weight - in the first instance initial live weight was chosen

G = daily live-weight gain, kg

then for 'a' and 'b' to represent the energy required for maintenance and for daily gain respectively, the metabolic live weight chosen should be that calf weight which represents a calf consuming I. MJ.ME/day. Metabolic weights chosen above or below the correct weight would over or under estimate the contribution of the total energy intake used for maintenance. As the metabolizable energy available for gain is obtained by difference an over estimation of the maintenance requirement would leave less energy for gain hence on calculation the efficiency of energy utilization for gain would be higher. In animals gaining at a uniform rate of gain and on a fixed daily energy allowance the mean live weight during the period can be related to the mean energy intake. In the present experiment the metabolizable energy intake of the calves increased as appetite increased and the live-weight gain of the calves fed ad libitum was likely to have shown an exponential rate of change over the early part of the trial. Under these conditions the mean

energy intake of any particular calf may not necessarily coincide with the mean live weight over the total period. It was not possible to determine a value of W which was the weight of the calf consuming I MJ.ME/day. In view of this it was considered most appropriate to cover the range of individual calf weights and also to present the mean value. In this manner the maximum and minimum metabolizable energy requirements for maintenance would be covered. The three multiple regressions using initial, mean and final live weights were carried out on individual calf data for the four trials. For each trial period, the data was examined for all the calves grouped together. Separate analyses for each of the four houses were also carried out by fitting four parallel lines, one for each of the houses, and by four independent straight lines. The most appropriate analysis for each intake of calves was found by selecting that analysis which yielded the lowest residual mean square value. Where the four independent lines were fitted, the residual sum of squares of each of the plots was summed and the total residual mean square compared with that of the four parallel lines or the single regression line. The coefficients of 'a' and 'b' in equation (1) when $W^{0.75}$ was calculated using the initial mean and final live weights, and the residual sums of squares, numbers of degrees of freedom and variance accounted for, are shown for each analysis in Tables 3c.20 to 3c.23.

In preparing the data for these analyses initially the metabolizable energy intake of the calves was calculated from the sum of the daily metabolizable energy intakes from the day the calves arrived on the unit until they were weaned. On an examination of the daily live-weight gain of the calves it was found that during all four intakes a large proportion of the calves lost weight when they first arrived on the unit. The energy balance of an animal which initially

Table 3c.20

Values of the Coefficients of 'a' and 'b' in the Equation I = $aW^{0.75} + bG$ Spring'74

Value of W in equation	Coefficient	Values of the coefficients of 'a' and 'b' in the regression equation					
		Single line	4 Parallel	A1	A2	B1	B2
	a	0.335	0.285	0.005	0.468	0.397	0.237
	b	22.440	22.558	31.734	19.032	21.616	23.702
			23.262				
Initial			23.557				
Weight			23.778				
Degrees of Freedom		116	113	27	28	26	29
Residual S.S.		333.2	308.3	71.03	58.38	74.66	81.53
Variance accounted		59.89	62.87	-	-	-	-
	a	0.326	0.275	0.017	0.493	0.382	0.242
	b	19.835	20.452	32.465	13.858	18.744	21.490
			21.117				
Mean			21.421				
Weight			21.693				
Degrees of Freedom		116	113	27	28	26	29
Residual S.S.		339.10	314.20	71.00	61.75	77.23	79.68
Variance accounted		59.18	62.18	-	-	-	-
	a	0.294	0.24409	0.027	0.491	0.328	0.234
	b	18.617	19.565	33.064	9.818	18.067	19.918
			20.227				
Final			20.558				
Weight			20.854				
Degrees of Freedom		116	113	27	28	26	29
Residual S.S.		349.40	322.70	70.93	67.11	81.79	78.77
Variance accounted		70.49	71.36	-	-	-	-

Table 3c.21

Values of the Coefficients of 'a' and 'b' in the Equation $I + aW^{0.75} + bG$ Autumn'74

Value of W in equation	Coefficient	Values of the coefficients of 'a' and 'b' in the regression equation					
		Single line	4 Parallel	A1	A2	B1	B2
	a	0.294	0.366	0.214	0.244	0.367	0.282
	b	21.718	22.459	16.710	25.613	21.632	25.317
			17.042				
Initial			22.246				
Weight			22.041				
Degrees of Freedom		124	121	30	29	30	29
Residual S.S		959.40	311.40	53.52	38.86	114.30	83.54
Variance accounted		28.47	76.78	-	-	-	-
	a	0.292	0.369	0.218	0.250	0.362	0.282
	b	19.205	19.121	14.636	23.212	18.598	22.826
			13.684				
Mean			18.903				
Weight			18.713				
Degrees of Freedom		124	121	30	29	30	29
Residual S.S		965.50	313.50	52.37	38.99	116.80	84.90
Variance accounted		39.28	80.28	-	-	-	-
	a	0.280	0.358	0.215	0.244	0.347	0.274
	b	17.370	16.580	12.988	21.441	16.377	20.918
			11.145				
Final			16.368				
Weight			16.204				
Degrees of Freedom		124	121	30	29	30	29
Residual S.S		973.80	320.20	51.79	39.76	120.20	86.66
Variance accounted		38.75	79.86	-	-	-	-

Table 3c.22

Values of the Coefficients of 'a' and 'b' in the Equation $I = aW^{0.75} + bG$ Spring'75

Value of W in equation	Coefficient	Values of the coefficients of 'a' and 'b' in the regression equation					
		Single line	4 Parallel	A1	A2	B1	B2
	a	0.366	0.355	0.369	0.492	0.338	0.369
	b	21.270	21.241	22.233	19.295	22.009	20.912
			22.026				
Initial			20.959				
Weight			21.430				
Degrees of Freedom		96	93	24	23	23	20
Residual S.S		380.90	365.30	57.28	167.80	99.47	40.42
Variance accounted		52.81	54.72	-	-	-	-
	a	0.382	0.375	0.384	0.425	0.351	0.404
	b	17.223	12.275	18.251	14.795	18.372	16.126
			18.006				
Mean			20.872				
Weight			21.368				
Degrees of Freedom		96	93	24	23	23	20
Residual S.S		362.60	346.60	50.28	162.90	93.70	38.37
Variance accounted		55.07	57.07	-	-	-	-
	a	0.372	0.367	0.378	0.397	0.344	0.407
	b	14.361	14.424	15.184	12.294	15.673	12.509
			15.150				
Final			14.017				
Weight			14.538				
Degrees of Freedom		96	93	24	23	23	20
Residual S.S		355.60	338.70	46.32	162.50	90.17	38.40
Variance accounted		55.94	58.03	-	-	-	-

Table 3c.23

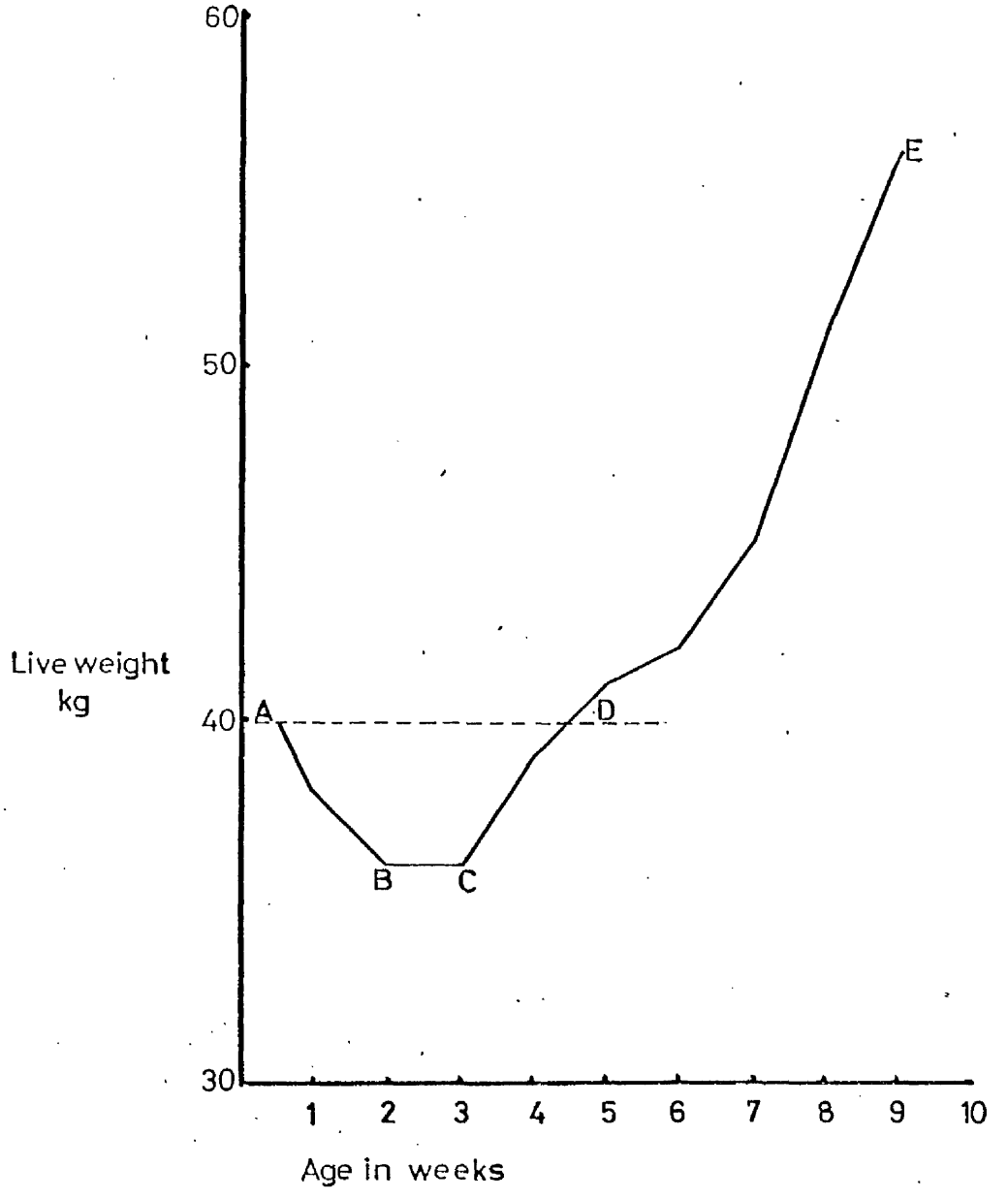
Values of the Coefficients of 'a' and 'b' in the Equation $I = aW^{0.75} + bG$ Autumn'75

Value of W in equation	Coefficient	Values of the coefficients of 'a' and 'b' in the regression equation					
		Single line	4 Parallel	A1	A2	B1	B2
	a	0.262	0.249	0.378	0.324	0.301	0.164
	b	24.177	23.527	21.282	22.862	22.855	26.235
			24.277				
Initial			24.329				
Weight			23.983				
Degrees of Freedom		107	104	25	28	25	23
Residual S.S		357.5	347.5	145.3	45.95	59.11	87.74
Variance accounted		70.41	71.23	-	-	-	-
	a	0.260	0.247	0.389	0.324	0.295	0.161
	b	21.930	21.378	17.434	19.981	20.435	24.878
			22.133				
Mean			22.191				
Weight			21.864				
Degrees of Freedom		107	104	25	28	25	23
Residual S.S		356.0	345.8	144.0	43.15	60.72	87.67
Variance accounted		70.53	71.37	-	-	-	-
	a	0.251	0.238	0.379	0.313	0.284	0.156
	b	20.202	19.724	14.682	17.843	18.567	23.775
			20.490				
Final			20.552				
Weight			20.247				
Degrees of Freedom		107	104	25	28	25	23
Residual S.S		356.5	346.0	144.1	41.74	62.70	87.64
Variance accounted		57.93	61.16	-	-	-	-

loses and then gains weight cannot be considered to be the same as that of an animal which shows a similar total gain in weight but achieves this by consistently gaining in weight. As an example, the weight gain of one calf during the Autumn '75 intake is shown in Figure 3c.5. The pattern of weight gain in this instance was representative of the change in weight of nearly half the calves examined over the four trials. Three phases of growth can be identified. From A to B, over a period of approximately ten days, the calf lost 4 kg in weight. Between B and C the calf may have lost and then gained weight or it may have maintained itself. From C to E the calf gained weight to weaning at point E. Seebeck (1973) showed that during weight loss in Brahman cross and Africander cross steers of approximately 390 kg at the start of the experiment, muscle and fat approximately reversed the path taken during development, while bone, fascia and tendon remained approximately constant. No evidence of a proportionately early loss of fat and later loss of muscle, or vice versa, was found. These results showed an important difference with earlier work when it was found that the amount of muscle was reduced in a greater proportion than that expected from the pattern of development during body weight gain (Seebeck and Tulloh 1968a, b). Between points A and B on Figure 3c.5 weight loss occurred although the calf continued to consume energy in excess of maintenance. This may have been due to the calf scouring. By analogy with Seebeck (1973) the weight loss may have occurred as a result of muscle and fat catabolism. It may also have been due to dehydration which was noted to occur in many of the calves. Between points C and D the calves gained the weight which was lost between A and B. The content of the gain between C and D was unlikely to be the same as that between D and E. Between C and D the calf may have rehydrated. It was shown by Seebeck (1973) that during weight loss, bone fascia and tendon remained approximately constant. The energy of bone accretion

Fig. 3c.5.

Age in weeks versus live weight of a calf preweaning



plus the formation of fascia and tendon will therefore be absent from the gain represented by C to D compared with the gain from D to E.

It can be seen that if the live-weight gain of the calf is considered over the period from D to E then approximately four weeks trial data is lost. It was considered that the trial calves maintaining themselves or actively gaining weight could be considered to be in a similar state of energy balance whereas those losing weight could not be regarded as in the same state. Point B on Figure 3c.5 represents the earliest point at which it could be stated with reasonable certainty that the calf maintained itself. The data from the four trials were therefore corrected to the point at which all calves began to maintain themselves. Although it could not be categorically stated that no weight loss occurred between B and C the first date from which no weight loss was recorded was taken as the starting date for each individual calf. The results of the multiple regression analyses shown in Tables 3c.20 to 3c.23 were derived from the live-weight gain and energy intakes of the calves represented in Figure 3c.5 by the period from B to E i.e. from the point at which the calves maintained themselves.

In examining the data of Tables 3c.20 to 2c.23 it should be borne in mind that from the previous examination of the literature a mean value of 0.42 MJ.ME/kg$^{0.75}$ was adopted as the maintenance requirement of the calf and that the energy required per kg of live-weight gain had been reported to vary between 11.2 and 13.8 MJ.ME (Holmes and Davey, 1976). The fact that the present data shows a degree of agreement with these results can be concluded from the calculations of the theoretical live-weight gains from the rations fed shown in Tables 3c.16 to 3c.19. In those calculations a value of 0.42 MJ.ME/kg$^{0.75}$ for maintenance yielded values for the ME required per kg live-weight

gain ranging from 8.59 to 18.16 MJ.

The mean values of the maintenance and live-weight gain coefficients obtained from pooling the data obtained from the four single regression lines which each represent a total intake are shown in Table 3c.24.

Table 3c.24

Values of the Coefficients of 'a' and 'b' in the Equation

$I = aW^{0.75} + bG$

Value of Fin Equation	Coefficient of Maintenance		Coefficient of Live Weight Gain	
	a	S.E.	b	S.E.
Initial wt.	0.314	0.046	22.401	1.28
Mean weight	0.315	0.052	19.548	1.94
Final weight	0.299	0.052	17.638	2.47

From Table 3c.24 it can be seen that there was no effect on the coefficient for maintenance when either the initial, mean or final weights of the calves were substituted in the equation. However as would be expected the effect of using mean and final weight was to reduce the coefficient of live-weight gain. Thus as the live weight of the calf increases the total metabolisable energy required to maintain the calf increases and as I, the mean daily metabolisable energy intake (MJ.ME/day) calculated over the total trial period was a constant the energy apportioned for gain was less. A comparison of these results with those expected from the literature shows a wide discrepancy both in the coefficient for maintenance and the coefficient for live-weight gain. The value of the coefficient of maintenance is approximately 25% lower than would be expected from the literature and the coefficient of live-weight gain is approximately 60% higher than the mean value obtained from Holmes and Davey (1976).

From these results it is pertinent to consider that the equation; $I = aW^{0.75} + bG$ has partially described the data shown by the reduction in the coefficient of live-weight gain when mean and final weights are

substituted for the initial weight in the equation. However, the results suggest that the portioning of the energy intake into maintenance and live-weight gain in the manner used did not follow the physiological utilization.

One of the factors which may have influenced the results was the extrapolation from the actual live-weight gain data to the point where live-weight gain = 0 in order to estimate the maintenance requirement. The error incurred on extrapolation was dependant on the degree of extrapolation. In the present case the degree of extrapolation required was dependant on the minimum live-weight gain of the calves on each of the four trials. The range of daily live-weight gains on each of the four trials is shown in Table 3c.25.

Table 3c.25

The Range of Daily Live-Weight Gains (kg) of Individual Calves From Arrival to Weaning for Each of the Four Intakes

	Daily Live-Weight Gain (kg)		
	Mean	Maximum	Minimum
Spring'74	0.547	0.804	0.214
Autumn'74	0.509	0.778	0.245
Spring'75	0.549	0.875	0.286
Autumn'75	0.496	0.775	0.187

The range in live-weight gains between the maximum and minimum obtained averaged 0.57 kg/day over the four intakes. Thus the extrapolation required to obtain the maintenance requirement has meant an extension by half as much again out with the range of the recordings made. Hence, the error in extrapolation may be considerable.

The residual mean square values obtained from the single line, four parallel lines and four independent lines regressions are shown in Table 3c.26.

Table 3c.26
Residual Mean Square Values Obtained from the Single Line, Four Parallel Lines and Four Independent Lines Regressions

	$W^{0.75}$	Single line	4 Parallel lines	4 Independent lines
Spring'74	initial	2.87	2.63	2.58
	mean	2.92	2.78	2.61
	final	3.01	2.86	2.69
Autumn'74	initial	7.74	2.57	2.44
	mean	7.79	2.59	2.46
	final	7.85	2.65	2.50
Spring'75	initial	3.97	3.93	4.03
	mean	3.78	3.73	3.81
	final	3.70	3.64	3.73
Autumn'75	initial	3.34	3.34	3.32
	mean	3.33	3.33	3.30
	final	3.33	3.33	3.34

Those results show that in general a better fit of the equations to the data is achieved when an allowance is made for individual house effects by using either four parallel or four independent regression lines compared with using a single regression line. There is however no consistent trend in the coefficients of 'a' and 'b' obtained for each of the four house regressions during each of the four calf intakes. Thus it has not been possible to identify any influence of housing on the requirements for metabolizable energy of the calf for maintenance and gain.

One of the striking features of this examination has been the manner in which the maintenance coefficient was consistently under-estimated by the method of extrapolation. As the total metabolizable energy intake is apportioned to either maintenance or gain then an under estimate of either the metabolizable energy requirement for maintenance or gain leads to an over estimate of the remaining function. In the results so far obtained by multiple regression analysis the

metabolizable energy required for gain has been over estimated. The data obtained from the calculations of the theoretical live-weight gains from the rations fed, shown in Figure 3c.4, strongly suggests that the metabolizable energy content of the gain increases as the rate of live-weight gain increases. If this is the case then a graph of live-weight gain versus metabolizable energy intake would be curvilinear and the linear relationship so far considered would be inappropriate. The underestimate of the maintenance requirement so far obtained could also be partially explained if the relationship is curvilinear. Referring to the theoretical comparison shown in Figure 3c.6 it can be seen that if the true representation of the data is given by a curve then a linear extrapolation will always underestimate the intercept when live-weight gain equals zero. From this it was considered that an examination should be made of the relationship between the energy available for live-weight gain and the live-weight gain. Previous examinations of the metabolizable energy requirements for maintenance and gain have not included a constant in the equation i.e. no departure from the origin was allowed in the fit of the equation. It was considered that this constraint may have prevented the equation from accurately representing the data and that an examination should be made on the effect of including the constant, although the physiological interpretation of the resulting equations is made more difficult. The results examined in this manner were those of the Spring'75 intake.

Including a constant in the equation the linear equation becomes:

$$I = C + dW^{0.75} + eG \qquad (2)$$

where I = mean daily ME intake

$W^{0.75}$ = the metabolic live weight

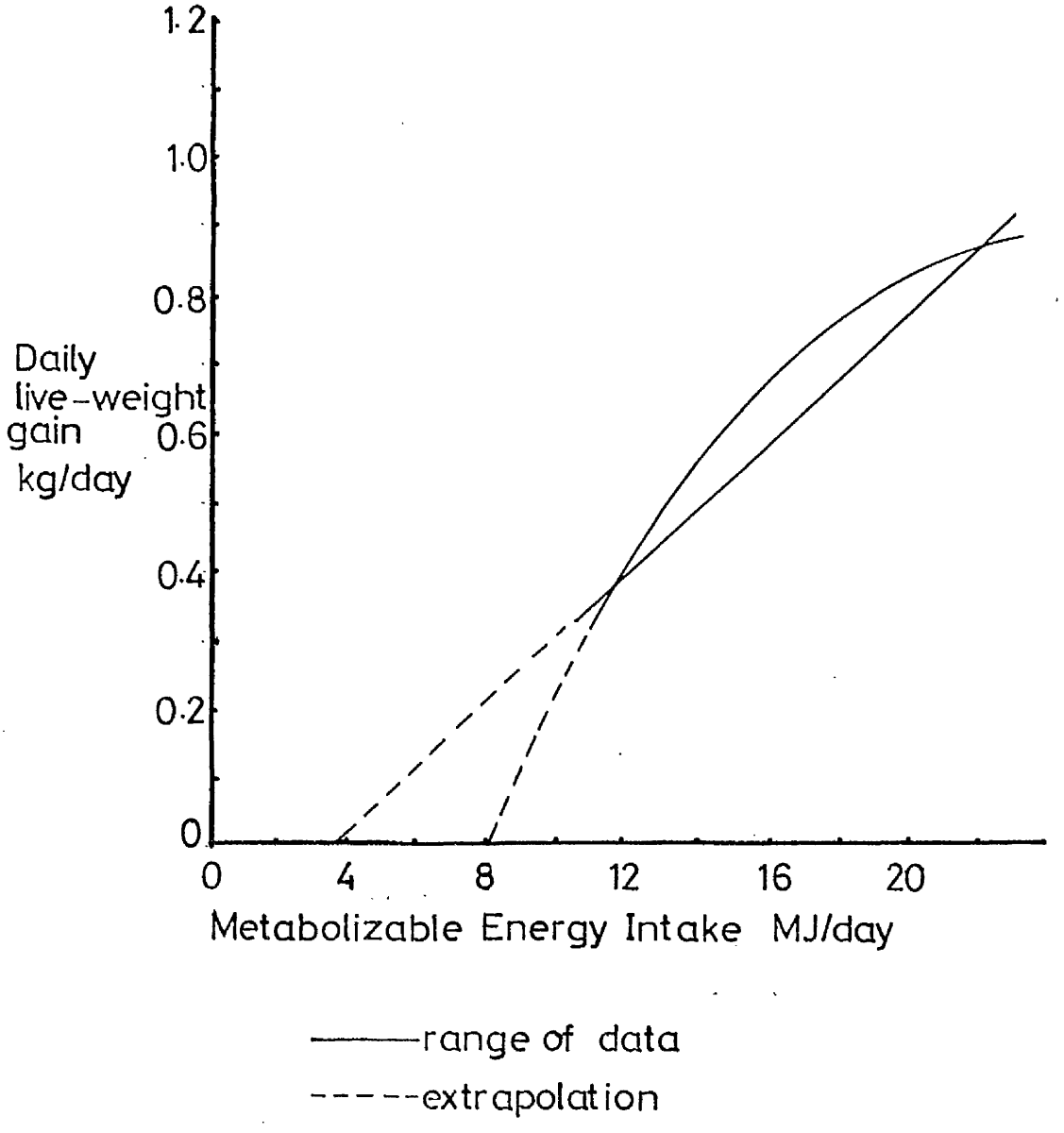
G = daily live-weight gain

C = a constant

and 'd' and 'e' = the coefficients of metabolizable energy required for maintenance and daily gain respectively.

Fig. 3c.6.

A theoretical comparison of the Results obtained using Linear or Curvilinear Regression.



The coefficients of 'C', 'd' and 'e' in equation (2) when W was the initial weight together with the standard errors and t values are shown in Table 3c.25 for the Spring'75 intake.

Table 3c.25

Values of 'C', 'd' and 'e' in Equation (2) Together with the Standard Errors and 't' Values

	Estimate	Standard Error	t Value
Constant C	2.118	2.400	0.88
d	0.281	0.147	1.92
e	20.020	1.750	11.46

It can be seen that the 't' value of the estimate of C is not significantly different from zero. Thus there is no evidence to suggest that the inclusion of the constant gives any better fit of the equation to the data than when using equation (1). Thus metabolizable energy intake can be completely accounted for in terms of maintenance and gain. A comparison with the residual mean square value using the initial weight and the single line regression shown in Table 3c.22 shows that the use of equation (2) gave a poorer fit. The residual mean squares were 3.968 and 4.623 for equations (1) and (2) respectively.

The effect of considering the relationship between the metabolisable energy available for gain and the live-weight gain as being curvilinear was first examined by considering:

$$E_G = mG + nG^2 \qquad (3)$$

where E_G = metabolizable energy available for gain

G = daily live-weight gain

and 'm' and 'n' are the coefficients of the gain

This relationship is the simplest curvilinear fit that can be used.

The line fitted to the data is then of the form:

$$I = F + h\,W^{0.75} + jG + kG^2 \qquad (4)$$

where I, $W^{0.75}$ and G are the same values as those used in equation (2).

F = a constant

h = the coefficient of metabolizable energy required for maintenance

and j and k are the coefficients of metabolisable energy required for gain

The values of F, h, j and k in equation (4) together with the standard errors and 't' values are shown in Table 3e.26.

Table 3e.26

Values of F, h, j and k in equation (4) Together with the Standard Errors and 't' Values

	Estimate	Standard Error	t Value
Constant F	2.5727	4.39	0.59
h	0.2784	0.15	1.86
j	18.475	12.60	1.47
k	1.389	11.20	0.12

In this instance the 't' value of k was not significantly different from zero i.e. there is no evidence of a curvilinear fit. The most appropriate equation was chosen by comparing the residual mean square values of the analysis of variance of each equation. The residual mean square value obtained using equation (4) was 4.671. It can be seen therefore that using equations (2) and (4) has not improved the fit of the line to the data compared to using equation (1).

A further examination of the relationship between the energy available for gain and the live-weight gain was considered in the form:

$$E_G = p \times e^{G} \qquad (5)$$

where E_G = metabolizable energy available for gain

and e = the exponential

this may also be expressed in the form:

$$E_G = q \times \log (G) \qquad (6)$$

The line fitted to the data is then of the form:

$$I = R + sW^{0.75} + ve^{G} \qquad (7)$$

The values of R, s and v in equation (7) together with the standard errors and 't' values are shown in Table 3c.27.

Table 3c.27

Values of R, s and v in equation (7) together with the Standard Errors and 't' Values

	Estimate	Standard Error	t Value
Constant R	-6.355	2.720	-2.34
s	0.261	0.148	1.77
v	11.337	0.995	11.39

The residual mean square value of 4.657 obtained using equation (7) again does not show any improvement on that obtained using equation (1) hence again no improvement of fit has been obtained.

A further term ($s + wG^{}$) was added to equation (7) the new values of R, s and v plus w, the standard errors and t values are shown in Table 3c.28.

Table 3c.28

Values of R, s and v in equation (7) when (+wG) is Included in the Equation Plus the Standard Errors and 't' Values

	Estimate	Standard Error	t Value
Constant R	1.509	9.740	0.15
s	0.279	0.150	1.87
w	18.598	22.100	0.84
v	0.810	12.600	0.06

It can be seen that when the term (+WG) is included in the equation the exponential term (v) ceases to play an important part in the equation as evidenced by the very low 't' value. The residual mean square value obtained in this instance (4.672) again did not show any improvement on that obtained using equation (1). Thus it can be concluded that the exponential form of the equation does not give any improvement on the simpler linear equation detailed earlier.

In all the examinations for possible curvilinear fit the initial, mean and final weights of the calves were substituted for W and the effect of housing was examined in each analysis. In nearly all instances there was no evidence to suggest that curvilinear regression analysis gave any better fit to the results than linear analysis and there was no suggestion that an improvement was obtained by including a constant in the regression equations.

DISCUSSION

In an examination of the performance of the calves it is pertinent to consider the live-weight gains achieved during the trial and to compare them with the performance of calves reared by other authors using similar systems and with the theoretical gains expected from the known metabolisable energy intakes.

Roy (1970) stated that the maximum weight gain that can be achieved with Friesian calves of 40 kg (88 lb) birth weight weaned onto dry feed at five weeks of age is about 1kg/day from birth to 12 weeks of age. The extended use of liquid feeding past five weeks of age enables this figure to be increased to 1.2 kg per day. The highest weight gain obtained by Leaver and Yarrow (1972a) with British Friesian dairy calves between 5 and 60 days of age was 0.58 kg/day This figure was achieved by feeding 640 g/day of a high fat milk

replacer once daily plus concentrates to a maximum intake of 2kg/day. The milk replacer was offered for a total of 28 days and the calves were housed in an insulated building which had mechanical ventilation but no artificial heating. Mitchell and Broadbent (1973) in a comparison of climatic and controlled environment calf houses fed 454 g of milk substitute once daily to British Friesian male calves. At purchase the calves had an average weight of 46.7 kg, and they were weaned at an average of 51 days from collection. From collection to weaning calves in the climatic and controlled houses gained 0.35 and 0.39 kg/day respectively. From collection to final live weight the calves in the climatic and controlled environment houses gained 0.56 kg/day over 76 and 80-day periods respectively.

In the present trial calves on the HF treatment had mean live-weight gains during each of the four crops ranging from 0.527 to 0.593 kg/day. These gains were achieved over approximately 70 days between six and 76 days of age with calves which weighed approximately 36 kg at the start of the experiment. Thus the live-weight gains were similar to those obtained in the experiments of Leaver and Yarrow (1972a) and Mitchell and Broadbent (1973). It is difficult to make a close comparison with the two previous pieces of work in which the age of the calves, the type of calves and the level and duration of milk feeding were not identical to the present trial. When, however, the performance of the calves is compared with the figures quoted by Roy (1970) in which 1.2 kg/day is suggested as being attainable it can be seen that the live-weight gains fall far short of the maximum attainable. A more frequent feeding system might have produced better live-weight gains although gains by young calves in excess of one kilogramme per day are seldom reported in practice.

There is no evidence to suggest that the season during which the calves were born (Spring vs Autumn) had any effect on the subsequent

performance of the calves. It has only been possible to compare the performance of the HH treatment calves in this manner as this was the only treatment which did not change during the four calf intakes.

On only one occasion were significant differences found between the mean daily live-weight gains of the calves in each of the four houses. During the Autumn 1974 intake calves in the A2 houses performed significantly better ($P < 0.01$) than calves in the B1 and B2 houses (Table 3c.4). Examination of the unweighted mean performance shows that in descending order the performance of the calves according to housing treatment was A2 > A1 > B2 > B1. It was not possible to test this data for significant differences. It was not considered appropriate to compare the performance of the HL and LL treatment groups from each house for as has been previously stated the concentrate consumption of these two groups differed between houses producing different levels of nutrition. However, when the performance of the HH and LH treatment calves from each house were examined although the houses were not ranked in the same order as when the unweighted overall means were compared the A2 house calves performed best in five out of the eight comparisons. The fact that separate regression equations for each house were more appropriate than the pooled regression equation suggests that there was an effect of the type of housing on the maintenance and production requirements of the calves. This effect was not consistent throughout the four calf intakes and it has not been possible to determine the absolute effect of house type on the maintenance and production requirements for metabolizable energy.

Having noted that there was a tendency overall for calves in the A2 house to perform best and for calves in the B1 house to have the poorest performance it is pertinent to consider the overall metabolizable energy intake. From Table 3c.15 it can be seen that the mean

daily metabolizable energy intake of calves in the A2 house was higher than calves in the other three houses. In this instance, however, calves in the B2 house had the lowest metabolizable energy intake. It was not possible to draw any conclusion from Table 3c.16 to 3c.19 as to the effect of housing environment on the efficiency of metabolizable energy utilization, there being no distinct trend in house effect. It can therefore be stated that the better performance of the calves in the A2 house compared with the calves in the other three houses was probably due to a higher metabolizable energy intake of the calves in the A2 house compared with the animals in the other three houses.

If the anomolous result for the A1 house during the Autumn'74 trial is ignored then during the four calf trials calves in the B2 house had lower intakes of metabolizable energy than calves in each of the other houses. Reference to Tables 3c.10 and 3c.13 shows that there was no consistent effect of a reduced consumption of either concentrates or hay by calves housed in the B2 house. It is probable therefore that the reduced metabolizable energy intake of the B2 house calves is the additive effect of occasional lower intakes of concentrates, hay and milk replacer (this may have been the result of calves scouring).

During three of the four intakes the performance of calves on the HL treatment was higher than that of the calves on the LH treatment, as shown in Table 3c.3. During all four calf trials the metabolizable energy intake of the HL calves was higher than that of the LH calves and the efficiency of utilization of metabolizable energy for gain was lower in the HL calves. It is likely therefore that during the two 1974 intakes and the Autumn'75 intake the reduced efficiency of utilization of metabolizable energy by these two groups was a result of higher metabolizable energy intake producing higher liveweight gains and as has been found the energy requirement of

the gain increases with increased rates of gain.

A comparison of the concentrate intakes of calves on the HH and LH treatments showed that calves receiving restricted levels of milk replacer tended to compensate by consuming more concentrates. These results confirm those of Loever and Yarrow (1972 a and b). Calves on the low level of milk replacer feeding also had a greater appetite for hay. The increased appetite for hay and concentrates by calves fed the low level of milk replacer did not compensate to the extent needed to enable the metabolizable energy intake of the LH calves to equal that of the HH treatment calves. It was also found that calves on the restricted concentrate feeding treatments had a greater appetite for and consumed more hay than the ad libitum concentrate treatment calves.

When the mean daily concentrate intakes of all the calves of each trial were compared the calves purchased during the Spring consumed more concentrates than calves purchased during the Autumn. It has been stated that a comparison of the HH treatment calves did not indicate an effect of season on calf performance. However, reference to the mean performance of the calves during the four calf intakes shown in Table 3c.3 shows that overall, calves born during the Spring performed better than Autumn born calves. Spring born calves on the LH treatment consumed approximately 1.34 M.J.M.E. per head per day more than their Autumn born counterparts. This demonstrates a nutrition x season interaction in that the performance of HH treatment calves was unaffected by season, whereas LH treatment calves consumed more concentrates during the Spring. Thus the overall concentrate allowance to the restricted concentrate calves was greater during the Spring, resulting in better performance than that of the corresponding Autumn born calves. These results are in contradiction

to the conclusions drawn by Appleman and Owen (1970) when it was found that Autumn born calves generally performed better. As indicated above this may have been due to the fact that during the present experiment the metabolizable energy intake was greater in the Spring born calves compared with the Autumn born animals.

When the theoretical gain calculated from the daily metabolizable energy intake was compared with the actual live-weight gain of the calves it was found that a better agreement was obtained between the theoretical and actual live-weight gain if the metabolizable energy requirement of the gain was allowed to increase as the rate of gain increased. Using the literature value of 0.42 MJ.ME/$kg^{0.75}$ as the maintenance requirement of the calf it was calculated that as the level of feeding increased the metabolizable energy required per kilo gramme of gain increased from 10.5 MJ.ME/kg gain when calves were gaining at the rate of 0.3 kg/day to 18 MJ.ME/kg gain when the calves were gaining at the rate of 0.6 kg/day. In making this calculation two assumptions were made which at present are not possible to verify. It was assumed that the maintenance requirement of the calves did not alter with level of feeding, and it was also assumed that the metabolizable energy content of the diet remained constant over the levels of feeding used. Although it was hoped to examine the latter effect during the metabolism trial, levels of feeding equivalent to the high levels achieved during the main trial were not obtained during the metabolism trial. Over the levels achieved during the metabolism trial there was no suggestion of a reduction in the metabolizable energy content of the ration. It is considered however that a slight reduction in the metabolizable energy content of the concentrates may have occurred on the ad libitum concentrate treatment in ten week old calves consuming in excess of 3 kg of concentrates per day.

There may also have been a reduction in the metabolisable energy content of the milk replacer as rumination developed and the efficiency of the oesophageal groove became less. Coupled with this probable reduction in metabolisable energy of the diet there would also be a reduction in net energy as rumination developed and the heat increment of feeding increased.

It has been suggested that the maintenance requirement of steers may be affected by the level of feeding and that low levels of feeding produce a reduction in the maintenance requirement (Crabtree, Kay and Webster 1976). It was further suggested that a period of adjustment was necessary on the reduced plane of nutrition before a reduction occurred in the maintenance requirement (Crabtree - personal communication). It was pertinent to consider therefore that if older steers were able to reduce their metabolic rate under conditions when energy intake was low the same effect may occur in calves.

An investigation was carried out to determine the effect of using separate multiple regression equations of the form of equation (1) for each of the groups of calves on any one level of nutrition in each of the four houses. There was no suggestion that using the separate regression equations improved the fit of the equations to the data. This was partly due to the high within treatment variation due to the maximum number of individuals on each treatment being eight. It was not possible to combine the results from calves on the same nutritional treatment but from different houses as the effect of housing environment on the maintenance requirement was unknown. It has not been possible, therefore, to discount differences in the maintenance requirements of the calves on different levels of nutrition as accounting for some of the disparity in metabolisable energy content of the gain at various rates of gain; the energy content of the gain

in this instance was calculated by difference, by subtracting the maintenance requirement from the total metabolisable energy intake.

The multiple regression technique used to apportion the metabolisable energy intake into that required for maintenance and gain was not successful in accurately predicting the maintenance and live-weight gain requirements. There is strong evidence to suggest that a curvilinear relationship should be used to fit the data. Firstly, the comparison of the expected live-weight gains with the actual live-weight gains showed an increased requirement for metabolisable energy as the rate of gain increases. Secondly, linear regression analysis consistently underestimated the maintenance requirement when the results were pooled from the four intakes and the three regressions using initial, mean and final weights were considered.

The fact that none of the curvilinear forms of the analyses gave any improvement in the fit of the equations to the data is contra expectations. It is considered that this may partly have been due to the high degree of variation in the live-weight gain of the calves. It is further considered that the gut fill of the calves may have attributed to the non-curvilinearity of the data. The data so far have been considered without accounting for gut fill. If in calves showing the highest rates of gain gut fill was greater than in low gaining calves as a result of higher concentrate intakes, then in low gaining calves the actual live-weight gain would be a greater percentage of the total recorded gain than in high gaining calves. This effect would be likely to produce a curvilinear relationship between the actual live-weight gain and metabolisable energy intake if the apparent live weight gain/metabolisable energy relationship was linear.

The effect of gut fill on the live-weight gain of the calves was examined by calculating the gut fill corrected live-weight gain of

three groups of calves. Gut fill was calculated as 4.1% of the initial live weight of the calf (gut fill of pre-ruminant calf Roy, 1970) and according to the equation of Roy (1970) where:-

$$y = 0.20x_1 - 3.33x_2 + 0.40x_3 + 2.90$$

where y is the weight of contents (kg)
x_1 is the weaning weight (kg)
x_2 is the daily concentrate intake (kg)
and x_3 the daily hay intake (kg)

The gut fill corrected daily live-weight gain was then calculated from the difference between the corrected weaning and corrected initial weight of the calves and the days from arrival to weaning. These corrections were made on the live-weight gain data of the Autumn'74 calves. Corrections were made on the data of calves showing gains of less than 0.3 kg/day, 0.42 to 0.48 kg/day and greater than 0.6 kg/day. The data from 56 calves was examined. Gut fill corrected live-weight gain was then compared with the actual live-weight gains. The percentage reductions in mean daily live-weight gain by correcting for gut fill were in the less than 0.3 kg/day, 0.42 to 0.48 kg/day and greater than 0.6 kg/day groups 63, 38 and 30 respectively.

Firstly, it can be seen that the degree of correction is dependent on the live-weight gain of the calves. Such a correction would tend to produce a curvilinear relationship. Secondly, the greater percentage correction occurring in the low live-weight gain is contra expectations. However, examination of the live-weight gain data shows that the highest gaining calves received the high level of milk replacer. The mean concentrate consumption of these calves was less than that of the LH calves hence the actual correction was lower in the high gaining calves. Also as the difference in concentrate intake between the high and low concentrate intake groups was of the order of 0.5 kg/day and the live weights at weaning of the low medium and high

nutritional groups were not very different then the actual weights of gut contents did not differ greatly between nutritional groups. When however the correction was considered as a percentage of the actual live-weight gain it can be seen that as the live-weight gain of the LL group was considerably less than the other three groups then the percentage correction was considerably greater.

In previous work (Forbes and Robinson 1969, Chestnutt et al 1975) the animals were fed in such a manner that the live-weight gain over the trial period was a constant. It was therefore possible to relate the mean metabolic live weight to the mean energy intake over the trial period. In the present trial an attempt was made to allow some of the calves to express their natural growth potential hence the metabolizable energy intake was not restricted to obtain set live-weight gains. This has resulted in it not being possible to relate the mean daily live-weight gain to the mean metabolizable energy intake. Chestnutt et al (1975) considered that the use of curvilinear regression may have been more appropriate in the expression used to describe the energy relationships in the more mature cattle used in their trial. It was considered at the outset of the present trial that the tissue laid down by the calves would have had a similar proportion of fat to lean over the trial period considered. It was also considered that during the period to 12 weeks of age the protein and fat content and hence the total energy content of the gain would be similar for the calves on the three levels of nutrition. The results obtained so far strongly suggest that the energy requirement of the gain increased with increasing live-weight gain. There is the suggestion therefore that the proportion of fat to lean was not constant over the range of live-weight gains and range of nutritional treatments considered in the present trial.

Forbes and Robinson (1969) noted a larger residual standard

deviation when the experiment lasted for 47 days compared with 100 days. The experiments of Cheetnutt et al 1975 used experimental periods of 84 days duration. In order to predict the mean live-weight of the calves and relate it to an average daily live-weight gain two approaches may be adopted. Live-weight gain may be restricted to a uniform rate of gain and in order to achieve accuracy it would appear that this rate of gain should be maintained over a period between 84 and 100 days duration. A range of live-weight gains should be used such that extrapolation to zero gain is reduced to a minimum out with the range of experimental results. It would not be possible to achieve either high or low rates of gain in young calves of two to three weeks of age which could be maintained over more than an 84-day experimental period. A second approach would be to allow the calves to express their normal rate of exponential growth. The accuracy with which the mean daily live-weight gain is related to the mean metabolizable energy intake is then increased by reducing the duration of the trial period. However, as reported by Forbes and Robinson (1969) this has the effect of increasing the residual standard deviation. In each of the two alternative approaches considered there remains the difficulty of determining the form of the curvilinear relationship. Following these reasonings it is considered that the multiple regression technique used to determine the metabolizable energy requirements for maintenance and live-weight gain is inappropriate for use with young calves.

Production Trials

Section 3d

Calf Health

INTRODUCTION

A higher incidence of scouring in young calves has been noted during cold November weather. (Williams-Smith, 1962). The beneficial effect of colostrum in preventing scouring was also noted and although environmental temperatures of 1.2 to 13.3°C were not detected as being the cause of increased scouring, the question remains as to whether environment may affect calf scour.

The decreased retention time of food in the adult ruminant as a result of low temperature stress has already been noted (Kennedy et al 1976). Also a decrease in dry matter digestibility has been shown in calves of between 200 and 300 kg live weight with a reduction in environmental temperature (Christopherson 1976). The presence of undigested feed in the lower gut of the calf aids in bacterial proliferation, thus if the effect of low temperature stress is similar in the young calf to that in the adult ruminant it is to be expected that an increased incidence of scour will occur when the calves are stressed by low temperatures.

Level of milk replacer feeding and its effect on calf scour has already been documented (Leaver and Yerrow 1972; Roy 1964). Stiles, Grieve, Butler and Willoughby (1974) in an investigation into the effect of fluid intake level and dry matter concentration on the incidence of scours in milk replacer fed calves identified a higher level of incidence of loose faeces, averaged over all levels of dry matter content, in calves on increasing fluid intakes. A higher incidence of scour was also noted during days 9-14 of age than during days 3-8 or 15-20. It was thus decided to use a method similar to that of Stiles et al (1974) in order to investigate the incidence of scour on the calf unit.

MATERIAL AND METHODS

The calves examined for scour were those which made up the Autumn'74 and Spring'75 intakes, when for each intake 132 and 127 calves were brought into the unit respectively. All calves were inspected between 9 a.m. and 10.30 a.m. before being given fresh bedding and inspections were made from the day calves arrived in the unit for a total of twenty-eight days.

Scour was recorded by visually assessing the faeces and awarding a score according to the following chart:-

	Record
formed and normal	1
putty-like appearance	2
fluid with some solids	3
watery	4
non-observed	5

Each calf was thus allocated one recording per day. Only fresh dung samples were recorded and an attempt was made not to record the same stool on consecutive days.

The average age of the calves on entry into the unit was for the Autumn and Spring-born calves, six days. The Autumn calves ranged in age from 1 to 13 days of age and the Spring calves from 1 to 13 days. In the Autumn intake the calves were more predominantly Friesian than during the Spring intake, however, both intakes tended to be of the Friesian x Friesian Ayrshire type calf.

Mean arrival weights were 34 and 33 kg for the Autumn and Spring born calves respectively. The range in live weight throughout the trial was slightly greater during the Spring intake (40.55-68.00 kg) compared with the Autumn intake (41.45-56.00 kg).

The levels of feeding were those previously given (Section 3a) namely, 600 and 300g of milk replacer per day with concentrates offered *ad libitum* and restricted.

Although HH and LH calves received concentrates ad libitum it must be noted that the concentrate restriction had not been established throughout the total period during which faecal examinations were made. During the major portion of this period the concentrate restricted calves received 200 and 100g of concentrates, during the Autumn and Spring trials respectively, until the required consumption was reached by the ad libitum calves.

When calves were seen to be scouring, medication was given and in cases of severe scour fluid intake was reduced.

Statistics The results from daily measurements were in the form of count data (number of days), and were arranged in contingency tables for chi-square analysis (Steel and Torrie 1960).

RESULTS

A preliminary examination of the results showed that when the calves had been in residence on the unit for approximately fourteen days, the majority were voiding faeces of a formed and normal nature. The results have therefore been considered over the first fourteen days during which the calves were resident on the unit. As calves were brought in to the unit over a fourteen day period, the dates between which recordings were taken were not identical for all calves of one intake. Thus daily environmental recording data cannot be correlated directly with the scour recordings.

Calves arrived on the unit and were randomly allocated to treatment and to house. All houses were filled in order from the number one to the number four cells. It was found in practice that in most instances cells one and two were filled during the first week and cells three and four during the second week.

For this reason an initial examination was made of the results comparing cells one and two with cells three and four.

The total number of occasions on which any particular scour score was made is shown in Table 3d.1 grouped according to the cells the calves occupied. Figures in the body of the table represent the number of individual recordings of each score.

Table 3d.1

Scour Score Grouped According to House Cells

Scour Score	Autumn		Spring	
	Cells 1 & 2	Cells 3 & 4	Cells 1 & 2	Cells 3 & 4
1	65	11	70	21
2	403	219	254	175
3	97	152	179	149
4	30	28	134	81
Total obs	595	410	637	426
	χ^2 = 76.610 3df***		χ^2 = 13.642 3df***	

For both the Autumn and Spring crops there was a significantly greater incidence of loose faeces ($P < 0.01$), in calves housed in the 3 and 4 cells compared with those housed in the 1 and 2 cells.

Results were also analysed for the Autumn and Spring crops in total and are shown in Table 3d.2.

Table 3d.2

Scour Score Grouped According to Whether Calves were Autumn of Spring Born

Scour Score	Autumn'74	Spring'75
1	76	88
2	623	429
3	246	327
4	57	215
Total obs	1002	1059
	χ^2 = 137.464 3df***	

A significantly greater incidence of scour ($P < 0.01$) was found for the Spring'75 intake compared with the Autumn'74 intake.

Comparisons between houses were analysed in a similar manner. For the Autumn intake the level of scour was significantly greater ($P < 0.01$) in the A1 and B1 type houses compared with A2 and B2 type. For the Spring'75 intake there was less scour in the A2 type house compared with the other three houses. There was a high level of severe scour in the B2 type house while the A1 and B1 type houses behaved similarly. All these differences were significant at the 1% level. The level of scour according to house for the Autumn'74 and Spring'75 intakes is shown in Table 3d.3.

Table 3d.3

Scour Score Grouped According to House for Autumn and Spring Born Calves

Scour Score	Autumn'74				Spring'75			
	A1	A2	B1	B2	A1	A2	B1	B2
1	17	20	14	25	24	27	16	21
2	179	170	153	121	113	112	117	87
3	63	59	63	61	109	76	80	62
4	16	13	17	11	46	42	54	73
Total obs	275	262	247	218	292	257	267	243
	$\chi^2 = 10.956$ 9df				$\chi^2 = 30.979$ 3df***			

The affect of nutritional treatment was examined for both the Autumn and Spring born calves. During both intakes there was a significantly higher incidence of scour ($P < 0.01$) in calves fed the high level of milk replacer. Scour score grouped according to the level of milk replacer feeding is shown in Table 3d.4.

Table 3d.4

Scour Score Grouped According to Level of Milk Replacer Feeding

Scour Score	Autumn'74		Spring'75	
	High Milk	Low Milk	High Milk	Low Milk
1	30	46	33	55
2	289	333	213	216
3	150	97	175	153
4	39	19	119	96
Total obs	508	495	540	520
	χ^2 = 24.22 3df***		χ^2 = 8.99 3df*	

There was no effect due to the level of concentrate feeding. This result confirms expectations, as over the period during which the observations were made the concentrate difference had not been established. The scour recorded for the Autumn and Spring intakes according to nutritional treatment is shown in Table 3d.5.

Table 3d.5

Scour Score Grouped According to Nutritional Treatment for Autumn and Spring Born Calves

Scour Score	Autumn'74				Spring'75			
	LL	LH	HL	HH	LL	LH	HL	HH
1	32	14	18	12	29	26	12	21
2	149	184	136	153	119	97	106	107
3	49	48	67	83	81	72	91	84
4	14	5	20	19	46	50	67	52
Total obs	244	251	241	267	275	245	276	264
	χ^2 = 45.569 9df***				χ^2 = 15.008 9df			

Blood immunoglobulin levels of calves, obtained from blood samples taken on the day after entry into the unit, were compared for the Autumn and Spring born calves. Calves reared during the Spring of '75 had

significantly lower ($P<0.01$) levels of blood immunoglobulins than calves reared in the Autumn of '74. Mean values of blood immunoglobulins for the Autumn'74 and Spring'75 intakes were 18.84 $\pm$ 8.06 and 11.85 $\pm$ 7.43 mg/ml plasma respectively.

From the scour scores obtained for the two crops of calves a figure was calculated, representative of the total faeces voided over the fourteen day period, for each individual calf. This was obtained by weighting each particular score and multiplying it by the number of occasions on which each score was observed. Weighting was carried out by allotting a score of 1, one unit, a score of 2, two units, a score of 3, three units and a score of 4, four units. By multiplying the number of times a particular score was recorded by its unit value then summing the total units for any calf, one figure representative of the faecal matter voided by the calf may be obtained. The higher the total number of units, the more loose were the faeces of the calf. This figure was then corrected for the number of observations made over the fourteen day period, i.e. if nine observations were made in any one fourteen day period, five non-observations, then the total score over the nine days was multiplied by 14/9. The assumption is made, in making this calculation, that the score obtained from direct observations was representative of the performance of the calf over the total fourteen day period. This may not have been the case in every instance, but was felt to be acceptable in order to make the comparison.

Regression analyses were then carried out with blood immunoglobulin as the independent variable and scour score as the dependent variable. Since previously an effect of level of milk feeding on calf scour has been recorded then the effect of level of milk feeding was removed from the present analysis. A negative non-significant corre-

lation was found (r = -0.1204, t = 1.09 N.S.), of the effect of level of blood immunoglobulin on calf scour, for calves of the Spring'75 crop. The Autumn 1974 results were examined in a similar manner. No correlation was found on this occasion between calf scour and blood immunoglobulin level.

During the Spring'75 intake a severe outbreak of Salmonella infection was recorded. It was considered that the immunoglobulin status of the calf would not significantly affect its ability to overcome Salmonella infection and that scour was likely to occur irrespective of the level of blood immunoglobulin. Any calf identified as being infected with Salmonella was therefore removed from the preceeding analysis. Calves infected with Haemolytic ecoli were removed from the analysis for a similar reason.

DISCUSSION

The results are in general agreement with the literature in showing a predominantly greater incidence of scour in calves up to an average age of 20 days. It has already been stated that calves were examined for scour when purchased and no calf was brought on to the unit that was visibly scouring. It is concluded from this that it was mainly the treatment of the calf on the unit that precipitated any scouring. The time for which maximum scour was recorded was also coincident with the period over which changes in the level and frequency of feeding milk replacer to the calves occurred.

In the present work a higher level of scour was noted in calves fed the high level of milk replacer during both the Autumn and Spring intakes. Although during the period in question the final levels of milk replacer feeding were only achieved towards the end of the 14 days the level of liquid offered on each treatment was the same. Thus

the increased scour on the high level of milk feeding was a result of the increased concentration of milk replacer offered on the high level of milk replacer feeding. As previously stated no effect of level of concentrate feeding was identified.

The cause of the higher incidence of scour in calves purchased during the second week is difficult to identify. It is possible however that as the number of calves and the duration of time for which the unit was occupied increased then calves entering the unit later, were challenged by a larger build up and more diverse spectrum of infection. It is suggested that as the number of animals increased the level of stockmanship declined due to the pressure of work involved. It is suggested that the two factors in this instance acted in conjunction.

The comparison between the Autumn and Spring intakes agrees with the literature in that a higher incidence of scour was noted in calves born during the Spring. However in view of the incidence of Salmonella during the Spring'75 intake the comparison must be viewed with caution. Although calves infected with Salmonella were not included in the analysis, it cannot be categorically stated that other calves were not carriers, which may not have been identified as a result of rectal swabbing.

An analysis of the results according to the housing of the calves showed that during the two intakes studied, calves in the A2 house had significantly less scour than calves on the remainder of the unit. Although no significantly greater incidence of mortality was noted in the B2 house during the Spring of 1975 it is suggested that the higher incidence of scour in the B2 house during the Spring resulted from the enclosed nature of the building. This allowed an increased build up in the atmosphere of the house of pathogenic organisms, notably

Salmonella, which infected the calves but which were not subsequently identified from rectal swabs.

The lack of correlation of the level of blood immunoglobulin with calf scour would tend to suggest that the blood immunoglobulins possessed by the calves when they entered the unit, were not specific for the pathogens encountered by them on the unit. Although no correlation was identified in this work it cannot be stated that the level of blood immunoglobulin does not affect the incidence of calf scour. The fact that calves born during the Autumn had a significantly higher mean level of blood immunoglobulins compared with calves born in the Spring of '75 (18.84 and 11.85 mg/ml plasma respectively) cannot be discounted from contributing to the lower incidence of scour recorded in the Autumn born calves.

CONCLUSION

Bought-in calves were most susceptible to scour up to 20 days of age. There was a lower incidence of scour recorded in Autumn born compared with Spring born calves. The reason for this was not identified but may be attributed to the environment or the immunoglobulin status of the calves. There was a greater incidence of scour in calves fed 600g compared with 300g of milk replacer per day. As the volume of liquid fed was the same on both levels of feeding the increased incidence of scour on the high milk replacer treatment was due either to the absolute level of milk replacer powder fed or the increased concentration of the reconstituted replacer. No effect of level of concentrate feeding on calf scour was recorded. Calves receiving the LH treatment had a lower incidence of scour than HL treatment calves. Over the period which the recordings were made the full concentrate restriction had not been achieved therefore the total metabolizable energy intake of the HL calves was greater than the LH calves. The level of metabolizable energy intake cannot in this instance be ruled out as a factor affecting calf scour. Calves housed in the A2 house had significantly less scour than calves in any of the other three houses.

Production Trials

Section 3e.

Mortality

INTRODUCTION

Causes of Mortality

Calf mortality may be affected by a number of parameters acting directly or additively. It is therefore questionable whether the actual cause of death is or was the major debilitating factor in the life of the calf. The suggestion is made that factors not strictly classified as stock management may affect mortality rates. It is difficult to reason in terms of management why the wife and children of the owner or manager should rear more calves on a percentage basis than the owner or hired man. (Hartman, Everett, Black and Warner, 1974). 'Kindness' is difficult to measure scientifically. To study the effects of management on calf mortality, one must therefore consider the tangible factors which may lower the calves' ability to survive. These in turn, however, may represent only part of the cause of death.

Reviews of postnatal mortality have, in the main, been the result of the collation of veterinary post-mortem reports from various research centres. Experience has shown that post-mortem examinations are not always carried out within 24 hours of the calf having died. Attributing death to the results of a post-mortem examination presupposes no change in the corpse, between death and examination, which would have resulted in a change of opinion as to the cause of death. Williams, Smith (1975) considered that the enteric form of Escherichia coli infection was in particular over-diagnosed. The main reason for this was that E.coli is a normal inhabitant of the alimentary tract and multiplies rapidly in most parts of the tract after death of the calf. A similar effect was noted for streptococci, Clostridium welchii, and lactobacilli. The number of E.coli found in the intestine of a calf a few hours after death bore no resemblance to those present immediately after death; furthermore, after 24 hours, appreciable numbers of E.coli were present

in the liver.

The seasonal trend in calf mortality is well documented. More calves and a greater percentage of calves die in the Spring (in the first six months of the year) than in the Autumn. This trend is more marked in Scotland than in England and Wales. (Vet. Record, 1964). Martin, Schwabe and Franti (1975) found that mortality increased during mid-summer (June-August) and mid-winter (November to January), the rate being 20% higher in winter than in summer. Similarly, Speicher and Hepp (1973) found a mortality of 17.1% of all calves born in winter whilst in summer the value was 10.3%.

There is also good agreement in the literature on the age and related causes of calf mortality. Martin et al (1975) found that of all the deaths of calves of less than five weeks of age, 55% occurred during the first week of life and 27% during the second. Mortality in calves between five weeks and three months old was generally less than 2%. Results of the 1964 survey (Vet. Record) show that estimates vary from 33 to 48% in the first week and from 66 to 80% in the first month. These figures should be viewed with caution as they do not directly represent the number of calves dying but are calculated from the number of calves offered for post mortem examination.

Herd size has also been shown to be a factor affecting the mortality of calves. Mortality in herds of < 100 cows and herds of >100 cows was 15.8 and 27.2% respectively. (Hartman, et al, 1974).

In a second examination of veterinary reports (Hugh-Jones, 1972) the major ascribed organ systems associated with mortality were, the Digestive (25.9%), Respiratory (12.6%) and the Body as a whole (28.6%). The digestive diagnoses reached their peak diagnostic rate with calves 1-3 weeks old and then decreased in importance. Respiratory diagnoses were proportionally most important with animals 2-8 months old. These findings differ slightly from the 1964 report (Veterinary Investigation

Service 1964) which found Septicaemia was the most important during the early part of the first four weeks, whereas gastro-enteritis became more important later. From the total deaths due to Septicaemia 46.7% died in the first week. Of the calves dying from gastro-enteritis 72% were between one and four weeks old.

In this present work contact was not made with the calf until it was at least four days old. It is not proposed therefore to deal with congenital and developmental abnormalities which were not encountered. It is, however, recognised that dystocia may have an effect on the survival of the calf which may not be apparent at the time of purchase.

In the normal healthy calf Escherichia coli is one of the first organisms to become established in the alimentary tract after birth. A strain of E.coli is only likely to be pathogenic if it either manages to enter the tissues during the first few days of life, resulting in a septicaemia, or if the strain, although restricted to the alimentary tract, has the ability to proliferate in the anterior region of the small intestine and to produce an enterotoxin (Roy and Ternouth, 1972).

Of the infectious diseases E.coli was the most commonly diagnosed causative organism of death during the first seven days of life (Hugh-Jones 1971). Roy et al (1972) considered E.coli as being the most important cause of enteric diseases during the first 2-3 weeks of life and Salmonellosis being more important in the slightly older pro-ruminant calf. The increase in salmonellosis as a causative organism is interesting to note. The 1964 (Vet. Investigation) report found salmonellosis to be the cause of 29.6% of all deaths up to six months of age, whereas prior to 1955 the incidence of the disease was negligible. The 1971 investigation (Hugh-Jones 1971) however, found salmonella diagnoses formed 11% of all diagnoses.

Respiratory diagnoses were most common during the eighth to nineteenth weeks with the highest diagnostic rates in the 5-8 month period

(Hugh-Jones 1972). Of over 800 respiratory diagnoses, 34% were solely Pneumonia. The most frequent specific diagnoses involved Pasteurella with the majority in the 4-19 week period. "Virus Pneumonia" (11% of all respiratory diagnoses) was similarly distributed over the whole age range. Thomas (1973) on examination of twenty-seven outbreaks of respiratory disease in both dairy and beef calves found that the majority of outbreaks occurred in animals below four months of age. The cause of pneumonia is probably a combination of viral and bacterial infection, and environmental stress probably precipitates the attack. (Prenatal and Postnatal Mortality in Cattle, 1968).

Thomas (1973) considered that the clinical findings could be classified according to the presence or absence of upper and lower respiratory signs, these may, however, frequently be coincidental. The work confirmed a major involvement of bacteria in the aetiology of pneumonia of calves. It did not, however, show a correlation between the presence of virus and the subsequent development of either upper or lower respiratory disease syndromes. It was suggested that viruses may be involved in the mild upper respiratory (coughing) syndrome but that present evidence was strongly against the importance of viruses in the acute lower respiratory disease stage.

Blood Serum Immunoglobulins

The role of blood serum immunoglobulins in aiding in the survival of young calves is well documented. Irwin (1974a) from a sample of 58 calves found that of ten calves that died, eight had serum immunoglobulin levels of below 20 mg/ml. In a subsequent examination mortality was 11.24% in market bought calves with serum immunoglobulins of below 20 mg/ml but was only 1.55% in calves with serum immunoglobulins of above 20 mg/ml. (Irwin 1974b). The disease incidence was also higher in the low immunoglobulin status calves. Penhale, Logan, Selman,

Fisher and McEwan (1973) found that the cause of death was positively correlated to the serum immunoglobulin status of the calf. The three classes of immunoglobulins (IgG, IgM and IgA) were deficient in calves dying as a result of septicaemia, whilst intermediate levels were found in calves dying with enteric diseases. Calves dying of septicaemia had mean levels of IgG, IgM and IgA of 0.8, 0.2 and 0.11 mg/ml respectively whilst surviving calves had levels of the three types of 7.5, 0.8 and 0.22 mg/ml respectively.

Penhale et al (1973) showed that there was a progressive closure of the absorption mechanism for the absorption of colostral immunoglobulins and that plasma levels were inversely related to the delay interval between birth and when the calf first receives colostrum. The rate of closure differed for each class of immunoglobulin and it was calculated by extrapolation that the time interval which would lead to a complete deficiency of serum immunoglobulins of the IgM, IgA and IgG types was for each type 16, 22 and 27 hours respectively.

A seasonal variation in blood serum immunoglobulins has been demonstrated (Gay, Fisher and McEwan 1965). Bought-in market calves had serum immunoglobulin levels of below 10 colorimetric units during the months of November to April. Throughout the remainder of the year values were in excess of double those obtained between November and April.

The half lives of the three classes of immunoglobulins, IgG, IgM and IgA are 18-20, 2-3 and 4 days respectively. The endogenous production of immunoglobulins in the calf may take place within the first 10 days of life (Fisher and Martinez, 1975). The results are in good agreement with those of Logan, Penhale and Jones (1972) when the half lives of IgG, IgM and IgA were estimated as 21, 4 and 2.8 days respectively. In this latter experiment serum levels of the three immunoglobulins reached a minimum between two and four weeks of age after which the IgG and IgM

levels began to rise slowly approaching adult levels at 12 weeks old. However, IgA levels remained low throughout the observation period. Logan (1974) in a later experiment found that in a group of calves which were not considered to be hypogammaglobulinaemic (generally less than 10 mg/ml of serum immunoglobulins), at five weeks of age, IgG and IgA levels were still decreasing but the IgM level reached a minimum at four weeks and by five weeks had begun to increase. This contrasted with the hypogammaglobulinaemic calves in which IgM synthesis began as early as one week of age.

With the implication of specific serum immunoglobulins in the development of the immunity of the calf to specific diseases Logan (1974) questioned the validity of using the zinc sulphate turbidity test which can only give a value of the total levels of serum immunoglobulins present. It has been shown that the rate of gut closure differs for each class of immunoglobulin (Penhale et al 1973), hence late suckling calves, although they may have high total levels of serum immunoglobulins, may be deficient in the IgM class which is the first excluded. These calves would be very susceptible to colibacillosis especially in its septicaemic form which has been shown to be inhibited by the IgM fraction (Logan and Penhale 1971).

In view of the correlation of low levels of serum immunoglobulins with high calf mortality it was considered that the immunoglobulin status of the calves in the present trial should be monitored in order to further illucidate the causes of calf mortality.

MATERIALS AND METHODS

Calves

The data studied in this experiment consisted of the reports of post-mortem examinations made on calves that died during the present calf environment study carried out at the Experimental Unit of the Department of Animal Husbandry of the West of Scotland Agricultural

College. The breeds, ages, method of calf collection and treatment of calves on arrival at the unit, together with the methods of rearing, have been presented elsewhere (Section 3c).

All calves were rectally swabbed when they arrived at the unit. During the Spring and Autumn of 1975 several calves were identified on the results of rectal swabbing as being carriers of Salmonella Typhimurium and Salmonella Dublin. These calves were slaughtered, the former to conform with Public Health regulations and those carrying S. Dublin as a precaution against the transfer of the organism to the remainder of the stock. Post-mortems were routinely carried out on the bodies of these animals. These reports, however, have not been included in the analyses of the results.

It is interesting to note that although Salmonella was positively identified in three calves as a result of rectal swabbing, the organism was not identified following post-mortem examination and subsequent examination of the bacterial fauna of the major organs.

All calves that died were transported at the earliest possible opportunity to the Veterinary Investigation Laboratory where the post-mortem examination was made by the Veterinary Investigation Officer of the day.

Serum Immunoglobulin Measurements: Twenty-three of the Spring'74 calves were blood sampled the day after they arrived on the unit. During the Autumn'74 trial all the calves were blood sampled on three occasions: (1) the day after they arrived on the unit (2) approximately 34 days after arrival (3) approximately 64 days after arrival. The Spring and Autumn 1975 calves were all blood sampled the day after arrival and the Spring'75 39 days after arrival and the Autumn'75 27 days after arrival.

Blood serum immunoglobulins were measured by the zinc sulphate turbidity method.

RESULTS

In total 307 calves were purchased comprising four intakes, two Spring and two Autumn. Of these, 61 calves were submitted for post-mortem examination, 8 having been slaughtered as a result of positive Salmonella identification from faecal samples and one case in which the calf was moribund. Including the calf which was slaughtered because it was moribund, these figures represent a total mortality of 12.03%. Excluding the nine calves which were slaughtered, average calf mortality over the two years was 10.25%.

In individual crops of calves mortality ranged from 1.56% during the Autumn 1974 crop to 14.84% during the Spring 1975 crop. The number of calves which died in each of the four crops, excluding those slaughtered, is shown in Table 3e.1. A total of 34 calves died from the two Spring intakes compared with 18 from the two Autumn intakes.

Table 3e.1
The Number of Calves Dying and Percentage Mortality in the Four Calf Crops Examined

	Spring'74	Autumn'74	Spring'75	Autumn'75
No. of calves which died	15	2	19	16
Total purchased	128	128	123	128
Mortality %	11.72	1.56	14.84	12.5

Age of the Calf

In order to examine the affect of the age of the calf on mortality, the calves were grouped according to their age when they died. It should be remembered that calves were brought onto the unit between seven and ten days of age. The period of 1-10 days was therefore taken as the initial period during which calf mortality could not be attributed to the treatment of the calf on the unit. Subsequent periods were arbitrarily grouped into seven day intervals. Calf mortality grouped according to age and intake is shown in Table 3e.2.

Table 3e.2

The Numbers of Calves Which Died Grouped According to Age and Intake

Age in Days	Spring'74	Autumn'74	Spring'75	Autumn'75	Total
1-10	3	0	1	0	3
11-17	9	0	5	6	20
18-24	0	0	4	1	5
25-31	2	0	5	4	11
32-	1	2	4	5	12

It can be seen that peak mortality occurred between 11 and 17 days of age when calves had been on the unit an average of seven days. Mortality fell between 18 and 24 days of age, but was high again between 25 and 31 days. Of all calves dying, 39% died between 11 and 17 days of age.

All the calves on the unit were either pure Friesian, Friesian x Friesian x Ayrshire or Friesian x Ayrshire and all were bull calves. Within each crop, however, the number of calves of each type of cross was not constant. The effect of breed on calf mortality was therefore examined, and is shown in Table 3e.3. The figures in brackets represent the numbers of each type purchased.

Table 3e.3

The Effect of Breed on Calf Mortality
Figures in Brackets Represent The Number of Calves of Each Breed Type

	Spring'74	Autumn'74	Spring'75	Autumn'75	Total
Friesian	4 (34)	2 (73)	9 (58)	5 (55)	20 (220)
Friesian x F Ayrshire	6 (30)	0 (28)	4 (17)	7 (39)	17 (114)
Friesian x Ayrshire	5 (63)	0 (26)	6 (50)	4 (34)	15 (173)
χ^2 squared with 2 df = 3.7205 N.S.					

Having ascertained that there was no breed effect it was possible to proceed to consider house and nutritional effects, since previously it was

not known whether the different crosses were uniformly distributed over the four housing and four nutritional treatments.

In all instances differences between means were tested using a contingency table and chi-squared analysis (Principles and Procedures of Statistics. Steel and Torrie). Initially results were analysed by grouping all four intakes.

Effect of Nutrition

Mortality grouped according to nutritional treatment is shown in Table 3e.4. At the age during which highest mortality occurred the full nutritional treatments had not been established thus the figures have been regrouped according to level of milk replacer feeding and level of concentrate feeding. Table 3e.5.

Table 3e.4

Calf Mortality Grouped According to Nutritional Treatment

	L.L.	L.H.	H.L.	H.H.
Total No. calves	128	125	127	127
Dead	17	15	9	11
Alive	111	110	118	116
% Mortality	13.3	12.0	7.1	8.7
χ^2 with 3 df 3.4216 N.S.				

Table 3e.5

Calf Mortality Grouned According to Level of Milk Replacer and Level of Concentrate Feeding

	Low Milk	High Milk	Low Conc.	High conc.
Total No. Calves	253	254	255	252
Dead	32	20	26	26
Alive	221	234	229	226
% Mortality	12.6	7.9	10.2	10.3
	χ^2 = 3.14 1df. N.S.		N.S.	

When calves from all four intakes were grouped together, on no occasion was any significant difference found between treatments. It was noted, however, that mortality was higher in calves on the low-low treatment and in general there was a higher rate of mortality in calves being offered the low level of milk replacer.

Effect of Housing

Calves were grouped according to the house they occupied when they died. The total number of calves which died, together with calf mortality (%) for each of the four houses is shown in Table 3e.6.

Table 3e.6

Calf Mortality Grouped According to House

	A1	A2	B1	B2
Total No. of calves	127	127	126	127
Dead	13	8	16	15
Alive	114	119	110	112
% Mortality	10.2	6.3	12.7	11.8
χ^2 with 3 df 3.3094 N.S.				

When all four calf crops were grouped together no significant difference in calf mortality was found between the four houses. The figures from the four crops in total were also regrouped to examine the effect of housing environment (insulated versus minimum insulated) and house type (A versus B type houses). The results grouped in this manner are shown in Table 3e.7.

Table 3e.7

Calf Mortality Over the Total Period Grouped According to Housing Environment and House Type

	Insulated	Minimum Insulated	A type	B type
Total No. of calves	254	253	254	253
Dead	23	29	21	31
Alive	231	224	233	222
% mortality	9.1	11.5	8.3	12.3
	χ^2 = 0.7979 with 2 df N.S.		χ^2 = 2.1965 with 2 df N.S.	

As can be seen, there was no significant effect of insulation or house type on calf performance although mortality was lower in the insulated buildings and in the A type houses.

Seasonal Interactions

Having considered all four intakes as a whole it was considered pertinent to view each intake separately as it could not be categorically stated that the climatic environment did not differ significantly between the four trials over the rearing period. Chi-squared analyses were carried out as before to examine differences between means due to the effect of housing and nutrition on the incidence of mortality among calves during the Spring 1974, Spring 1975 and Autumn 1975 intakes. The Autumn 1974 crop was omitted from these analyses as only two calves died during the experiment. It should also be noted that the levels of feeding differed somewhat between the three crops examined. During the Spring 1974 crop milk replacer was fed at 400 and 600g once daily to the low and high calves respectively, whilst for the Spring and Autumn 1975 crops the milk replacer levels were set at 300 and 600g/day on the two treatments. The restricted concentrate level was set as previously described (Section 3a) according to the level of milk replacer offered.

There were no significant differences in the levels of calf mortality encountered in each of the four houses during each of the three calf intakes which were examined. The effect of type of housing, A or B and level of insulation, 1 versus 2 type housing, was examined in a similar manner but no significant differences in the level of mortality were identified.

Examination of the mortality grouped according to nutritional treatment showed there was no significant effect due to nutrition for the Spring 1974 and Autumn 1975 intakes. However, during the Spring 1975 intake there was a significantly higher mortality rate in calves on the Low-Low level of nutrition. The mortality of calves according to nutritional treatment for the Spring 1975 intake is shown in Table 3a.8.

Table 3a.8

Calf Mortality Grouped According to Nutritional Treatment for Calves Reared During the Spring of 1975

	L.L.	L.H.	H.L.	H.H.
Total No. Calves	32	29	31	31
Dead	11	4	2	2
Alive	21	25	29	29
% Mortality	34.4	13.8	6.5	6.5
χ^2 with 3 df = 12.677 **				

In this instance mortality was not specifically related to the low level of milk replacer feeding as there was no significant difference between the levels of mortality of calves on the LH, HL and HH treatments.

Causes of Mortality

Calf mortality was grouped according to what was considered to be the main cause of death. The main causes considered were:

Gastro Enteritis
Salmonella type organisms
Pneumonia
Septicaemia
Other causes

If at any time, as a result of rectal swabbing or subsequent post-mortem examination, salmonella type organisms were isolated in a calf, this was considered to be the causative agent. In some cases, however, it was questionable whether this was the main cause of death. The total numbers of calves dying according to the above five causes are shown in Table 3e.9 according to which intake the calves belonged.

Table 3e.9
The Number of Calves Dying from Four Specific Causes

	Gastro Enteritis	Salmonella type organisms	Pneumonia	Septicaemia	Other Causes
Spring 1974	8	0	3	2	3
Autumn 1974	0	0	0	0	2
Spring 1975	4	9	5	0	1
Autumn 1975	6	6	1	1	2
Totals:	18	15	9	3	8

Of the eight other causes of death noted in the above table, four calves died of bloat, three of general septicaemia which may have resulted from a naval infection and one calf was positively diagnosed as having joint-ill.

The age at which calves died was highly correlated with the cause of death. The mean ages of calves dying from Gastro Enteritis, death related to Salmonella type organisms or Pneumonia were calculated and analysed by analysis of variance for differences between the mean age

at death. Calves dying through gastro-enteritis were significantly younger ($P<0.01$) than calves whose death was associated with Salmonella, the average ages of the calves that died being 18 and 33 days respectively. The average age of calves dying of Pneumonia was 27 days, although this figure was not significantly different from the other two. It can be seen also that more calves died from pneumonia during the Spring intakes than during either of the two Autumn intakes (8 deaths versus 1 death respectively). It should be noted also that during the first two calf crops there was no incidence of salmonella. However, during the second two crops 47 and 40% of all calves which died were infected with Salmonella. There was no seasonal effect on the incidence of deaths associated with Salmonella or Gastro Enteritis.

The Effect of the Level of Blood Immunoglobulins on Calf Mortality

Blood samples were taken from a small sample of calves from the Spring 1974 intake, the day after calves arrived at the unit. All calves on the remaining three intakes were sampled the day after they arrived at the unit. The immunoglobulin levels of calves bought in the Spring and Autumn 1974 and the Spring 1975 were measured by a zinc-sulphate turbidity test according to McEwan, Fisher, Selman and Penhale (1970) where it was shown that the relationship existing between the turbidity developed by the zinc sulphate test and the concentration of bovine gamma globulin was linear up to 30 mg bovine gamma globulin per ml. Thereafter, the turbidity would appear to increase in an exponential manner.

Blood immunoglobulins of the Autumn 1975 calves were calculated by difference from the values of total protein and albumin. A highly significant correlation has been shown between zinc sulphate turbidity and plasma globulin measurements obtained by difference in ewes and lambs. (Ap-Solami and Sinclair, 1977).

The mean values of the blood immunoglobulin levels of all calves obtained from blood samples taken the day after the calves arrived on the unit are shown in Table 3e.10.

Calves of the Autumn'74 intake were blood sampled on two further occasions and calves of the Spring and Autumn'75 intake on one other occasion. The mean values of the blood serum immunoglobulins obtained on these occasions, together with the average age of the calves when they were sampled are also shown in Table 3e.10. Levels of blood serum immunoglobulins were significantly lower ($P < 0.01$) in Spring born calves when they arrived at the unit compared with Autumn born calves. The mean level of serum immunoglobulins found in calves of the Autumn '75 crop was significantly greater ($P < 0.001$) than that found in the Autumn'74 calves.

As the level of serum immunoglobulins in the Spring'74 calves was obtained from a sample of all the calves brought onto the unit it was not possible to obtain an estimate of the immunoglobulin levels of calves that died. Mean values obtained at the first sampling of the serum immunoglobulin levels of the calves that died during the Autumn'74 and the two 1975 intakes are shown in Table 3e.11 together with the mean levels of calves that survived.

Table 3e.11

Mean Values of Blood Serum Immunoglobulins of Calves that Survived and Calves that Died During Three of the Calf Crops

	Blood serum immunoglobulins mg/ml		
Calf Crop	Surviving Calves	Mortalities	Significance
Autumn'74	18.84 $\pm$ 8.06	22.09 $\pm$ 10.29	N.S.
Spring'75	11.61 $\pm$ 7.28	8.39 $\pm$ 5.79	$P < 0.001$
Autumn'75	30.52 $\pm$ 10.98	32.34 $\pm$ 14.45	N.S.

The mean ages of calves that died during the Autumn'74, Spring'75 and Autumn'75 calf crops were 34, 27 and 29 days respectively. It can be

Table 3e.10

The Mean Values of Blood Serum Immunoglobulin Levels Found in Samples Obtained From Calves of Varying Ages During Each of the Four Calf Crops

Calf Crop	Sample 1		Sample 2		Sample 3		Significant Differences Between Blood Ig levels on Different Sampling Occasions
	Age days	Ig level mg/ml	Age days	Ig level mg/ml	Age days	Ig level mg/ml	
Spring'74	8	12.76 ± 3.93					
Autumn'74	7	18.26 ± 7.94	41	13.85 ± 3.64	71	18.69 ± 4.35	$P<0.001$ Sample 2<Sample 1, Sample 3
Spring'75 *	7	11.24 ± 7.24	46	19.56 ± 4.18			$P<0.001$ Sample 1<Sample 2
Autumn'75 *	7	30.56 ± 11.46	34	32.41 ± 4.79			N.S.

Differences between means were examined by an analysis of variance.

* Where only 2 samples were involved a Student's 't' test was employed.

seen that the blood immunoglobulin levels of calves that died in the Spring '75 were significantly lower when the calves arrived on the unit than calves that survived and that during the Spring'75 intake calves that died were generally younger than the calves that died during the other two intakes.

On the second sampling occasion the mean level of blood serum immunoglobulins of calves of the Autumn'74 intake was 4.31 mg/ml lower ($P < 0.001$) than the level found on the first sampling. When these calves were sampled again at 71 days of age the level of blood serum immunoglobulins had risen by 4.84 mg/ml. There was no significant difference in the levels between the first and third sampling of the Autumn'74 calves. At the second time of sampling at 46 days of age calves of the Spring'75 intake had a significantly higher ($P < 0.001$) mean (+ 8.32 mg/ml) level of blood immunoglobulins than when they were first sampled at seven days of age. There was no significant difference between the levels of blood immunoglobulins found at seven or 34 days of age in calves of the Autumn'75 intake.

The effect of the level of nutrition offered to the calves and their ability to produce their own blood serum immunoglobulins was examined by comparing the change in the mean blood serum immunoglobulin levels of calves on each of the four nutritional treatments between successive samplings. Changes in the mean immunoglobulin levels of the calves are shown in Table 3e.12 for each of the four levels of nutrition. The treatment group means were compared by analysis of variance.

Table 3e.12

Changes in Blood Serum Immunoglobulins of Calves Between Successive Samplings

	Age of calf (days)	Nutritional Treatments				Minimum SEd
		LL	LH	HL	HH	
Autumn'74	7-41	-3.9	-4.76	-4.51	-5.77	1.13
	41-71	+5.17	+4.13	+5.01	+5.47	
	7-71	+1.27	-0.63	+0.50	-0.30	
Spring'75	7-46	+8.3	+9.8	+5.9	+9.8	1.01
Autumn'75	7-34	-1.155	+4.27	-1.05	+5.02	1.4

There was no suggestion that the development of passive immunity in young calves was affected by the nutritional status of the calf. There was no discernible trend in the change of immunoglobulin level of young calves fed each of the four levels of nutrition. There was no indication that significant differences would be obtained by using the individual calf data hence the examination was not carried further.

DISCUSSION

During the two years of the trial a total of 52 calves died. Of the total number of calves bought this figure represented a mortality of 10.25%. Mortality ranged from a minimum value of 1.56 per cent in the Autumn'74 crop to a maximum 14.84 per cent in the Spring'75 intake. Although there was no significant difference between the mortality in the two Spring and two Autumn crops more calves died during the Spring intakes compared with the Autumn intakes (34 compared with 18 deaths). These results agree with the recent reports on calf mortality (Vet. Record 1964; Martin, Schwabe and Franti, 1975; Speicher and Hepp 1973) and confirm that calf mortality in this instance under climatic housing conditions was higher in Spring born calves.

The results show that of all the calves that died on the unit peak mortality (39%) occurred between 11 and 17 days of age. As the average age of the calves when they entered the unit was 6 days, peak mortality occurred when the calves had been in residence for between four and eleven days. These results are not directly comparable with the literature values for the period of peak mortality as the population considered in the present study represents a sample of the total calf population which survived to the time of purchase. Kilkenny (1975) obtained an average value for the mortality up to 3 months of age of 5.8% for calves purchased un-weaned approximately one week old by specialist calf rearers. The 90% range in the above survey was 0-19.7% mortality. The mortality encountered during the present trial was therefore above the average values quoted in the literature for un-weaned bought-in calves.

The calves purchased for the present trial ranged from pure Friesian to Friesian cross Ayrshire. There was no significant effect of the breed of the calf on calf mortality.

When the results were considered over the four intakes there was no significant effect of nutritional treatment on the mortality of the calves. However, there was a suggestion that mortality was higher in calves fed the low level of milk replacer and especially in calves on the LL treatment. This trend was similar to the results obtained during the Spring 1975 intake when a significantly higher ($P < 0.05$) level of mortality was found in calves on the LL level of nutrition. On this occasion the low level of milk replacer feeding could not be implicated as the cause of the higher incidence of mortality as there was no significant difference between the LH, HL and HH treatments. Thus during the Spring of 1975 a low level of nutrition as a result of low levels of milk replacer and concentrate feeding was directly related to a higher incidence of mortality. In none of the other

three intakes was there any significant effect of the level of nutrition on calf mortality.

When all four intakes were combined there was no significant effect of housing on calf mortality although there was a suggestion that mortality was lower in the A type houses and that insulation in both types of houses reduced mortality. When the four calf crops were examined separately there were no significant differences between the levels of calf mortality in each of the four houses.

If death due to Salmonella type organisms is classed as a digestive disturbance, then the major ascribed organ systems were digestive (63%), respiratory (29%) and the body as a whole (21%). These values differ from the pattern of mortality found by Hugh-Jones (1972). The ages of calves dying when the causative agents were either gastro enteritis or Salmonella type organisms is in good agreement with the results of Roy et al (1972) where it was found that deaths associated with Salmonella type organisms occurred in older calves compared with calves whose death was associated with other Coliform bacteria. In the present trial calves whose death was associated with pneumonia type organisms were generally younger than would be expected from the literature. There were more deaths associated with pneumonia type organisms in Spring born calves compared with calves born in the Autumn (6 compared with 1), however the numbers were not sufficiently large to make house comparisons. There was no apparent seasonal effect of deaths due to gastro enteritis or associated with Salmonellae type organisms.

An examination of the serum immunoglobulin status of the calves showed that calves born during the Spring had significantly lower blood serum immunoglobulin levels at seven days of age than calves that were born during the Autumn (12.2 cf 24.8 mg/ml respectively). It is unlikely that these values directly represent the amount of serum

immunoglobulins received by the calf from the dam, due to the drop in levels of serum immunoglobulins with age up to four weeks (Penhale and Jones, 1972; Fisher and Martinez, 1975). The levels received were probably slightly above those measured at seven days of age. The seasonal variation in serum immunoglobulins measured in this trial confirms results of Gay, Fisher and McEwen (1965) who found levels of serum immunoglobulins of market calves lower between November and April. During these months serum immunoglobulin levels were below 10 mg/ml whilst during the remainder of the year the levels were above 20 mg/ml.

Mortality in the present trial was higher during the Spring intakes than the Autumn intakes although only during the Spring'75 crop was a significantly lower level of blood immunoglobulins found in calves that died. Higher calf mortality has been associated with low levels of blood immunoglobulins. Of a total of 178 market bought calves 30 out of a total of 31 that died had blood serum immunoglobulin measurements of below 10 mg/ml (Gay Anderson, Fisher and McEwan, 1965). Irwin (1974), found that mortality in calves with serum immunoglobulins of less than 20 mg/ml was 11.24% compared with 1.55% in calves with immunoglobulin levels of above 20 mg/ml.

Stott, Wiersma, Menefee and Radwanski (1976) found a positive correlation between stress in the neonatal calf and a reduction in the ability of the calf to absorb maternal antibodies from colostrum. Thus calves which were high temperature stressed had a lower level of passive immunity. It was suggested that the increased secretion of adrenal steroids during stress may have restricted immunoglobulin absorption. The present results which have shown a lower level of blood serum immunoglobulins in Spring born compared with Autumn born calves are in agreement with the results of the survey made by Gay et al (1965b) and the cause may have been a reduced immuno-

globulin absorption according to the postulate of Stott et al (1976).

The correlation between low levels of blood immunoglobulins and an increased mortality rate is only partly substantiated by the present work when a correlation between mortality and lower blood immunoglobulins was only found during the Spring'75 intake. However, on the other two occasions when mortality was examined with respect to blood immunoglobulin levels the mean blood immunoglobulin levels of all calves were significantly higher ($P < 0.001$) than the levels found in the Spring'75 calves. These results would suggest that there is a threshold of blood immunoglobulin level below which a reduction in blood immunoglobulins is positively correlated with calf mortality.

During the Autumn 1974 intake the mean level of blood immunoglobulins was significantly lower in calves when they reached 41 days of age than when they were seven days old. Logan (1974) found that serum immunoglobulins in suckled calves reached a peak at 24 hours post partum. After 24 hours the levels of individual IgG, IgA and IgM and hence total immunoglobulins fell at varying rates in accordance with the different half lives for each class of immunoglobulin. At five weeks old IgG and IgA levels were still decreasing but the IgM level reached a minimum at four weeks and by five weeks had begun to increase. Stott et al (1976) also found that serum immunoglobulin concentrations fell between two and ten days after birth. In the present experiment the Spring'75 calves, which could be considered hypogammaglobulinaemic, were actively producing serum immunoglobulins by 46 days of age. This result agrees with the findings of Logan (1974) when it was found that IgM synthesis began as early as one week old in hypogammaglobulinaemic calves. The results of the Autumn'75 crop do not agree with the literature as there was no change in the level of blood immuno-

globulins between seven and 34 days of age. High levels of blood immunoglobulins (>30mg/ml) were found in these calves at seven days of age and it may be that under situations of high concentrations of blood immunoglobulins active secretion by the calf begins at an earlier age.

There was no evidence in the present experiment to suggest that the level of nutrition upon which the calf was reared had any effect on its ability to develop its own passive immunity.

From the previous discussion it can be concluded that during the two Spring intakes the levels of serum immunoglobulins in the calves when they arrived at the unit resulted in them having a lower resistance to disease than calves in the two Autumn intakes and hence more calves died. The Spring'75 crop as a whole may be classed as hypogammaglobulinaemic as the change in the level of serum immunoglobulins with age exhibited the typical pattern of an early rise in blood serum immunoglobulins expected from hypogammaglobulinaemic calves (Logan, 1974). The frequency of occurrence of sub critical temperatures shown in Table 2b.7 shows that during February the mean outside temperature recorded at Brickrow was 3.6°C. If this can be considered representative of temperatures in the West of Scotland during this period then it is pertinent to consider that calves born during this period were low temperature stressed; the critical temperature of the young calf is above 8.6°C (Webster, 1977). The action of stress in lowering blood immunoglobulin absorption, postulated by Stott et al (1976), would, in conjunction with the low temperatures experienced by Spring born calves at birth, partly explain the low serum immunoglobulin levels of Spring born calves.

From the information presented it is obvious that the Spring'75 intake was a typical. Several factors have acted in combination to

reduce the viability of the calves. The blood immunoglobulin synthesis of the calves followed a pattern characteristic of hypo-gammaglobulinaemic calves and it was shown that a low level of nutrition specifically reduced viability. Although temperatures were generally lower during the Spring intakes, slightly higher temperatures found in the B2 houses did not significantly reduce calf mortality. From the results it can be stated that viability can be increased by raising the level of calf nutrition, however the advantage obtained from feeding higher levels of nutrition is only attained in calves which in this case were found to be deficient in serum immunoglobulins. In this instance the benefit of a higher plane of nutrition was obtained in calves which were achieving mean live-weight gains in excess of 0.506 compared with 0.303 kg/day. The results do not indicate that the viability of calves in optimum health condition is affected by nutrition.

The incidence of Salmonella during the Spring and Autumn 1975 calf crops accounted for 47 and 40% of the total calf mortality during those two crops. Of the 22 positive identifications of Salmonella (15 deaths, 7 slaughtered), Salmonella typhimurium was isolated on seven occasions and Salmonella dublin on 15 occasions. The average age of calves dying of infections associated with Salmonella was 33 days. Osborne (1975) from results of surveys and experiments suggested that very young calves are more commonly infected in the immediate post partum period by contact with material (e.g. teats) contaminated by the faeces or vaginal discharge of the dam or some other adult animal. Once individual animals are infected and become excreters, spread to other calves of approximately the same age is most likely to occur by the oral route if animals are kept in groups. However, infection could occur by other routes, although this would be unlikely to produce severe disease immediately.

It was suggested that the stress of transport could activate a latent infection and that the seasonal incidence of the calfhood disease suggests that a common predisposing factor may be chilling and/or high humidity particularly where enzootic pneumonia co-exists.

Of the total number of recorded incidences of Salmonella only ten cases were isolated cases in which no other calf in the same cell was infected. The remaining twelve cases occurred as pockets of the disease when either two or up to four adjoining calves became infected. It cannot be stated whether these pockets of the disease were introduced by one carrier in each instance but it is pertinent to consider that they do to a degree represent the cross infection of calves which occurred on the unit. When intakes of calves were also considered a total of 17 of the identified cases had either arrived on the unit in the same group of calves or were penned adjacent to one another. Thus only five cases of Salmonella could be considered as truly isolated cases. A total of 14 cases of Salmonella were identified during the Spring of 1975 and eight during the Autumn of 1975. These results would tend to support the seasonal effect noted by Osborne (1975) with a higher incidence reported during the colder more humid period.

Production Trials

Section 3.f

Post-rounding

INTRODUCTION

Compensatory growth is recognised as a phenomenon whereby an animal having undergone a period of food restriction is able, upon realimentation, to attain the live weight of an unretarded counterpart. The value of the process is greatest when it enables animals to be reared on reduced levels of feeding when food is scarce or high in price. The process ceases to be of value if the starved animal is permanently stunted or if the cost of achieving the final product is greater than it would have been had the animal not experienced a period of reduced growth rate.

The phenomenon of compensatory growth has been demonstrated in older cattle. However, the literature on the effect of feed restriction and realimentation in young cattle is not conclusive as to whether compensatory growth occurs. The review of the literature presented here will show compensatory growth in older cattle together with the effects of feed restrictions and realimentation on the different classes of cattle from adults via progressively younger stock to calves.

Compensatory growth was shown to occur in 90 Hereford steers restricted after having reached 212 kg live weight, (Hironaka and Kozub 1973). The control animals were fed ad libitum and the treated animals fed to achieve live-weight gains of 0.90 and 0.45 kg per day, over periods of 12 and 24 weeks. Following restriction although the restricted steers gained faster than the full fed steers, the compensation was not sufficiently rapid to allow these steers to attain the weight of the controls at the same age. The total energy required by the steers to reach a market weight of 489 kg was similar for the full fed and restricted groups. This work also demonstrated a reduction in the proportion of fat in the restricted group, as indicated by a trend in reduction of backfat thickness. It was calculated that the total maintenance energy requirement increased as the feeding period increased; this was

compensated for in the restricted group by a decrease in the energy required per unit gain as the carcass was leaner. Thus the energy required to reach the same slaughter weight was the same although the restricted animals took longer. It was estimated that, as the realimentated steers consumed more feed per day than the full fed animals, they deposited fat at a faster rate; however, the period of fat deposition was so shortened that total deposition tended to be less.

Compensatory growth was also shown to occur in more severely restricted steers, restricted at a lower live weight. Ledger (1973) restricted steers (Boran-Zebu) when they reached a mean live weight of 185 kg at a mean age of 387 days. Control steers were fed ad libitum and treated animals were kept at maintenance for 12 or 24 weeks, or fed to lose 15 per cent of body weight both over 12 and 24 weeks. A sixth group were fed to lose 25 per cent of body weight in 12 weeks. Steers were slaughtered at 275 and 360 kg live weight. The required levels of live weight loss were not attained due to the increasing efficiency of food utilization as the degree of undernourishment was increased. At each of the two slaughter weights there was no significant difference between the control and treatment groups contents of fat, lean and bone. In this experiment significantly larger quantities of isocaloric food were fed to the restricted groups compared with the control group up to slaughter at 275 kg live weight. A significantly longer period of time was also required by the restricted groups to reach the slaughter weights. Thus, unlike the results of Hironaka et al, although these restricted steers utilised energy more efficiently during the period of restriction, the increased time for which the animals had to maintain themselves in reaching the slaughter weight was not compensated for by the animal depositing less fat and hence requiring less energy per kilogramme of gain. Total energy intake from birth to slaughter was therefore greater in the restricted animals compared with the controls. Following realimentation the two groups

previously restricted for 24 weeks at maintenance and to lose 15 per cent live weight grew 42 and 40 per cent faster and ate 34 and 25 per cent less food respectively then did the control group between 185 and 270 kg live weight.

Fox, Johnson, Preston, Dockerty and Klosterman (1972), compared the performance of Hereford steers initially weighing 230 or 247 kg , restricted to maintenance for five or six months, with full fed steers reared to slaughter weights of 364 and 454 kg. The results showed that steers restricted and then full fed required more time to reach 454 kg but the total energy and protein intakes needed to reach this weight were similar for both continuously full fed and restricted then full fed steers. At 364 kg live weight the restricted steers required significantly more energy per kg gained from the starting weight. The compensating steers were fed a high energy ration after the period of restriction. These results also showed that compensatory steers made a greater proportion of the protein gain during the initial part, and a greater proportion of the fat gain during the latter part of the full feeding programme, compared to continuously full fed controls. Thus, at 364 kg body weight, compensatory steers had a higher per cent empty body protein and a lower per cent empty body fat compared with the controls. However, there was no difference between the two groups in final body composition at 454 kg. Fox et al considered that increased efficiency of energy and protein utilization during the full feeding period was responsible for compensatory growth. There was a trend for net energy for maintenance and gain and efficiency of metabolizable energy utilization to be higher for compensatory steers. Compensatory steers were consistently more efficient in protein utilization then controls, particularly during the first part of the full feeding period. It was also suggested that during recovery, compensatory cattle may require a higher protein:energy ratio in the diet.

In an experiment to examine the food intake of compensating steers it was found that food intake at a given age was practically the same for compensating compared with full fed animals. In this instance the ability of the steers to compensate was attributed to the lower maintenance requirement of the lighter realimentating animals thus more feed was available for live-weight gain. (Lopez Saubidet and Verde 1976). It was concluded that age was a better predictor of food intake than was live weight. In this experiment animals that compensated were 8 months old and averaged 193 kg live weight at the start of the restriction period of 100 days. During feed restriction daily live-weight gain ranged from 1.0 to -0.25 kg/day. Overall feed conversion efficiency from 193 to 450 kg live weight was inversely proportional to the severity of the feed restriction. The converse was true during the period of realimentation.

In a similar experiment, in which bull calves were fed maintenance rations from 180-270 days of age and then allowed to realimentate to a slaughter weight of approximately 500 kg live weight, the gross feed conversion ratios of the restricted and control steers were not significantly different. However, in the post restriction period the restricted steers compensated by being more efficient in converting energy to gain. (Drori, Levy, Forman and Holzer, 1974). It was also found that during the period when the animals were fed to maintain themselves a high energy ration was utilized more efficiently than one with a low concentration of energy. This contention was supported by the changes in body measurements which, when steers were fed a ration of high energy concentration, were double those obtained on the low energy ration. During the realimentation period the group fed 85% of ad libitum had significantly leaner carcasses than realimentating ad libitum fed steers. No benefit in food conversion efficiency was obtained from this later restriction.

Morgan (1972) showed that calves reared on a maintenance ration between 112 and 224 days of age were able to compensate slightly and during realimentation gained weight significantly faster than full fed controls. This advantage was lost when adjustment was made for variation in gut fill. It was also found that the nutritional history of the animal did not significantly alter the dressing percentage, fleshing index or conformation at slaughter. There was also an absence of treatment effect on the connective tissue and fat contents of the longissimus dorsi muscle and on the diameter of the muscle. These results are at variance with those obtained when restrictions were applied to Israeli-Friesian bull calves, (Lovy, Folman, Holzer and Drori, 1971). These calves were restricted to maintenance or 125% maintenance at 90, 135 and 180 days of age. The six treatments were imposed for periods of 30, 75 and 120 days. The results indicated no compensatory growth and the daily gain of the treated animals throughout the experiment was significantly lower than that of the control animals. Examination of the conformation of the calves suggested that the restricted feeding affected the soft tissues more severely than the skeleton. At slaughter weights of 450 and 525 kg the carcasses of the treated calves had less fat and a significantly higher percentage of saleable meat than the controls. This would explain why the conversion of energy to live-weight gain upon realimentation was more efficient in the treated animals compared with the controls. The gross energy conversion ratio of the treated calves to slaughter was poorer than in the control calves, due to the longer time taken to reach slaughter weight and hence the longer time for which the calves had to maintain themselves. The degree of fatness in treated calves was inversely related to the duration of restricted feeding.

Morgan (1972) found that after calves were restricted to gaining 0.36 kg/day from birth to 16 weeks of age, upon realimentation the

live-weight gain of the restricted calves was at no time greater then that of the full fed controls. Lonsdale and Taylor (1969) weaned calves at 38, 41, 55 and 76 days of age. Those calves weaned at 76 days of age were considered controls and the period of restriction was the length of time for which weaned calves did not receive milk compared with the controls. Average weights at weaning were 58, 58, 75 and 95 kg for the groups weaned at 38, 41, 55 and 76 days respectively. Differences in live weight attained at 70 days of age when all calves were weaned were maintained up to 400 days of age. At no time was the live-weight gain of the restricted calves any greater than the full fed controls and no marked compensatory growth was exhibited. The feed offered during the realimentation period consisted of ample pasture of high digestibility, or highly digestible silage plus a concentrate allowance. There was a slight tendency for the animals weaned at 55 days of age to catch up on those weaned at 76 days of age.

Growth rate between purchase and slaughter was found to be positively correlated with growth rate between birth and 107 days of age, (Everitt, Evans and Franks, 1969). Everitt (1972) in a further experiment compared full fed calves gaining at 0.75 kg/day to weaning at 112 days with calves gaining at 0.38 kg/day and weaned at the same time. At weaning the difference in live weight between the two groups was 42 kg. At 400 days of age the restricted calves had compensated slightly and the difference between the groups was reduced to 35 kg. In a comparison between calves reared from birth to 84 days of age at 0.67 and 0.44 kg/day, the non restricted calves continued to grow slightly faster for a further 243 days compared to calves previously on the low treatment (Reardon and Everitt, 1972). This pre-weaning treatment did not affect the ability of the calf to recover from a subsequent nutritional check at the yearling stage. Voluntary intake and the efficiency of conversion of digestible energy to live-weight

gain was the same for both groups when allowances were made for differences in live weight. The latter was to be expected when it was found that there was no difference in carcass composition between the two groups at 637 days of age.

This discussion demonstrates that steers restricted between 180 and 270 days of age, on realimentation, are able to compensate and grow faster than full fed controls. There is less fat in the gain of these animals compared with the controls and hence they grow more efficiently (Drori et al, 1974). The situation becomes less distinct when the restriction occurs between 112 and 224 days of age, although a direct comparison of these two results is not valid as in the latter instance the restriction was imposed for a longer time (Morgan 1972). There is no suggestion of compensatory growth in calves restricted at 90, 135 and 180 days of age for various periods of time (Levy et al, 1971) which at the later age is at variance with the results of Drori et al (1974). The composition of the gain in the animals used by Levy et al (1971) is in agreement however with the gains of the animals used by Drori et al (1974). Results with young calves (Morgan, 1972; Lonsdale et al 1969; Everitt et al 1969; Reardon et al 1972) have shown that young calves reared at 0.44 kg/day are unable to make up the difference in live weight achieved at weaning by calves gaining in excess of 0.6 kg/day. No results are quoted on the ability of calves growing at intermediate rates of gain to compensate when allowed to realimentate compared with calves growing faster to weaning. The treatments imposed pre-weaning in the present trial have imposed various rates of liveweight gain to weaning, hence it was decided to examine the effects of these rates of gain on post weaning performance.

MATERIALS AND METHODS

Animals and Design

The animals used in the trial were Friesian, Friesian x Friesian Ayrshire and Friesian x Ayrshire bull calves which had previously been reared on the four nutritional treatments and the three levels of nutrition imposed during the pre-weaning trial. Pre-weaning, two calves on each nutritional treatment were housed in each cell of the four climatic calf houses and all calves were fed individually. Post-weaning there were no facilities for individual feeding thus group feeding records were taken. At weaning the 32 calves in each house were regrouped such that each cell of eight calves contained individuals which pre-weaning had received the same nutritional treatment. Calves which had died were not replaced, thus the number of calves per cell ranged from eight in a complete cell to four where calves on a particular pre-weaning treatment had died. Each of the four houses, therefore, contained four cells of calves, each cell containing a maximum of eight calves from the same pre-weaning treatment.

Housing and Management

Post-weaning the individual calf crates were removed from the 'A' type houses and calves were allowed access to a feed fence placed across the width of the cell. The animals were allowed to run as a group in the cell. The individual crates in the 'B' type houses, constructed around the cubicle divisions, were also removed and the animals were similarly allowed access to a feed stance outside the cubicle area.

The regrouping of calves according to prior nutritional treatment resulted in groups of calves of varying live weight being non uniformly allocated to cells within a house; each treatment was not equally represented in each cell. A preliminary examination of the environmental recording results had shown that between cell environmental

differences, comparing inner cells with outer cells, were negligible. It was considered, therefore, that there would be no between cell effects on the performance of the calves and that the non-uniform placement of treatments within a house would not affect the analysis of the results.

There was a basic difference between the accommodation of calves in the 'A' and 'B' type houses. Calves in the 'A' type houses were run in a pen in which there were no supplementary divisions. A system of built up dung was used and the animals received fresh straw bedding when necessary. The dung was removed from the buildings at the termination of each calf trial. Groups of animals in the 'B' type houses were housed in cubicle accommodation and were bedded with wood shavings when required. Dung was removed from the feed stance area and from between the cubicles twice weekly.

All the animals were weighed weekly and were castrated by Burdizzo during the second week of the trial. Feed was offered twice daily, morning and afternoon.

Diets and Feeding

All calves were weaned abruptly on the first day of the trial. An estimation was made of the total concentrate intake at weaning of each pen of regrouped calves. Due to the pre-weaning treatments calves on the two ad libitum concentrate treatments were consuming approximately 500g more concentrates per head per day than calves on the restricted treatments. Over the following week the amount of concentrates offered to the previously restricted calves was increased whilst that of the previously ad libitum groups was kept constant such that, at the termination of the first week, all calves were receiving an equal allowance of concentrates. This was of the order of 1.8 kg of concentrates per

head per day. The level of concentrates offered to the calves was increased such that four weeks post-weaning all animals were receiving an allowance of 2.5 kg of concentrates per head per day. The concentrates offered were a commercial brand of calf rearing cubes (B.O.C.M. Silcock Calf Rearing Ration) containing 14% protein.

The roughage proportion of the ration consisted of hay or silage, or hay and silage, and was offered to the calves ad libitum. The ration was offered to the calves morning and afternoon. Feed refusals were removed twice daily and weighed. The composition and chemical analysis of the rations offered to the four crops of calves post weaning are shown in Table 3f.1.

Table 3f.1

Composition and Chemical Analysis of the Rations Offered to the Four Crops of Calves Post Weaning

	Daily Intake kg/head	Description	% CP in DM	M/D
Spring 1974				
Concentrates	max. 2.5		16.6	12.5
Hay	ad libitum		5.7	7.0
Silage	ad libitum	red clover silage	16.4	7.0
Autumn 1974				
Concentrates	max. 2.5		15.3	12.5
Hay	0.5		5.5	7.7
Silage	ad libitum	1st cut grass	15.1	10.7
Spring 1975				
Concentrates	max. 2.5	1st and 2nd cut grass	17.4	12.5
Hay	ad libitum		7.5	8.4
Silage	ad libitum for 21 days		17.3	9.7
Autumn 1975				
Concentrates	max. 2.5		16.6	12.5
Hay	ad libitum		7.5	8.4

The age of the calves at the start of the post-weaning trials together

with the duration of the four trials is shown in Table 3f.2.

Table 3f.2

The Age of Calves at the Start and the Duration of the Four Post Weaning Feeding Trials (Days)

	Spring'74	Autumn'74	Spring'75		Autumn'75
Age at start of trial (days)	77	76	83	76	76
Duration of trial (days)	91	84	77	84	77

The two periods for which the Spring'75 calves were on trial was due to the fact that calves in the number three and four cells of both the 'A' and 'B' type houses were weaned a week later than calves in the number one and two cells. This was because the later weaned calves were later arriving on the unit.

Statistical Analysis

The results have been analysed by an analysis of variance technique. Analyses of differences between live-weight gains of calves on different treatments have been carried out using individual calf data. Results pertaining to initial and final weights and feed intakes have been analysed using group means.

RESULTS

Starting Weight

Although the levels of feeding used during the first intake (Spring'74) were slightly higher than for the other three intakes and seasonal differences occurred between the four crops the four intakes have been combined in an examination of weight at weaning. The mean live weights of calves at weaning of each of the four calf crops are

shown for the four nutritional treatments in Table 3f.3. A significant interaction was found between the season during which the calves were reared to weaning and nutritional treatment, therefore the results have been tabulated according to level of nutrition and season of rearing together with the overall means.

Table 3f.3

Mean Live Weight (kg) at Weaning Grouped According to Rearing Period and Nutritional Treatment

	Live weight in kg.				mean	Levels of Significance P 0.05
	LL	LH	HL	HH		
Spring'74	74.3	82.6	82.9	85.6	81.3	LL < LH, HL, HH
Autumn'74	61.8	71.8	74.9	79.8	72.1	LL < LH < HH LL < HL
Spring'75	66.2	81.0	79.7	85.7	78.2	LL < LH, HL, HH
Autumn'75	60.8	68.4	72.1	76.8	69.5	LL < LH < HH LL < HL
Mean	65.7	75.9	77.4	81.9		LL < LH, HL, HH

During the pre-weaning trials the calves receiving a restricted level of nutrition during the Spring'74 intake received a higher level of nutrition than the restricted calves of any of the other three intakes. The Spring'75 pre-weaning trial lasted 77 days, whilst the other three trials were each of 70 days duration. The increased levels of feeding used during the Spring'74 pre-weaning trial and the extended period of the Spring'75 pre-weaning trial may partly account for the higher weaning weights of the calves from these two trials compared with the weaning weights of calves from the two Autumn intakes.

Daily Live-Weight Gain

There was no significant effect of pre-weaning level of nutrition on the daily live-weight gains of calves during the post-weaning trial, although the live-weight gains of calves previously on the LL treatments tended to be lower than calves on the other three treatments. The

durations of the four post-weaning trials are shown in Table 3f.2 and the post-weaning daily live-weight gains of calves grouped according to pre-weaning nutritional treatment is shown in Table 3f.4, for the four crops of calves.

Table 3f.4

Post-Weaning Daily Live-Weight Gain (kg/day) Grouped According to Pre-Weaning Nutritional Treatment

	Pre-Weaning nutritional treatment				
	LL	LH	HL	HH	Mean
Spring'74	0.906	0.930	0.931	0.916	0.921
Autumn'74	0.739	0.750	0.722	0.712	0.731
Spring'75	0.818	0.853	0.851	0.818	0.835
Autumn'75	0.738	0.718	0.756	0.799	0.753
Mean	0.800	0.813	0.815	0.811	

It is considered that the slightly lower daily live-weight gain of calves on the LL treatment may have been due to the lower weight at weaning of calves on this treatment.

An examination of the results between intakes showed that the post-weaning daily live-weight gain of calves of the two Spring intakes was higher than that of calves reared during the Autumn. This may have been partly due to the higher average weight at weaning of calves reared during the Spring.

A statistical examination of the between season differences has not been made due to the fact that there was no replication of any one particular intake hence no estimate may be made of the within season error.

The live weight of calves at weaning grouped according to house of origin is shown in Table 3f.5 and daily live-weight gain from weaning to sale grouped according to house of origin is shown in Table 3f.6.

Table 3f.5

Live Weight (kg) at Weaning Grouped According to House of Origin

	House of Origin			
	A1	A2	B1	B2
Spring'74	81.8	82.9	82.3	78.1
Autumn'74	73.1	72.9	72.8	69.4
Spring'75	78.2	79.7	77.3	77.4
Autumn'75	70.4	72.1	67.3	68.3
Mean	75.9	76.9	74.9	73.3

Table 3f.6

Daily Live-Weight Gain (kg/day) During the Post-Weaning Period Grouped According to House of Origin

	House of Origin			
	A1	A2	B1	B2
Spring'74	0.933	0.925	0.904	0.920
Autumn'74	0.752	0.728	0.712	0.731
Spring'75	0.853	0.820	0.820	0.847
Autumn'75	0.735	0.784	0.711	0.817
Mean	0.818	0.805	0.787	0.818

Within any one period there was no significant effect of housing environment on the performance of the calves. However, during three of the four intakes the live-weight gains of the calves in the B1 house were poorer than those of calves in the other three houses. On the fourth occasion calves in the B1 house had equal lowest live-weight gain with calves in the A2 house. Over the four intakes calves in the A1 house performed best on three occasions and on the fourth occasion were ranked third best. As the mean live weight at weaning of the calves in the B1 house was not the lowest when all four houses were compared this factor cannot totally explain the poorer performance of those calves.

Sale Weight

Differences in weight at the end of the post-weaning trial reflected the non-significant differences in live-weight gain from weaning to sale and the differences in live weight at weaning. Calves fed the LL level of nutrition pre-weaning were significantly lighter ($P < 0.01$) at sale than calves reared on the other three levels of nutrition. The difference was consistent throughout the four post-weaning trials. Mean live weights of calves at the termination of the four post-weaning trials are shown grouped according to pre-weaning nutritional treatment in Table 3f.7.

Table 3f.7

Mean Live Weight (kg) of Calves at the End of the Post Weaning Trial Grouped According to Pre-Weaning Nutritional Treatment

	Pre-weaning nutritional treatment					
	LL	LH	HL	HH	Mean	$P < 0.05$
Spring'74	143.2	152.5	152.4	154.1	150.5	LL<LH, HL, HH
Autumn'74	123.6	134.9	135.6	139.7	133.5	LL<LH, HL, HH
Spring'75	129.1	146.9	143.8	148.6	142.1	LL<LH, HL, HH
Autumn'75	117.5	123.8	129.4	131.3	131.3	LH<HH LL<LH, HL, HH
Mean	128.4	139.5	140.3	143.4	-	LL<LH, HL<HH

The change in weight of calves from arrival to sale grouped according to pre-weaning level of nutrition and to housing environment is shown in Figures 3f.1 and 3f.2 respectively. Mean live weights of all calves from each of the four intakes were used to construct these figures.

Compensatory Growth

In order to estimate whether compensatory growth had occurred in the nutrient restricted calves the differences in average pen weights between calves previously fed the high, medium (LH + HL) and low levels of nutrition were calculated at weaning and at sale. A paired Students 't' test was then used to compare the differences between the average

Fig. 31.1.
Age versus live weight according to level of nutrition for calves from arrival to sale.

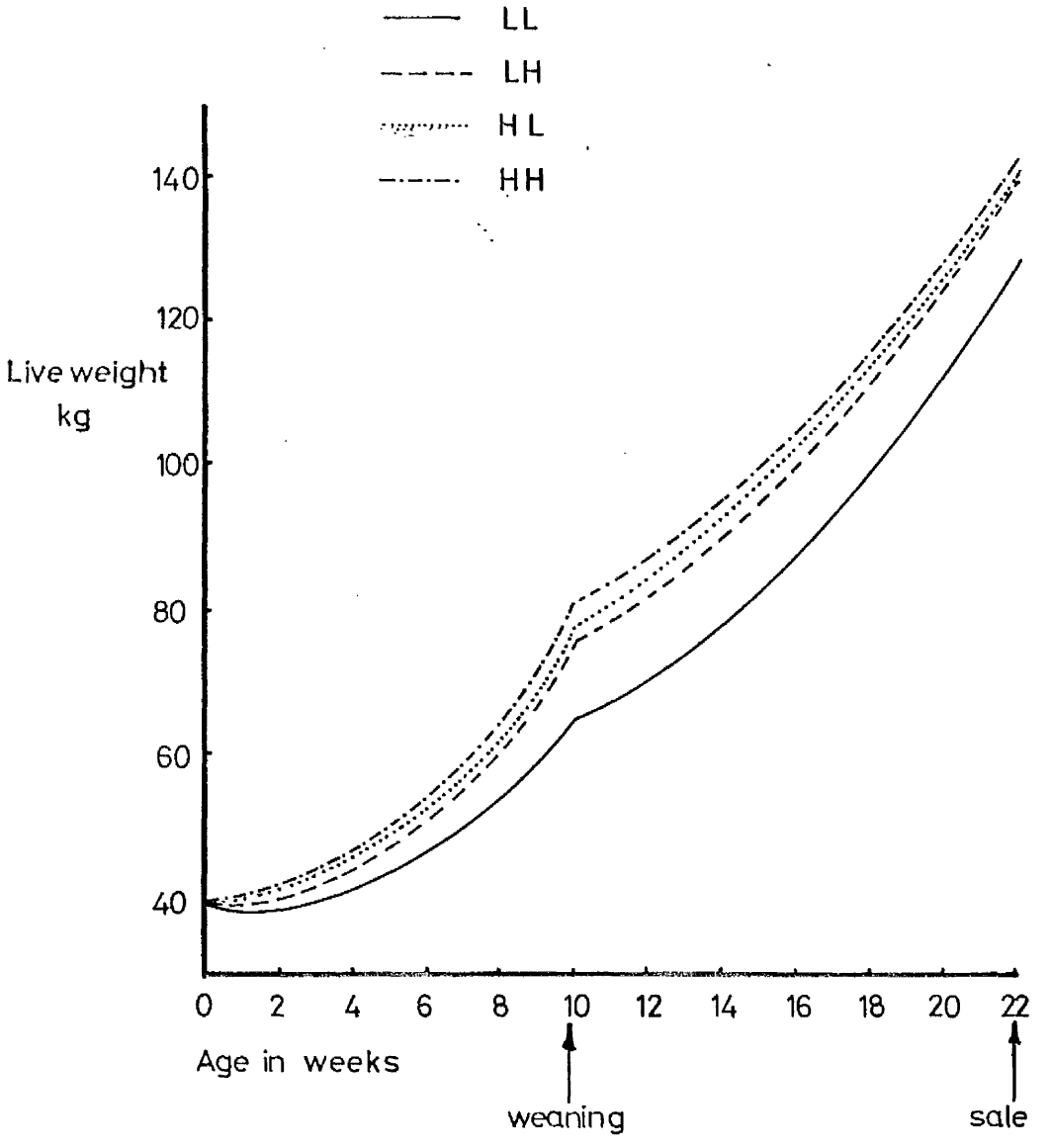
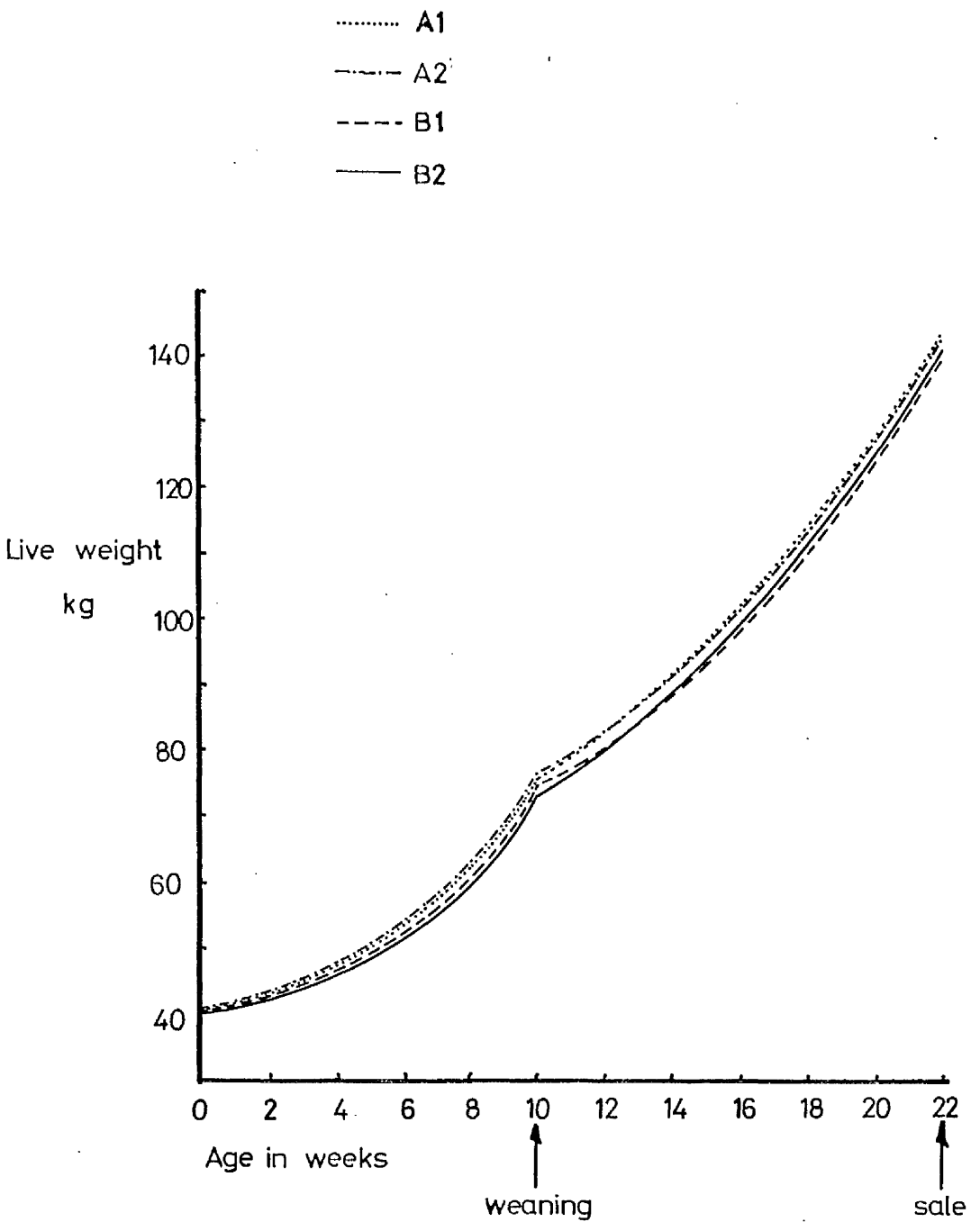


Fig. 3f.2.

Age versus live weight according to housing for calves from arrival to sale.



weights of pens of high and low or high and medium calves at weaning and at sale. In this instance average treatment live weights obtained for each calf trial were used. The differences in live weight between the different treatments are shown for each calf crop in Table 3f.8.

Table 3f.8

Differences in live weight (kg) between treatment groups at weaning and sale

	High - low Kgs			High-Medium Kgs		
	Weaning	Sale	Difference	Weaning	Sale	Difference
Spring'74	11.30	10.90	-0.40	2.85	1.70	-1.15
Autumn'74	18.00	16.10	-1.90	6.45	4.50	-1.95
Spring'75	19.50	19.50	0	5.35	3.30	-2.05
Autumn'75	16.00	13.80	-2.20	6.55	4.70	-1.85
$t = 15.25^{n.s.}$ 3d.f				$t = 168^{n.s.}$ 3d.f		

Having ascertained that differences were significant using the treatment means it was not considered necessary to examine the data using individual calf live weights. Differences in weight between treatment groups were less at sale than at weaning showing that calves previously fed restricted levels of nutrition had compensated and gained weight slightly faster than the high fed group during the post weaning period. However, during the post weaning phase there were no significant differences in daily live-weight gain between treatments. Table 3f.4.

The apparent discrepancy between the fact that no significant differences in live-weight gain data were obtained but a small degree of compensatory growth was found may be due to the statistical examination of the results. The live-weight gain data was analysed using individual calf data and missing plot techniques were used to calculate data for calves that died. As mortality was higher on the L. treatment

a greater degree of correction as a result of missing data was applied to this treatment. Compensatory growth data was calculated using calves present and hence did not contain the bias introduced by inserting the missing data.

The ability of the low restricted calves (treatment LL) to compensate compared with the medium restricted (average of the HL and LH groups) was tested by comparing the differences between average pen weights of calves of the low and medium treatment groups with calves of the control (HH group) at weaning and at sale viz:

WL_W = (Mean wt. of HH group minus Mean wt. LL group) at weaning

WL_S = (Mean wt. of HH group minus Mean wt. LL group) at sale

then $WL_S - WL_W$ expresses the degree of compensation of the low group.

similarly

WM_W = (Mean wt. of HH group minus Mean wt. $(\frac{LH + HL}{2})$ groups) at weaning

WM_S = (Mean wt. of HH group minus Mean wt. $(\frac{LH + HL}{2})$ groups) at sale

then $WM_S - WM_W$ expresses the degree of compensation of the medium group. the values of $(WL_S - WL_W)$ and $(WM_S - WM_W)$ obtained from the four houses during each of the four calf crops were compared. There was no significant difference of the effect of pre-weaning level of nutrition on the ability of the calves to make compensatory growth. The mean decreases in difference for the two groups $(WL_S - WL_W)$ and $(WM_S - WM_W)$ were -1.13 and -1.90 kg respectively.

Energy Utilization

Energy Utilization energy utilization for maintenance and for live weight gain of calves on the four treatments was calculated. The metabolizable energy of the rations used over the four intakes was calculated together with the energy density, M/D. The mean weight of each of the pens of animals over the total post-weaning period was calculated

together with the mean live-weight gains over the total post-weaning period. From the total ME intake of a pen of animals, the average ME intake per head per day during the post weaning trial was determined. The metabolizable energy concentration of the ration, together with the mean daily ME intakes per calf are shown in Table 3f.9 for the four calf trials. The mean live weights of calves during the post-weaning trial are also shown in Table 3f.9.

Table 3f.9

Mean Metabolizable Energy Consumption (MJ.ME/day) and Mean Live Weight (kg) of Calves During the Post-Weaning Trials

Intake	Diet	M/D	Mean Energy Consumption MJ.ME/day/calf	Mean Live Weight (kg)
Spring'74	Concentrates/Hay/ Red Clover Silage	10.1	36.7 ± 0.9	113.6 ± 11.7
Autumn'74	Concentrates/Grass Silage/Hay	11.8	32.9 ± 1.7	102.7 ± 6.6
Spring'75	Concentrates/Grass Silage/Hay	11.2	35.0 ± 1.6	110.1 ± 7.7
Autumn'75	Concentrates/Hay	11.5	33.8 ± 1.0	97.5 ± 6.3

The mean energy consumption per day was relatively constant over the four nutritional treatments in any one trial, as can be seen by the small standard deviation of energy intake in each of the four trials.

The differences in the metabolizable energy requirements per unit of live-weight gain and the efficiency of metabolizable energy utilization for live-weight gain were compared on the basis of the actual gains achieved as a percentage of the gain expected from calculations based on the M.A.F.F. recommendations (Bulletin 33). In this manner differences between the diets in the values of M/D and between the efficiency of conversion of metabolizable energy to gain (k_g) in animals of differing live weights were accounted for. Comparing the absolute efficiency of conversion of all calves during the four intakes would not take into account these required corrections.

From the mean values of daily metabolizable energy intake per calf during each trial, the theoretical live-weight gain of the calves was calculated using the system recommended in the M.A.F.F. Technical Bulletin 33 (Energy Allowances and Feeding Systems for Ruminants) and compared with the actual live-weight gain of calves over the total period. The live-weight of the calves was taken as a pen mean over the total post-weaning trial of any one crop. The theoretical live-weight gain so calculated for animals of the mean live-weight over the period refers to the live-weight exactly half way through the duration of the trial if the rate of live-weight gain was uniform. If the actual live-weight gain of the calves was increasing exponentially over the post-weaning period then the mean live-weight gain calculated referred to calves past the mid point in time of the trial. These calves would then be heavier and have a larger requirement for maintenance. A comparison of theoretical versus actual live-weight gain in this instance would underestimate the efficiency of the calves. An examination of the live-weight gain data of the calves during the post weaning period, showed however that the rate of live-weight gain tended to be linear. In this instance the comparison of theoretical and actual live-weight gain in this manner was valid. Actual live-weight gains as a percentage of the theoretical live-weight gain are shown in Table 3f.10 for the calves in each of the four intakes grouped according to pre-weaning nutritional treatment. A value in excess of 100% shows calves that performed better than predicted and hence made more efficient use of the dietary energy.

Table 3f.10

Actual Live-Weight Gains as a Percentage of the Predicted Live-Weight Gains

	Pre-weaning nutritional treatment				Mean	P < 0.05
	LL	LH	HL	HH		
Spring'74	125.3	132.0	134.3	134.3	131.4	LL < HL, HH
Autumn'74	107.5	98.8	101.5	106.0	103.4	LH < LL
Spring'75	109.0	118.5	125.8	117.0	117.5	HH < HL LL < LH, HL, HH
Autumn'75	93.0	95.2	100.5	114.5	100.8	LL < HH
Mean	108.7	111.1	115.5	117.9	-	LL, LH < HL, HH

Differences in efficiency of energy utilization were tested by an analysis of variance technique. Significant differences between nutritional treatments are shown in Table 3f.10. It can be seen that with three out of four of the calf crops the LL treatment calves performed less efficiently than the other three treatments. A significant interaction ($P < 0.01$) was found between level of nutrition and date of calf crop. The main cause of the interaction occurred during the Autumn'74 calf crop when treatment differences were reversed and there was no significant difference ($P < 0.05$) between the efficiency of energy utilization between the LL, HL and HH or the LH, HL and HH treatments. Calves on the LL treatment however were most efficient and were significantly more efficient than calves on the LH treatment ($P < 0.05$).

The main effect of season lay between the Spring and Autumn intakes. Calves of the Spring'74 intake were more efficient than the Spring'75 calves and both Spring intakes were more efficient than the two Autumn born crops. These differences were significant at the 1% level.

Table 3f.11

Metabolizable Energy Required in Excess of Maintenance Per kg Live-Weight Gain

	Pre-weaning nutritional treatment				Mean
	LL	LH	HL	HH	
Spring'74	20.17	19.82	19.41	19.23	19.66
Autumn'74	19.41	22.08	21.16	20.77	20.85
Spring'75	21.46	20.22	18.57	20.22	20.12
Autumn'75	28.83	23.59	22.36	21.18	22.74
Mean	21.22	21.43	20.37	20.35	-

The data presented in Table 3f.11 supports that presented in Table 3f.10. During three of the four calf intakes, the conversion of metabolizable energy to live-weight gain was poorer in the LL treatment calves than in the other three treatment groups. As shown in Table 3f.10 the trend was reversed for the Autumn'74 intake. The between intake differences obtained in Table 3f.11 followed the same trend as those obtained in Table 3f.10, the Spring'74 calves were most efficient and the Autumn'75 calves least efficient. The value of the method of comparison used in Table 3f.10 can be seen from the fact that when the M/D of the ration and the efficiency of energy conversion to gain (k_g) were taken into account the Spring'74 calves were approximately 30% more efficient than the Autumn'75 calves. Using the absolute values as in Table 3f.11 the Spring'74 calves were only 13% more efficient compared with the Autumn'75 intake.

Feed Intake

In an attempt to distinguish how the low and medium treatments were capable of compensating in growth when in fact their feed conversion efficiency was lower an examination was made of the feed

intake of the calves. Mean daily feed intakes (kg of fresh material) on a per calf basis for each pen of calves were divided by the average weight over the total period of calves in that pen. This process was carried out in order to take account of the differences in live weight of pens of calves which would result in differences in voluntary intake. Voluntary intake (kg fresh material per day per calf) is shown in Table 3f.12 corrected to an average body weight of 100 kg.

Table 3f.12
Voluntary Intake (kg of fresh wt per day) of a 100 kg Calf

	Pre-weaning nutritional treatment				Mean	$P < 0.05$
	LL	LH	HL	HH		
Spring'74	4.8	4.4	4.4	4.2	4.5	N.S.D.
Autumn'74	4.6	3.6	4.2	3.5	4.0	LL, HL>LH, HH
Spring'75	4.0	3.9	3.7	3.7	3.8	N.S.D.
Autumn'75	3.9	3.5	3.5	3.2	3.5	LL>HH
Mean	4.4	3.9	3.9	3.6		LL>HH

The voluntary intake of calves receiving the LL treatment was significantly higher ($P < 0.01$) than calves on the HH treatment. There was a trend for voluntary intake to be inversely proportional to pre-weaning level of nutrition, however differences between all four treatments did not achieve significance.

The differences in voluntary intake between different calf crops were analogous to the trend in decreasing dry matter content of the rations. Calves receiving rations in which the forage was predominantly silage (Spring and Autumn'74) had larger voluntary intakes than calves which received mainly hay or hay alone. The difference only reached significance between the Spring'74 and Autumn'75 crops ($P < 0.01$).

The dry matter intake (kg DM/day) corrected to the intake of a 100 kg calf is shown in Table 3f.13. The means of the daily dry matter

intakes of the calves on the four pre-weaning levels of nutrition are shown for each of the four calf intakes.

Table 3f.13

Daily Dry Matter Intake (kg DM/day) Corrected to the Intake of a 100 kg Calf

	LL	LH	HL	HH	Mean	Significance P< 0.001
Spring'74	3.45	3.10	3.09	3.00	3.16	LL > HL, HH
Autumn'74	2.77	2.81	2.64	2.57	2.69	N.S.
Spring'75	3.15	2.81	2.75	2.71	2.86	LL > HL, HH
Autumn'75	3.33	3.09	2.95	2.63	3.00	LL > HL, HH
Mean	3.18	2.95	2.86	2.73		LL > LH > HL > HH

As the diets offered to the calves on each of the four nutritional treatments did not differ between nutritional treatments during any one intake then it can be seen that as expected the between treatment differences in dry matter intake closely followed the trend in voluntary intake of fresh material shown in Table 3f.12.

From Table 3f.13 it can be seen that during three of the four intakes the post-weaning dry matter intake of calves which received the LL level of nutrition pre-weaning was higher than the intake of calves previously fed the other three treatments, however the differences only achieved significance ($P < 0.001$) between the LL and the two high milk replacer treatments. Overall the post-weaning dry matter intake of the calves was inversely proportional to the pre-weaning level of nutrition. When comparisons were made between calf intakes the highest dry matter consumptions were achieved on the diets in which the roughage was predominantly supplied by hay. The highest dry matter intake was achieved when hay was fed *ad libitum* with red clover *ad libitum*. During the two intakes when the diet was mainly silage (Autumn'74 and Spring'75) although the total consumption of fresh material was higher

than during the Autumn'75 intake, dry matter intake was lower. This would suggest that the bulk of the silage was a limiting factor in voluntary intake.

Daily Live-Weight Gain From Arrival to Sale

The results were analysed on the basis of the daily live-weight gain from the arrival of the calf on the unit to sale. Mean daily live-weight gains of the four nutritional treatments groups from arrival to sale are shown in Table 3f.14 for the four intakes of calves.

Table 3f.14

Mean Daily Live Weight Gains (kg/Day) From Arrival to Sale, Together with the Duration of the Four Trials

	Duration of Trial (days)	Pre-weaning level of nutrition				Mean
		LL	LH	HL	HH	
Spring'74	160	0.69	0.75	0.75	0.76	0.74
Autumn'74	155	0.59	0.63	0.63	0.65	0.62
Spring'75	161	0.58	0.69	0.68	0.70	0.66
Autumn'75	147	0.57	0.59	0.63	0.70	0.62
Mean	-	0.60	0.67	0.67	0.70	-

The results were analysed separately for each trial using individual calf initial and final weights. A summary of the treatment differences is shown in Table 3f.15.

Table 3f.15

The Effect of Pre-Weaning Level of Nutrition on Daily Live-Weight Gain (kg/day) from Arrival to Sale

Calf Intake	Treatment		Daily Live Wt. Gain	Level of Significance	Treatment Differences
Spring'74	Level of milk replacer	Low High	0.725 0.757	N.S.	
	Level of concentrates	Low High	0.726 0.756	N.S.	
Autumn'74	Level of milk replacer	Low High	0.590 0.644	0.01	Low < High
	Level of concentrates	Low High	0.593 0.641	0.01	Low < High
Spring'75	Level of milk replacer	Low High	0.638 0.695	0.05	Low < High
	Level of concentrates	Low High	0.633 0.700	0.01	Low < High
Autumn'75	Level of milk replacer	Low High	0.582 0.667	0.01	Low < High
	Level of concentrates	Low High	0.600 0.649	N.S.	

The results show that when the pre-weaning nutritional treatments were established according to feeding 600 and 300g of milk replacer per day, then the differences in live-weight gain established pre-weaning were such as to significantly affect the daily live-weight gain from arrival to sale. From arrival to sale there was no significant effect of housing treatment on daily live-weight gain.

DISCUSSION

The four pre-weaning nutritional treatments imposed on average from 10 to 70 days of age resulted in differences in live weight of the calves at weaning. Although the mean treatment effects reflected the differences in metabolisable energy intake between treatments, the differences mainly

achieved significance between the LL and the three other treatments. During the two Spring intakes calves receiving the LH treatments were significantly lighter at weaning than calves receiving the HH treatment. Calves born in the Spring were significantly heavier at weaning than calves born during the Autumn although this may have been a result of pre-weaning treatments rather than a seasonal effect.

Pre-weaning levels of nutrition did not have any significant effect on the live-weight gain of the calves from weaning to sale. Post-weaning calves comprising the two Spring intakes performed appreciably better than the Autumn crop calves (0.88 and 0.74 kg/day respectively). This may have been due to the higher weight at weaning of the Spring intake calves and hence partly due to the pre-weaning treatment.

The differences in weight at sale between treatment groups reflected the differences in weight between treatments at weaning and the non-significant differences between treatment daily live-weight gains from weaning to sale. A comparison of the differences in live weight between the HH and LL, and between the HH and medium treatment groups at weaning and at sale showed that at sale the live weight differences between the HH treatment and the other two levels of feeding had been reduced. The difference in live weight between the HH and LL and between the HH and medium treatment calves at sale was reduced by 1.13 and 1.75 kg respectively, compared with the differences in weight at weaning. The reduction of the differences in weight between the nutritional groups at sale compared with those at weaning was highly significant ($P < 0.001$) although the actual values were only small.

There was a tendency for calves fed the LL and HL treatments pre-weaning to have a higher voluntary intake post-weaning compared with the other treatment groups. Differences were only significant during the two Autumn intakes and when the means of treatments for the four

calf crops were compared. It was considered that the reduction in live weight difference between treatments from weaning to sale may have been the result of a greater weight of gut contents in the LL and HL treatment groups at sale compared with the HH groups.

An examination of the effect of gut fill was made by correcting the weights at weaning and sale for gut content according to Roy (1970) and the ARC recommendations for Livestock (Ruminants 1965). The weight of the gut contents at weaning was taken at 10.8% bodyweight, this being the average of the value of 6.3% bodyweight for calves receiving a skim milk diet and 15.2% for calves receiving hay + 1.8 kg concentrates (ARC recommendations). It is realised that the latter figure will only give an approximation as the ratio of hay to concentrates was likely to be slightly lower in practice. The weight of gut contents at sale was calculated according to:

$$y = 0.20x_1 + 3.3x_2 + 0.40x_3 + 2.9 \text{ (Roy 1970)}$$

where x_1 = live weight (kg)

x_2 = daily concentrate intake (kg)

and x_3 = daily hay intake (kg)

Where the calves were given silage, when the final weighing was made i.e. during the Autumn'74 intake, the silage intake was converted to an equivalent hay intake on a dry matter basis. Although, when the silage content of the gut was calculated in this manner the actual weight of gut contents was underestimated, due to the high moisture content of the silage, the value of the term is small in the above equation and hence the error was small. The differences in gut fill corrected live weight between treatment groups are shown in Table 3f.16.

Table 3f.16

Differences in Live Weight (kg) Between Treatment Groups at Weaning and Sale

	High-Low Groups			High-Medium Gps		
	Weaning	Sale	Difference	Weaning	Sale	Difference
Spring'74	10.0	8.6	-1.4	4.1	1.3	-2.8
Autumn'74	16.1	12.8	-3.3	5.7	3.6	-2.1
Spring'75	18.1	15.4	-2.7	4.8	2.6	-2.2
Autumn'75	14.3	11.0	-3.3	5.9	3.7	-2.3

Mean differences between the High and Low Groups and the High and Medium Groups were 2.7 and 2.3 kg respectively. These values compare with 1.13 and 1.75 kg for the two comparisons (HH-LL and HH-Medium respectively) when the uncorrected live weights were used. It can be seen that whether corrected or uncorrected live weights were used, the restricted calves upon realimentation were able to compensate slightly and reduced the deficit in weight compared with the High treatment group. The effect of correcting for gut fill has been to reverse the order of the ability of the low or medium groups to compensate. Uncorrected the medium group had a greater ability to compensate whilst the corrected data showed the Low group to compensate more. The small amount of compensation found in this experiment in calves restricted from approximately 5 to 75 days of age is contrary to what would be expected from the literature (Lonsdale and Taylor 1969; Everitt, Evans and Franks, 1969) where no compensatory growth was found in realimentating calves. The present results do not support those of Wardrop (1966) where it was found that upon realimentation low fed calves continued to have lower rates of gain. Everitt (1972) found a small degree of compensatory growth in calves reared to 112 days of age at a live weight-gain of 0.38 kg/day which is in agreement with the present results.

The fact that the previously well fed calves were more efficient in gaining weight compared with the restricted group upon realimentation is also contra expectations. Previous work has tended to show that compensatory growth was achieved by a more efficient conversion of energy to live-weight gain. (Hironaka and Kozub, 1973; Ledger, 1973; Fox Johnson, Preston Dockerty and Klosterman, 1972). It was calculated that the LL treatment calves required on average 0.84 MJ of net energy per kg of gain less than suggested in Bulletin 33 and a total of 0.75 MJ of net energy per kg of gain more than the HH treatment calves. The difference in energy requirement per kg gain compared with the ARC Bulletin 33 is in agreement with conclusion drawn by R.A.Edwards (1977) when it was found that Bulletin 33 tended to under-predict the live-weight gain of ruminants of less than 250 kg live weight. The increased requirement for gain by the LL calves compared with the HH is difficult to interpret. The results would suggest a greater fat deposition in the restricted calves per unit live weight gain compared with the full fed controls. Conversely the digestibility of the ration may have been lower in the realimentating calves thus less energy of the ration consumed being available for gain. Voluntary intake of the realimentating calves was higher than in calves which were previously on high levels of feeding. It is difficult, however, to consider how this may have resulted in either an increased passage through the gut or a reduced absorption of nutrients in the restricted calves, in order to produce a lower digestibility.

The possibility exists that the rumen of the LL treatment calves may have been less well developed compared with high fed groups. This is considered unlikely due to the fact that all calves received roughage for the same length of time and calves on the low concentrate feeding treatments consumed more hay pre-weaning compared with the high concentrate feeding groups; rumen development would thus have been encouraged on the low feeding treatments.

The live-weight gains of the calves are a reflection of the dry matter intake of the calves, the metabolizable energy value of the dry matter and the efficiency of utilisation of the metabolizable energy. It has been shown that the realimentating calves consumed more fresh material and more dry matter post-weaning compared with the pre-weaning high fed calves. However, when gut fill was taken into account the low group had still compensated. The diets fed post-weaning differed slightly in the concentration of metabolizable energy in the dry matter due to the different voluntary intakes of roughage of the calves on the four pre-weaning treatments. In calculating the actual gain as a percentage of the gain expected from the ARC recommendations differences in the M/D were accounted for. It is thus concluded that the reduced efficiency of utilisation of the metabolizable energy recorded in the low treatment calves has been the result of a reduction in the efficiency of conversion of metabolizable energy to gain. This would suggest an increased rate of fat deposition in the realimentating calves.

Fox et al (1972) showed that during realimentation protein gain constituted the main portion of the gain during early realimentation. Thus in older restricted cattle both muscle and fat deposition has been reduced by under-nutrition. It is suggested that, in the present work, even although the calves suffered a considerable restriction in live-weight gain pre-weaning, muscle and hence protein gain was not affected. It is suggested that the increase in muscle and organ weight in these young animals may be termed "essential" in that any reduction in muscle growth would have severely affected the ability of the calf to survive. Reduction in feed intake, however, may have severely depleted the fat stores and the interstitial fat cells in the calves. In the older steers there is likely to be the ability to allow a certain retardation or loss of muscle growth before the ability of the animal to survive is reduced. Thus in the latter

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instance of the older steer, upon realimentation the more efficient energy process (muscle deposition) is favoured before fat gain occurs. In the young calf, however, the very severe depletion of the fat stores may have resulted in a depletion of whole body insulation. Thus in the absence of a reduction in muscle growth during restriction, fat deposition is most necessary during realimentation. This would account for the less efficient gain in the realimentating calves.

Although there was no significant effect of housing environment on the performance of the calves from weaning to sale there was a tendency for calves in the A1 house to perform better than animals in the other three houses and calves in the B1 house to have the poorest performance. The mean differences in live-weight gain between calves in the A1 and B1 type houses would have resulted in a difference in mean live weight between houses of 2.2 kg at sale. At weaning the average weight of calves in the A1 house was 143.5 kg and that of calves in the B1 house 140.3 kg. The difference of 3.2 kg between the mean sale weights of calves in the A1 and B1 houses represents the maximum overall difference between the mean weights of calves in any of the two houses and resulted from a mean increase of one kg at weaning and 2.2 kg in post-weaning gain of calves in the A1 house.

The results show that post-weaning, calves of the Autumn'74 calf crop had poorer performance than the other three calf crops. The voluntary intake of these calves was not appreciably different from that of calves on the other three intakes and would have not been sufficient to compensate for the increased moisture content of the silage based ration. Thus the dry matter intake of the Autumn 74 calves post-weaning was slightly lower than the Spring crops, however, metabolizable energy intake per kg live weight was nearly the same in all four crops. The difference in performance as a result of this cannot be explained.

An analysis of the results from arrival to sale showed that significant differences were found as a result of the level of milk replacer feeding in live-weight gain from arrival to sale when milk replacer levels were set at 300 and 600g per day. There was no significant difference between treatments when the levels were set at 400 and 600g/day. This would suggest that under the conditions of this trial 400g/day was a satisfactory level at which to feed milk replacer, there being no advantage to feeding at 600g/day but a disadvantage to feeding at 300g/day on a once daily feeding system. This result should be viewed with caution as the experiment using 600 and 400g/day feeding was not repeated using a Spring intake of calves. A significant advantage was also to be found as a result of feeding concentrates ad libitum.

Performance from arrival to sale was not affected by the housing environment of the calves.

Production Trials

Section 3g

Conformation

INTRODUCTION

Species differ in their resistance to a period of undernutrition and it can be said that the earlier in development the animal suffers from undernutrition the more likely it is to have a permanent effect. Animals also differ in maturity at birth, hence the guinea pig can be affected at the same stage of development as the rat only by undernutrition *in utero*, (Widdowson, 1968). The calf, on the other hand, is relatively mature at birth. Similar to the guinea pig, undernutrition at a very early age can only be achieved *in utero*. Post partum undernutrition is therefore likely to achieve only a transient effect on muscle development in the calf.

Undernutrition does not delay the development of all parts of the body to an equal extent. Organs that develop early, like the heart, the kidneys and the brain, are less affected than the parts that develop late, such as the skin and skeletal muscles (Widdowson, 1968). During undernutrition the development of the bone is different from the development of other tissues in that active accretion on the outside and resorption on the inside go on at the same time, however, during undernutrition resorption outstrips accretion. This results in a very thin cortex and a large marrow cavity (Dickerson and McCance, 1961). Instead of being filled with the normal fatty marrow it is filled with an extracellular gel, which is denser and heavier per unit volume than normal marrow. The total weight of the skeleton, therefore, gives no true indication of the weight of the true bone tissue.

Retardation of growth due to a low plane of nutrition also delays sexual development and in such circumstances functional sexual development is more related to the size and development of the body than to chronological age. However, although undernutrition and retardation of growth may delay sexual development, they do not prevent some

development taking place in the primary and secondary sexual organs (Widdowson and McCance, 1960).

From the growth patterns of individual muscles it has been shown that most differential growth, of those muscles with diphasic growth patterns, occurs in early postnatal life. (Butterfield and Berg, 1966a). Most of these muscles change their rate of growth to the same rate as that of total muscle soon after birth. The time taken to attain this uniform rate is considerably modified by changes in the plane of nutrition (Butterfield and Berg, 1966b).

Muscles with similar growth patterns may be grouped together to form impetus groups. Muscles in the same impetus group may not be anatomically related. Those in the low and low-average impetus groups are small and located either distally on the limbs or deep in the carcass: those which are in the high-average group are either large muscles of the hind quarters and back, or muscles of the abdominal wall (Butterfield and Johnson, 1968).

The immediate postnatal phase in the calf is regarded as being the period during which the muscle weight is about doubled. The length of time over which this extends varies with the rate of growth, but is approximately 12 weeks in the well-fed calf. Sub-optimal nutrition over this period effects high impetus growth muscles more than total muscles when considered on an age scale, but the high impetus muscles and total muscle are retarded uniformly, when considered on a total muscle weight basis (Butterfield and Johnson, 1968).

Butterfield and Johnson (1968) concluded that the rate of growth of an animal will be found not to have influenced the relative growth rate of any muscles when animals containing the same muscle weight are being compared. Differences in muscle weight distribution caused by differences in rate of growth, will be greatest soon after birth and will disappear as the musculature gains weight.

The calves in the present trials were reared on four nutritional treatments incorporating three different rates of growth. The period for which the calves were exposed to these treatments was that considered by Butterfield and Johnson (1968) to be the phase during which high impetus muscle could be most affected by undernutrition and during which the musculature of the calf in general would be most affected by nutrition. It was therefore decided to make an appraisal of the conformation of the calves of two intakes in order to determine the effects of the four nutritional treatments on the conformation of the calves.

MATERIALS AND METHODS

The animals used in the experiment were those of the Autumn'74 and Spring'75 intakes. The examination of the Autumn'74 intake was considered a preliminary investigation and a sample of the calves were measured on two occasions post-weaning. All the calves comprising the Spring'75 intake were examined and the calves were measured on three occasions. The first two sets of measurements were made pre-weaning and the third set post-weaning. Although calves of the Autumn'74 and Spring'75 intakes were to be offered ultimately the same allowances of milk replacer and concentrates pre-weaning, during the Spring'75 intake an attempt was made to impose the nutritional restriction at an earlier age. It was considered that this, coupled with the fact that the Spring'75 calves would be reared during a period in which the climate would be of a harsher nature would impose a more severe nutritional stress on the calves. The levels of feeding comprising the four pre-weaning nutritional treatments are shown in the section on nutrition (Section 3a).

Post-weaning all the calves in each of the Autumn'74 and Spring'75 intakes were offered the same concentrate feed allowance. During the Autumn'74 intake all calves received 2 kg per head per day of calf nuts,

plus hay and silage ad libitum. During the latter stages when the second set of measurements were taken the concentrate allowance was increased to 2.5 kg per head per day and only silage was offered ad libitum. Post-weaning the Spring'75 calves were offered 2 kg per head per day of calf nuts plus hay ad libitum. Thus post-weaning the calves previously on the low levels of nutrition were given the opportunity to compensate for the feed restrictions imposed post-weaning. From weaning the Autumn'74 calves had 30 and 84 days up to the first and second measuring occasions respectively during which time compensation could be made for pre-weaning feed restrictions. The Spring'75 calves when measured on the third occasion had approximately 25 days in which feed was offered ad libitum during which time they were allowed to make compensatory growth.

Both intakes of calves were measured in the same manner. Four measurements were taken of each calf on each sampling occasion. They consisted of:-

1. Height at Withers: the distance from the ground to the highest point between the scapulae. Three measurements were taken, the animal being moved between each to a new normal and square stance.
2. Heart Girth: the vertical circumference of the body immediately behind the withers and fore legs, i.e. across the 5th or 6th thoracic vertebrae, taken as a minimum measurement.
3. Width of Hooks: the extreme width of the pelvis above the external surfaces of the tuber coxae of the ilia.
4. Stifle to Stifle or the Round: the horizontal distance from one patella around the thighs to the opposite patella. As stance affects this measurement a standard square position was sought.

Laird (1954) concluded that width of hooks was the most useful index of general and/or skeletal growth, although height at withers, heart girth, chest depth, length of body, and hooks to pins were also recommended. Stifle to stifle was endorsed as a measure of muscle growth, together with circumference of neck.

For measuring purposes the calves were haltered. They were not used to being restrained, so when haltered most of them adopted positions and stances which kept the retaining rope under tension. Efforts were made therefore to ensure that they were positioned normally for measurement, i.e. *legs* vertical and back straight, this being the stance recommended for measuring purposes, (Touchberry and Lusch, 1950).

Fischer (1975), in an experiment to estimate the accuracy of some body measurements on live beef steers obtained measurements for parameters common to this study in three instances; on the fourth measurement, stifle to stifle, the measurement obtained was from the patella to post midline. In all four instances the method of measurement was common to both experiments, namely:

Height at Withers : a measuring stick with one vertically sliding arm

Width of Hooks : calipers

Heart Girth : graduated plastic tape

Stifle to Stifle : graduated plastic tape

The graduated tape was tested by the application of a 1 kg weight and it was found that under this tension there was no distortion over a 30 cm length of the tape when compared with a 30 cm plastic rule. Fisher (1975) stated that the error involved in using a plastic tape increased as the size of the measurement increased, since the tape must be applied to the body surface over a greater distance. In the present work when the heart-girth measurement was taken, an attempt was made to apply a uniform tension in the tape equivalent to that when a 1 kg weight was

applied. This, it was considered, produced a good contact between the tape and the surface of the thorax. A similar precaution was taken when measuring the stifle to stifle. Fisher (1975) reported average residual standard deviations (R.S.D.) coefficients of variation (R.C.V.) and F-ratios for twice repeated measurements on 15 steers as shown in Table 3g.1.

Table 3g.1

Residual Standard Deviations and Residual Coefficients of Variation of Four of the Measurements of Conformation

Measurement	R.S.D. mm	R.C.V. %	F-ratio
Height at withers	9.83	0.86	11.84***
Heart girth	15.24	0.85	12.76***
Width of rump	10.12	2.44	8.52***
Patella to post midline	19.86	3.94	1.34

In this instance width of rump refers to the distance between the points on either side of the animal located at one half of the distance measured from the ventral point of the tuber coxae to the ventral tuberosity of the tuber ischii by means of pincer calipers. It can be seen, therefore, that with three of the four measurements taken the error of measuring was small, being less than 3% of the measurement. Thus three of the four measurements chosen may be used with confidence to relate to carcass characteristics. Caution should be used in placing emphasis on the stifle to stifle measurement. The means, standard deviations and ranges of age and live weight are shown for each of the occasions on which the Autumn'74 calves were measured in Table 3g.2 for the Spring'75 calves in Table 3g.3. In both tables the data has been grouped according to the pre-weaning level of nutrition which the calves received.

Table 3g.2

Mean Age, Live Weight and Number of Calves Sampled on Each of the Four Pre-Weaning Nutritional Treatments at the Two Sampling Occasions of the Autumn'74 Calves

Treatment	Nos. of Calves Sampled		1st sampling occasion			2nd sampling occasion		
			Mean	S.D.	Range	Mean	S.D.	Range
		Age (days)	94	-	88-100	149	-	143-154
LL	16	Live weight (kg)	76.5	8.0	54.0 -86.5	122	14	91.0-140.0
LH	16	Live weight (kg)	86.8	11.0	66.0-107.0	132	14	107.0-152.0
HL	16	Live weight (kg)	90.9	11.0	75.5-103.0	136	11	105.0-158.0
HH	16	Live weight (kg)	95.1	14.0	66.0-117.0	137	20	88.0-168.0

Table 3a.3

Mean, Standard Deviation and Range of Age and Live Weight of Calves of the Spring'75 Intake on the Four Nutritional Treatments at the Three Sampling Occasions

Treatment	Nos. of Calves Sampled		1st sampling occasion			2nd sampling occasion			3rd sampling occasion		
			Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
		Age (days)	40	-	37-47	68	-	65-75	103	-	100-110
LL	20	Live weight (kg)	44.1	6.7	34.0-57.0	61.2	9.1	47.0 -79.0	80.9	12.9	61.0-109.0
LH	26	Live weight (kg)	50.2	9.3	37.0-73.0	74.6	14.5	51.0-109.0	97.1	16.7	61.0-133.0
HL	26	Live weight (kg)	51.7	7.0	41.0-70.0	73.6	10.2	61.0- 92.0	96.0	12.2	66.0-122.0
HH	29	Live weight (kg)	54.4	8.2	40.0-76.0	79.4	10.2	66.0-102.0	101.8	12.8	77.0-130.0

RESULTS

The results from the two calf intakes were examined by an analysis of variance technique in which the effects of both nutrition and housing on the conformation of the calves were examined.

Autumn 1974 Trial

The values of the means of the four parameters measured on the first sampling occasion together with the mean live weight of the treatment groups are shown in Table 3g.4.

Table 3g.4

Mean Live Weight and Mean Values in cms of the Four Measures of Conformation Measured on the First Sampling Occasion

	Pre-weaning nutritional treatments				Signif. Level	Treatment Differences
	LL	LH	HL	HH		
Live Weight (kg)	76.53	86.8	90.87	95.06	*	HH, HL, LH>LL
Withers (cms)	80.76	82.78	84.91	84.63	**	HH, HL>LH>LL
Heart Girth (cms)	96.51	100.73	101.83	104.47	**	HH>HL, LH>LL
Hooks (cms)	21.49	23.46	23.81	23.87	**	HH, HL, LH>LL
Stifle (cms)	59.51	63.73	63.50	65.22	**	HH>HL, LH>LL

The calves making up the experimental material were obtained from two different calf houses hence the effect of housing was examined. The means of the four conformation parameters, examined according to house of origin are shown in Table 3g.5.

Table 3g.5

Mean Value of Live Weight and the Four Measures of Conformation (cms) Shown According to the House of Origin Obtained on the First Sampling Occasion

	House H1	House H2	Significance Level
Live Weight (kg)	88.4	86.2	N.S.
Withers (cms)	82.84	83.69	N.S.
Heart girth (cms)	101.24	100.54	N.S.
Hooks (cms)	22.99	23.32	N.S.
Stifle (cms)	63.03	62.93	N.S.

On no occasion was any effect found on the conformation parameters measured as a result of the housing treatment afforded to the calves.

The Autumn'74 calves were measured on a second occasion, 84 days after they had been weaned and a total of 55 days after the first measuring occasion. The values of the means of the four conformation parameters and the mean live weight of the treatment groups obtained on the second sampling occasion are shown in Table 3g.6.

Table 3g.6

Mean Values of the Four Measures of Conformation and the Mean Live Weight of the Treatment Groups Obtained on the Second Sampling Occasion

	Pre-weaning nutritional treatments				Signif. Level	Treatment Differences
	LL	LH	HL	HH		
Live weight (kg)	122.13	132.20	135.50	137.19	*	HH, HL, LH>LL
Withers (cms)	89.03	90.66	93.40	90.68	N.S.	
Heartgirth (cms)	112.06	114.75	116.25	116.44	N.S.	
Hooks (cms)	27.24	28.20	28.20	28.24	N.S.	
Stifle (cms)	68.76	71.61	72.48	73.14	*	HH>LH>LL HL>LL

A comparison of the results obtained from the two sets of measurements of the Autumn'74 calves showed that growth of the withers, heartgirth and hooks has occurred between the two occasions on which they were measured such that on the second measuring occasion no significant effect of nutritional treatment was apparent. Significant differences in live weight and the measure of the stifle were still present on the second measuring occasion and hence these measures had not been able to compensate as rapidly as the withers, heart girth and hooks. These results are summarised in Table 3g.7 where the value of the measure obtained for the LL treatment calves is expressed as a percentage of the value obtained for the HH treatment calves on the two measuring occasions.

Table 3g.7

The Values of Conformation of the LL Treatment Calves Expressed as a Percentage of the HH Treatment Calves

	LL/HH per cent 1st measuring occasion	LL/HH per cent 2nd measuring occasion
Live weight	80.50	89.02
Withers	80.50	98.18
Heart girth	92.40	96.39
Hooks	90.03	96.59
Stifle	91.24	94.01

Spring'75 Trial

During the Spring'75 intake at a time approximately 38 days following the arrival of the first calf, 12 calves were still being offered an allowance less than that required for maintenance, (calculated according to Roy 1970). The average live-weight gain of all the calves on the Spring'75 trial is shown in Table 3g.8 for the period from arrival to weaning.

Table 3g.8

Mean Daily Live-Weight Gain of the Calves from Arrival to Weaning Grouped According to Pre-Weaning Level of Nutrition

	LL	LH	HL	HH	P	Treatment Diff.
Mean daily live weight gain kg/day	0.303	0.517	0.506	0.574	0.05	HH > HL > LL LH > LL

Calves from all four houses were used on the trial. There was no significant effect on any of the measuring occasions as a result of housing on the live-weight gain or the live weights of calves on the same nutritional treatments in each of the four houses. Thus for the purpose of the following presentation the calves have been grouped according to the pre-weaning level of nutrition, irrespective of the house of origin.

The mean values of the live weight of the calves together with the means of the four measures of conformation grouped according to the pre-weaning level of nutrition obtained on the three measuring occasions are shown in Tables 3g.9, 3g.10 and 3g.11.

Table 3g.9

Mean Values of Live Weight and the Four Measures of Conformation Obtained on the First Measuring Occasion

	LL	LH	HL	HH	P	Treatment Diff.
Live weight (kg)	44.10	50.15	51.73	54.41	< 0.001	HH, HL, LH > LL
Withers (cm)	74.11	75.77	75.40	76.28	0.083	HH > LL
Heart Girth (cm)	80.95	82.06	84.98	85.62	0.003	HH, HL > LL
Hooks (cm)	17.87	18.69	18.74	19.15	0.006	HH, HL, LH > LL
Stifle (cm)	49.15	51.50	52.96	54.41	< 0.001	HH, HL > LL

Table 3g.10

Mean Values of Live Weight and the Four Measures of Conformation Obtained on the Second Measuring Occasion

	LL	LH	HL	HH	P	Treatment Diff.
Live weight (kg)	61.2	74.6	73.6	79.4	0.001	HH, HL, LH > LL
Withers (cm)	77.8	80.60	80.68	81.90	0.001	HH, HL, LH > LL
Heart Girth (cm)	87.88	93.52	94.36	95.10	0.001	HH, HL, LH > LL
Hooks (cm)	19.70	21.30	21.17	21.69	0.001	HH, HL, LH > LL
Stifle (cm)	54.05	58.62	60.26	60.86	0.001	HH, HL, LH > LL

Table 3g.11

Mean Values of Live Weight and the Four Measures of Conformation Obtained on the Third Measuring Occasion

	LL	LH	HL	HH	P	Treatment Diff.
Live weight (kg)	80.9	97.2	96.0	101.8	<0.001	HH, HL, LH > LL
Withers (cm)	81.50	84.48	84.66	86.33	<0.001	HH > HL, LH > LL
Heart Girth (cm)	99.35	104.06	103.84	105.74	<0.005	HH, HL, LH > LL
Hooks (cm)	22.29	24.14	23.99	24.44	<0.001	HH, HL, LH > LL
Stifle (cm)	60.52	62.90	64.32	65.05	<0.005	HH, HL > LH > LL

The three occasions on which differences approaching significance were found in the conformation of calves in different houses are shown in Table 3g.12.

Table 3g.12

Mean Values of the Measures of Conformation Grouped According to House

	A1	A2	B1	B2	P	Differences @ 5% level
First measuring occasion						
Heart Girth (cm)	83.42	81.34	83.75	86.04	0.17	
Second measuring occasion						
Stifle (cm)	60.16	60.30	57.22	57.43	0.039	A1, A2 > B1 B2
Withers (cm)	81.10	80.96	79.16	80.70	0.16	

From Table 3g.8 it can be seen that the live-weight gain on treatment LL was significantly less ($P < 0.05$) than that of calves on the other three treatments. This is borne out by the fact that on the three sampling occasions the average live weight of the calves on the LL treatment was significantly lower ($P < 0.001$) than the average live weight of the calves on any of the three other treatments. On the first measuring occasion the hooks measure was the only parameter in which the mean measure of the LL treatment calves was significantly smaller ($P < 0.05$) than the mean values of calves receiving the LH, HL and HH treatments. Calves receiving the HL treatment were significantly larger ($P < 0.05$) than LL calves in the stifle and heart girth measures whilst calves on the HH treatment had significantly higher values ($P < 0.05$) of the four measures of conformation than calves on the LL treatment.

The mean values of the four measures of conformation obtained on the second and third measuring occasions showed that calves on the LL treatment were significantly smaller in all four measures obtained on each occasion compared with the calves which received the three other nutritional treatments.

If the growth of calves on the HH treatment is taken as the maximum growth attainable under the present conditions, then the depression in growth, as a percentage of the maximum, can be calculated for calves on the low level of nutrition. The mean values of live weight and the four measures of conformation are shown in Table 3g.13 for the LL treatment as a percentage of the values found for the HH treatment for the 3 periods of measurement.

Table 3g.13

Growth of LL Treatment Calves as a Percentage of the Growth of the HH Treatment Calves

	HH Treatment %	LL Treatment % of HH		
		Period 1	Period 2	Period 3
Live weight	100	81	77	79
Withers	100	97	95	94
Heart Girth	100	95	92	94
Hooks	100	93	91	91
Stifle	100	90	89	93

From a comparison with the work of Widdowson (1968) then the measures of conformation most affected at any particular age will be those latest maturing. Thus in Table 3g.13 the measure of conformation showing the largest depression as a percentage of the HH treatment will be the latest maturing. The values of the measures of conformation obtained on the first and second measuring occasions place the four parameters in order of maturity, earliest maturing first, withers,

heart girth, hooks and stifle. The results from the third measuring occasion differ slightly from the other two occasions. This may have been the result of calves having been weaned in between the second and third measuring occasions. Post-weaning the calves received hay *ad-libitum* hence the animals on the LL treatment were able to compensate for the previous low levels of feeding.

In order to examine whether the relationship between live weight and body conformation was influenced by nutrition regression equations were calculated of the form:-

$$W = mx + c \quad - \quad (1)$$

where x was the measure of conformation and W was in turn live weight and metabolic live weight ($W^{0.75}$). The variance accounted for by using $W^{0.75}$ was not significantly increased compared with using W hence the latter was used in preference.

Multiple regression analysis was also considered, including any two of the conformation parameters in an attempt to improve the relationship between live weight and conformation. The variance accounted for was again not significantly improved upon compared with plotting live weight against any one parameter of conformation.

Regression analyses were carried out for each group of calves on any one particular nutritional treatment for each of the three measuring occasions. Individual values for m and c from equation 1 together with standard errors may be found in appendix 4. Three of the measures of conformation were highly correlated with live weight and in the case of heart girth, hooks and stifle the linear regression equation accounted for more than 60% of the variance (average variance accounted for in each of the regression equations = 71%, 73.5% and 60% for equations containing heart girth, hooks and stifle respectively).

Equations based on height at withers and live weight on average accounted for only 47% of the variance.

Between nutritional group comparisons were made of the values of m and c obtained from the regression equations. The comparisons were made for each of the measures of conformation obtained on each of the three measuring occasions. No significant difference was found in any one of the between nutritional treatment within measuring occasion comparisons made. Within any one measuring occasion the age range of the calves was 6 days. On the three measuring occasions when calves were approximately 40, 68 and 103 days old, the maximum differences in mean live weight between the nutritional groups at these three ages were 10, 18 and 21 kg respectively. It can thus be stated that at ages of 40, 68 and 103 days there were no significant differences in the rate of growth of any one of the four measures of conformation relative to live weight when groups of calves differed in weight by 10, 18 and 21 kg at the three ages respectively.

As no significant differences were found in the between nutritional treatments within measuring occasion comparisons of the values of the regression coefficients, the four nutritional treatments were grouped on each measuring occasion and regression equations calculated. The regression equations were calculated for each of the four measures of conformation regressed against live weight using the data from all the calves. Separate regressions were carried out for each of the measuring occasions.

The values of 'm' and 'c' in equation (1) for the four measures of conformation obtained from all calves measured at any one time are shown in Table 3g.14.

In each of the four regression equations calculated significant differences were found in the values of the regression coefficients obtained on each of the measuring occasions. For each of the four

Table 3g.14

Values of the Constant and Regression Coefficient for Each of theFour Measures of Conformation at Each of the Periods of Measurement

	1st measuring occasion		2nd measuring occasion		3rd measuring occasion		Probability	Treatment Differences
		S.E.		S.E.		S.E.		
Withers Constant	-108.94	15.2	-157.3	20.2	-180.4	23.1		
Regression coeff.	2.1131	0.201	2.86	0.25	3.26	0.27	< 0.05	P1 < P3
H. Girth Constant	-65.858	7.36	-102.6	11.5	-150.23	1.18		
Regression coeff.	1.3926	0.087	1.89	0.12	2.37	0.11	< 0.001	P1 < P2 < P3
Hooks Constant	-59.89	6.03	-73.39	8.01	-104.6	9.8		
Regression coeff.	5.9162	0.32	6.95	0.38	8.38	0.41	< 0.001	P1 < P3
Stifle Constant	-43.809	5.73	-44.31	9.62	-80.59	13.0		
Regression coeff.	1.8067	0.109	1.99	0.16	2.77	0.20	< 0.01	P1 and P2 < P3

conformation parameters examined the value of the regression coefficient was greater on the third measuring occasion.

These results may be interpreted to show that the live weight of the calves was increasing at a greater rate compared to any measure of conformation during the third measuring occasion compared with the first measuring occasion.

Error in Measurements

The age of the animal has been shown not to have an effect on the observer error variances and a doubling of body size was also shown not to haves a corresponding increase in observer error. (Taylor, 1963). Thus it is permissible to compare calves in different periods in the knowledge that there is no increase in the size of observer error as a result of the growth of the calves from one period to the next.

It is also pertinent to compare the standard errors obtained in this experiment with those of Fisher (1975). The standard errors obtained in this experiment, together with those of Fisher (1975) are shown in Table 3g.15. Included in the table is the ranking of earliness of maturing from Taylor (1963).

Table 3g.15

Standard Errors (cms) of Measurements of Conformation Together with the Ranking of Maturity

Measurement	Ranking of maturity (Taylor 1963)	Fisher (1975)	Standard Errors cm		
			Period 1	Period 2	Period 3
Withers	1	2.39	2.9	3.1	3.3
Heart Girth	2	3.85	3.6	5.0	5.5
Length from patella to posterior mid line	-	1.63	4.9	4.4	4.2
Width of hooks	3	-	1.2	1.4	1.4

The standard errors obtained in the present work agree to a reasonable degree with those of Fisher (1975). Although a comparison of length

from patella to posterior mid line is shown, this is not strictly valid as in the present work the measurement was made from patella to patella. However, as each measurement was only concerned with the location of two end points then the comparison has been made. The increase in error obtained in the present work is considered to be due to the fact that an accurate measure of the distance from patella to patella will be more affected by the stance of the calf than the patella to mid line distance. The 'round' (patella to patella) also includes a concave area beneath the tail which again decreased the accuracy of the measurement. It is thus recommended that in future work the patella to mid line distance be adopted. Taylor (1963) found hook width to be the most precisely measured body part. This is clearly endorsed by the present work. Withers and foregirth were also shown to be measured with low observer error. The present results would endorse this, the error involved, however, was slightly higher than that obtained by Fisher (1975). No trend in error with increasing size or age of the animals was identified from the present work.

It is interesting to note that in the present work single observations were made of each measurement of each animal during any one period. The compatibility of the error terms with those of Fisher (1975) obtained from repeat measurements of 15 beasts is considered to be as a result of the large number of animals used in the present work.

Three of the measurements chosen in the present work, withers, heart girth and hooks, may be considered as earliest maturing, later maturing and latest maturing respectively when compared with one another (Taylor, 1962). The patella to patella measurement was not included in the ranking as it was not a skeletal measurement but a measure of muscle growth. Muscle impetus groups are not included in these measures.

Heart girth was also the most highly correlated with both live and slaughter weight (Johansson and Hildeman, 1954).

DISCUSSION

From the results it can be seen that the levels of nutrition imposed pre-weaning affected the conformation of the calves. A reduction in food offered influenced skeletal growth shown by a reduction of height at withers and a reduction in width at hooks and also muscle growth shown by a reduction in the distance from stifle to stifle. From an examination of the Autumn'74 results there was no significant difference between the measures of hooks of calves on the HH, LH and HL treatments whilst differences were found between these treatment groups in the mean values of the three other measures of conformation. This would tend to suggest that the hooks were least affected by level of nutrition.

When the sample of Autumn'74 calves were measured 84 days after weaning the differences in the mean values of the measures of the withers, heart girth and hooks had been reduced such that there were no significant differences between the nutritional treatment groups. However, the mean value of the measure of the stifle was significantly less in the calves fed the LL level of nutrition compared with the three other nutritional treatment groups. Thus upon realimentation the skeleton of these calves had been able to more closely attain the proportions of the full fed calves than had the musculature of the poorly fed calves.

When the results were examined for the Spring'75 calves it was found that differences in levels of nutrition over a period of approximately 11 weeks prior to weaning produced differences in daily live-weight gain between the three levels of nutrition (Low, LL; medium HL and LH and High, HH). These rates of live-weight gain produced

differences in the average live weight of the calves on the three occasions on which conformation was measured. Better fed calves were not only heavier but had significantly larger measures of height at withers, heart girth, hooks and stifle.

On the first measuring occasion the mean value of the hooks of the LL calves was the only measure that was significantly smaller than the values obtained for calves on the other three nutritional treatments; differences between treatment groups for heart girth and stifle were obtained between HH, HL and LL and withers between the HH and LL groups. Thus during the Spring'75 examination the results would suggest that the measure of the hooks is most affected by under-nutrition and the withers the least affected.

When the four measures of conformation were compared by examining the reduction in growth of the nutritionally deprived calves compared with the full fed group, the four measures of conformation were ranked in the order in which they were affected by under-nutrition. Most affected was the stifle measure then hooks, heart girth and withers in descending order. This order was the same on the first and second measuring occasions but on the third occasion the growth of the stifle had increased such that the hooks were the most affected.

Widdowson (1968) stated that the earliest maturing features are least affected by under-nutrition. Thus the most affected measure of conformation, namely the stifle, should be the latest maturing and the least affected, the withers, the earliest maturing. Ranked in this manner the rates at which the four measures of conformation could be said to mature agreed precisely with the ranking of Taylor (1963).

The between nutritional treatment group comparisons made of the regression coefficients obtained from the regressions of live weight against any one of the four measures of conformation showed that there were no significant differences between the nutritional group regression

coefficients obtained on any particular measuring occasion. However, when comparisons were made between the coefficients obtained on different measuring occasions and calculated by pooling the nutritional groups, significant differences were found. There were significant differences in live weight between nutritional groups and between the pooled live weights of the calves on different measuring occasions. As measurements obtained on any one particular occasion related to calves of approximately the same age then it can be stated that in this experiment that the relationship between live-weight gain and the increase of any one particular measure of conformation was the same for groups of calves which differed in mean live weight by 10, 18 and 21 kg at the ages of 40, 68 and 103 days respectively. Although regression equations were calculated from the live weight versus measure of conformation the extrapolation to live-weight gain and rate of conformational growth may be made from the within group variability of each measure. The significant differences ($P < 0.05$) obtained between the three measuring occasions in the pooled values of the regression coefficients show that as the calves grew older the rate of live weight gain increased significantly faster than did the rate of conformational growth. Thus a comparison of the between nutritional treatment within measuring occasion effect and the between measuring occasion result suggests that the age of the calf is more important than absolute live weight in governing the relative growth rates of parts of the body compared with live-weight gain.

This may be explained by the fact three of the measures of conformation chosen relate more to the skeletal development of the animal than to the development of soft tissue. The results therefore more correctly suggest that skeletal development is not as dependent on the live weight of the animal than it is upon its age. This is in agreement with the work of Dickerson et al (1961) who suggested that

although the density of the bone may be affected by nutrition, active accretion continues hence skeletal size is not affected.

When the results of the Autumn'74 calves were examined it was shown that the skeletal measurements of the realimentating calves had more nearly attained the size of the full fed calves by 149 days of age compared with muscle growth. When the mean values of the LL calves were expressed as a percentage of the values of the HH calves the percentage of the skeletal measures increased from 87% of the HH treatment at 94 days of age to 97% of the HH treatment at 149 days of age. The percentage of muscle size increased from 91% of the HH treatment at 94 days of age to 94% at 149 days of age.

Thus from the results of the Autumn'74 and Spring'75 trials it can be seen that skeletal development is retarded by under-nutrition calves on the LL treatments were significantly smaller during weaning. The rate at which the skeleton grows is more dependent on the age of the calf than upon its live weight. Upon realimentation measures which pertain to the skeleton are able to make compensatory growth and by 149 days of age had reached 97% of the values of full fed animals. Muscle growth was unable to make the same compensation by 149 days of age than did skeletal growth.

Considering these results in relation to animals undergoing a period of restricted feeding then it is suggested that differences in the length of time as well as the degree of restriction may produce animals of different conformation. If two identical growing animals of the same live weight are fed to lose a total of 20 kg in weight, one over a period of 40 days, the other over a period of 80 days, then if skeletal growth continues independent of the weight of the animal, upon realimentation when they both achieve their starting weight the animal restricted over a period of 80 days may have larger skeletal dimensions than the animal receiving the 40-day restriction.

On only one instance was a measure of conformation affected by housing environment when it was found that the stifle of calves in the 'A' houses was larger than calves in the 'B' houses. It is interesting to note that this was the one measure most associated with the muscle growth of the calf. The reason for this is difficult to explain for on no occasion were any differences found in live weight-gain as a result of housing environment.

CONCLUSION

Undernutrition has been shown to retard growth. Both skeletal and muscle growth are affected by undernutrition. Undernutrition did not affect the rate of growth of any of the parameters measured when compared to live weight, except for the growth of the tuber coxae which were significantly retarded in growth prior to weaning.

It is therefore concluded that undernutrition of the calf up to twelve weeks of age is equivalent to producing a lag in the physiological age of the undernourished calves.

Section 4

General Discussion

GENERAL DISCUSSION

The ability to rear calves in houses devoid of supplementary heating and ventilation has been shown in several studies. There is very little evidence in the literature as to the affect of the design of climatic calf housing on the performance of the calves. The effect of level of feeding and the manner in which the feed is offered to young calves has been extensively studied. Little is understood, however, of the interactions between the level of feeding and the housing environment on the performance of calves. It was hoped in this study to illucidate the interactions between level of feeding and environment and to study the requirements of the calf in terms of the protection afforded by climatic housing and the level of feeding needed in order to sustain recognised levels of performance. It has already been stated that the micro-climatic features of the area in which the study was undertaken are unique to the site on which the houses stand and are modified by the surrounding topology. The macro-climate of this area, however, is characteristic of a large proportion of the west coast region of the British Isles. The overwhelming influence of the external environment on the climatic conditions within the calf houses, which has been found in this study, demonstrates the validity of using the results obtained to make comment on the affect of rearing calves in climatic houses of a similar nature in areas in which the macro-climate may be considered similar.

The success of a calf rearing system may be measured in terms of the number of calves reared, in relation to the number bought and the performance of these calves relative to the amount of food they consumed. Roy (1970) suggested that the maximum performance that could be achieved by young calves was 1.2 kg/day, although this level is seldom achieved in practice. Roy et al (1971) in an experiment in which calves were fed milk replacer to five weeks of age at approximately 350g/day plus

concentrates ad libitum achieved a performance of approximately 0.6 kg/day up to 98 days of age. These calves were housed in controlled environment buildings in which the mean temperature was maintained at either 14.8 or 21.3°C. Turner (1974) achieved mean daily live-weight gains of 0.61, 0.60 and 0.58 kg/day in calves reared in controlled environment housing, non-controlled environment and straw kennels respectively, these calves were weaned at four weeks of age.

In a feasibility study Mitchell (1972b) examined the value of climatic calf housing in the North East of Scotland. A live-weight gain of 0.54 kg/day from four days to 12 weeks of age was considered satisfactory for climatically housed calves being offered 450g of high fat milk substitute per day in two feeds. Performance of calves on once daily feeding systems averaged 0.65 and 0.62 kg/day when fed 0.45 and 0.34 kg/day of high fat milk substitute respectively (Randall and Swannack, 1975). These calves were for beef production and were reared from 10 days to 12 weeks of age in buildings in which there was no control of temperature; calves were weaned on average at 20 days of age. Fallon, 1977 (personal communication) reared calves from 7 to 56 days of age either indoors, in Patterson type houses, or in straw bale shelters. The live-weight gain of the calves ranged from 0.50 to 0.63 kg/day but there was no significant effect of the type of shelter offered to the calves.

Of the four feeding treatments used in the present trials the two ad libitum concentrate feeding systems most closely paralleled present practical calf rearing systems. From approximately 6 to 76 days of age, calves on the LH and HH treatments gained on average over all four intakes 0.49 and 0.55 kg/day respectively. These live-weight gains were lower than the gains achieved in the experiments of Roy et al (1971) and Turner (1974) when controlled environment housing was used. The

gain of the HH calves was better than that of the calves used by Mitchell (1972b) and was on a par with that achieved in the experiments of Fallon (1977). The performance in the present experiments is, however, poorer than that of the calves of Randall and Swannack (1975) although this is to be expected as all the calves in the latter experiment were beef type animals whereas in the present experiment a large number of the calves could not be classed as beef type. Also, the duration of the experiments of Randall and Swannack was longer than the present trials and hence older calves were being used which it is to be expected would have better live-weight gains.

Mitchell (1972b) considered a live weight gain of 0.54 kg/day as satisfactory. The gains achieved by the LH and HH treatment calves of 0.49 and 0.55 kg/day were satisfactory. A comparison with the work of Roy et al (1971) and Turner (1974) would suggest that better live-weight gains may be achieved when controlled environment houses are used, however, the merits of either system at this stage would be dependent on the relative cost of the controlled environment building and the value of the increased live weight gain of the calves.

A total of 507 calves were purchased for the four calf trials, of these 446 were reared. The loss of 61 calves represented a total loss of over 12%. This figure includes eight calves which were slaughtered as a result of positive Salmonella identification. The individual mortalities for the four calf intakes excluding the eight slaughtered calves were for the Spring'74, Autumn'74, Spring'75 and Autumn'75, 11.7, 1.6, 14.8 and 12.5% respectively. It is pertinent to consider that these eight calves would have been slaughtered irrespective of the housing treatment as it was not possible to attribute an effect of climatic housing to an increased incidence of Salmonella. Thus excluding

the slaughtered calves the average mortality on the unit over the four intakes was 10.4%. The average calf mortality experienced by specialised calf rearers purchasing unweaned week old calves and rearing to 3 months of age has been reported to be 5.8% (Kilkenny, 1975). The 90% range in the above survey was 0 to 19.7%. Overall, therefore, the mortality was higher than would be expected in a calf rearing enterprise. Certain factors should, however, be taken into consideration when the overall calf mortality is considered. During the Spring'75 intake a significantly higher level of mortality ($P < 0.05$) was recorded in calves receiving the LL level of nutrition. There was also a suggestion that in general, mortality was higher in calves on the low milk replacer treatment. Also during the Spring'75 intake a total of 14 cases of Salmonella were recorded. It is considered that these two factors constituted exceptional circumstances which invalidate a direct comparison between the overall calf mortality during the four trials and the figure of Kilkenny (1975). Examination of the calf mortality on the HL and HH treatments where the level of mortality was 7.1 and 8.7 per cent respectively over all four intakes indicates the closer agreement with the average calf mortality of specialist rearers when calves on the low level of milk replacer feeding were ignored.

The 1.56% calf mortality encountered during Autumn'74 does show that it was possible to rear calves in climatic calf houses on the West of Scotland in a manner which achieved satisfactory live-weight gains and below average calf mortality.

The criteria discussed so far as a means of assessing the housing have been calf performance and mortality. It is pertinent to consider these two factors in drawing a comparison between the four houses and then to consider the inter-relationships between the recorded environment and other factors which may affect calf production.

There was no significant difference between the performance of any group of calves from arrival to sale as a result of the house in which they were reared. Similarly, there was no significant increase in calf mortality as a result of the house in which the calves were reared. Having made these statements there were, however, distinct trends in calf performance which were attributable to house effects.

When the performance to weaning of the LH and HH calves in each of the four houses was compared calves in the A2 house generally performed best. The order of ranking of the four houses when the LH and HH treatments were compared was in general agreement with the ranking according to the unweighted mean performance, where the daily live-weight gain of the calves in each of the four houses was in the order A2 > A1 > B2 > B1.

In order to elucidate those factors which have produced the trends in calf performance and health as a result of the housing, the environmental differences between the houses may be considered. It was not possible to relate any period during which it was considered that temperatures were excessively low or humidity abnormally high to any period of reduced calf performance. Similarly, it has not been possible to relate any single feature of the environment to calf performance. Part of the reason for this has been the highly variable weight gains exhibited by all the calves throughout the duration of the four trials. Certain conclusions may, however, be drawn as to the effect of design and insulation on the environment within the calf houses. In conjunction with the reports from the literature the effect of the individual climatic parameters on calf performance may be postulated and examined with respect to the performance recorded.

It has been stated that the evidence from the literature on the effect of the temperature, at which a calf house is maintained, on calf

performance is conflicting. Several instances were cited of the beneficial effect of supplementary heating. From the view of the literature it was concluded that up to three days of age the critical temperature of the fed calf lies between 9 and 13°C and that by approximately one month of age the critical temperature has dropped and lies between 5 and 0°C. From Table 2b.7 it can be seen that throughout the year temperatures in the B2 house seldom fell below 4°C and only during February were temperatures recorded in the A1, A2 and B1 houses below 4°C for any significant length of time. As the critical temperature of the calf rapidly falls below zero °C and although the critical temperature is measured under still air conditions which are seldom found in practise, it is unlikely that any of the calves being fed above maintenance were temperature stressed over a period of time sufficiently long to be recorded as an effect on calf daily live-weight gain. It cannot be stated, however, that none of the calves were temperature stressed or that incidences of scour or mortality were not precipitated by low temperature stress.

It has been shown that house temperature as a percentage of the outside temperature range was 93, 73, 87 and 40% in the A1, A2, B1 and B2 houses respectively. Thus, if low temperature per se was affecting calf performance then it would be expected that the B2 house calves would have an advantage over the calves in the other three houses. The same conclusions may be drawn as to the effect of temperature fluctuations. The magnitude of the difference between the A1, A2 and B1 houses and the B2 house should be noted for there was a 20% difference in the range of internal temperature between the A1, A2 and B1 houses, whilst there was a 47% reduction in the range within the B2 house compared with the A2 house alone. On no occasion were differences in performance of the calves in each of the four houses found which showed any trend in the values similar to that found in the house temperature ranges. It has

been stated that overall, the performance of the calves in the A2 house was marginally better than that of the calves in the other three houses. It can be concluded, therefore, that the higher mean temperatures and smaller range of temperatures recorded in the B2 house did not improve the performance of the calves relative to those which experienced a wider range and slightly lower ambient temperature.

Relative humidity in the B2 house was generally higher than that recorded in the other three houses. The highest mean increment above external relative humidity amounted to 3mm Hg and occurred in the B2 house during the Spring'74 intake. Subsequently when the floor falls in the B2 house were corrected the highest mean increment was 2mm Hg. The average relative humidities recorded during the Spring'74 intake were 82, 75, 82 and 90% in the A1, A2, B1 and B2 houses respectively. The ideal range of relative humidity was considered to be between 60 and 80% (Mound, 1971; Martig et al 1976) and values of above 85% it was considered should be avoided (Appleman and Owen, 1975). It can be seen, therefore, that only in the B2 house during the Spring'74 intake were levels of relative humidity experienced which would be considered detrimental to calf health.

The greatest difficulty in interpreting these results lies in the identification of transient stress situations for although no significant effect of housing environment or house type was recorded as regards calf mortality, mortality tended to be lower in the insulated houses. Thus, the reduced temperature range and slightly higher mean ambient temperature recorded in the two insulated buildings may have been beneficial in aiding the recovery of calves severely stressed as a result of illness. An examination of the incidence of scour in the four houses showed that during the two intakes which were recorded, calves in the A2 house had a lower incidence of scour up to 20 days of age. During the Autumn'74

intake there was a suggestion that house insulation may have aided in reducing calf scour. This suggestion was emphasised in the case of the 'A' type houses during the Spring'75 intake but a very high incidence of scour was recorded in the B2 compared with the B1 and the other two houses. It was considered that, in view of the reduction in dry matter digestibility in cold temperature stressed calves of between 200 and 300 kg live weight demonstrated by Christopherson (1976), cold temperature stress per se may result in increased scouring in young calves. It has been shown that the mean house temperatures did not differ by more than 3°C. It is unlikely, therefore, that mean house temperature differences could account for the increased incidences of scour. It was shown, however, that the range of temperature was greater in the uninsulated compared with the insulated houses. It is suggested, therefore, that lower temperatures recorded in the uninsulated houses may have contributed to a greater incidence of scour. It may be concluded that transient low temperatures were detrimental in a situation in which the mean house temperature did not affect calf scour.

There was no significant effect of house type or level of insulation on the mortality of the calves when the four intakes were considered either individually or in total. However, the mortality of calves was generally lower in the 'A' type houses and lower in the more insulated buildings. Over the four calf intakes the degree of mortality in each of the four houses was inversely related to the mean performance of the calves in the houses i.e. mortality was lowest in the A2 house and highest in the B1.

When the performance and health of the calves was considered over the four intakes, no measure consistently showed any single house to be better than the other three. There was a suggestion, however, that calves were healthier and mortality was lower in the insulated 'A' type

house compared with the other three and that in this house calves performed better. The totally enclosed nature of the B2 house, although it resulted in overall higher mean temperatures, reduced temperature range and lower air movements did not give any improvement in calf performance and on one occasion a very high incidence of scour was noted in this house.

No single environmental factor can be implicated as the cause of the house differences. Lack of air movement in the B2 house was considered a contributory factor in the increased incidence of scour during the Spring'75 intake. A reduction in internal temperature range was postulated as being the reason for the reduction in scour in the A2 house. The reduction in calf scour of calves housed in the A2 house may partially account for the better performance of these calves.

Thus consideration of the results from all four houses shows benefit may be gained by incorporating some insulation in climatic calf houses. It would appear, however, that totally enclosing the building in an attempt to raise internal temperature and reduce air movement did not improve calf performance but had a marginally detrimental effect on the health of the calves.

During the four calf intakes it was found that the level of nutrition exerted a far greater influence on the performance, health and mortality of the calves than did the environment produced by vastly differing types of calf house design. The daily live-weight gain of the calves was increased by feeding high levels of milk replacer and concentrates ad libitum. The mean daily live-weight gain of the calves ranged from 0.30 kg/day on the low level of nutrition to 0.593 kg/day on the high level of nutrition. The levels of nutrition expressed in terms of multiples of maintenance of the calves, are shown in Table 4.1. These values were calculated from the mean weights of

the treatment groups and the mean metabolizable energy intakes, both calculated as the mean values between arrival and weaning. The maintenance requirement was taken as 0.42 MJ.ME/$kg^{0.75}$.

Table 4.1

The Four Nutritional Levels Expressed as Multiples of Maintenance

	LL	LH	HL	HH	Mean
Spring'74	1.65	1.73	1.83	2.11	1.83
Autumn'74	1.32	1.72	1.77	2.06	1.72
Spring'75	1.47	1.94	2.03	2.09	1.88
Autumn'75	1.39	1.87	1.89	2.08	1.79
Mean	1.46	1.80	1.88	2.09	-

During three of the four intakes HL treatment calves performed better than LH treatment calves. This was to be expected from the marginally higher level of feeding received by the HL treatment calves and the lower heat increment of feeding on the HL diet, hence the more efficient conversion of metabolizable to net energy.

Level of milk replacer feeding was also shown to affect calf mortality. Although the difference between the levels of mortality of calves on the two milk feeding treatments did not achieve significance, mortality was higher in the calves receiving 300g of milk replacer per day compared with those receiving 600g per day. During the Spring'74 intake when the low level of milk replacer feeding was set at 400g/day mortality on the low and high levels of milk replacer feeding was six and nine calves respectively.

Increased levels of scour were positively correlated with the 600g/day milk replacer feeding treatment. This result is in agreement with the work of Leaver and Yarrow (1972a). It was not possible to ascertain whether mortality was higher in scouring calves and hence

whether that mortality which occurred in calves receiving the high level of milk replacer feeding was associated with the level of feeding or was caused by other management factors.

A comparison of the two levels of milk replacer feeding showed that neither were ideal for rearing calves under conditions encountered during the present trials. Leaver and Yarrow (1972a) suggested a level of 320g of a high fat milk replacer should be used on a once daily feeding system. As these calves were reared in an insulated artificially ventilated building in which the temperature ranged from 0 to 18°C there is obviously a requirement for a higher level of milk replacer feeding by calves housed in more open buildings which were naturally ventilated. The high level of scour recorded on the 600g/day milk replacer treatment showed that benefit would have been gained in terms of less scour by feeding less milk replacer. A compromise between these two levels whilst reducing overall live-weight gain would probably have achieved an optimum level of performance together with minimum scour conducive to maximum viability. This is in agreement with the work of Randall and Swannack (1975) where it was found that feeding milk replacer at 340g per day significantly reduced calf performance compared with feeding 450g/day.

During the Spring'75 intake when a significantly higher level of mortality was found in calves receiving the LL level of nutrition no one house was implicated as either increasing the level of mortality or increasing the viability of the calves. Thus there was no interaction between level of feeding and housing environment over the range studied on the mortality of the calves. Higher levels of nutrition other than encountered on the LL treatment either as a result of increased levels of milk replacer or concentrate feeding did increase the viability of the calves. This is in agreement with the conclusions already drawn that nutrition influenced the performance of the calves to a greater extent

than the range of environments. It is also in agreement with the conclusions drawn by Webster (1977) that conditions suitable for well fed and healthy calves cannot be considered appropriate for a calf which for any reason is deprived of food or is in poor health.

The increase in the appetite for concentrates of the calves fed the low level of milk replacer, is in agreement with the results obtained by Leaver and Yarrow (1972b). It was suggested in this work that low levels of milk replacer feeding should be adopted in order to encourage concentrate intake and facilitate early weaning. It has been suggested that in the present study levels of milk replacer in excess of 300g/day would have been beneficial. The method of reducing the level of milk replacer feeding to levels of 320g/day recommended by Leaver and Yarrow (1972b) in order to encourage concentrate consumption and facilitate early weaning on the basis of the total amount of concentrates consumed cannot be recommended under the present trial conditions.

A season and nutrition interaction was recorded in the concentrate consumption of the calves. The calves offered concentrates ad libitum on the high level of milk replacer feeding were unaffected by the rearing season. Calves on the low level of milk replacer ad libitum concentrates treatment consumed more concentrates during the two Spring intakes compared with the Autumn intakes. The increased concentrate consumption of the Spring born LH treatment calves resulted in better daily live-weight gains of those calves compared with their Autumn born counterparts.

The fact that this interaction was not found with the HH treatment calves shows that the low level of milk replacer feeding was the reason for the higher consumption of concentrates during the Spring compared with the Autumn. Thus during the two Spring intakes calves receiving the low level of milk replacer had a greater feed requirement than the

Autumn born low milk replacer fed calves and had a higher concentrate requirement than calves receiving the high level of milk replacer. It is considered, therefore, that this may demonstrate an ability of the calf to increase its food intake by consuming more concentrates as a result of environmental conditions. Those environmental conditions which precipitated the increased concentrate consumption cannot be positively identified. However, as a reduction in the mean house temperature was the most noticeable environmental feature of the Spring compared with the Autumn intakes, it is suggested that this was the main cause of the increased concentrate consumption.

This response did not occur irrespective of the overall level of nutrition but has been shown in this instance to be dependent on the level of milk replacer feeding. It may be postulated that this effect demonstrates that the calf does not rely on the heat increment of feeding from rumination as a means of obtaining heat. Calves consuming high levels of concentrates had a higher heat increment of feeding than calves consuming less concentrates. The total metabolizable energy consumed per day pre-weaning by HH calves was greater than that of the LH calves. However, the HH treatment calves did not increase their concentrate consumption during the colder weather. Calves receiving the low level of milk replacer increased their concentrate consumption and hence gained a greater heat increment from the feed. Thus on the highest levels of metabolizable energy intake there was no indication of a specific increase in concentrate consumption in order to increase the heat increment of feeding.

Consumption of hay by calves on the low milk replacer treatment was greater than that by calves receiving the high level of milk replacer. This is in agreement with the results of Roy et al (1971) when it was found that the appetite of calves for hay was depressed by feeding milk replacer ad libitum. Calves on the restricted concentrate treatment consumed more hay than calves receiving concentrates ad libitum. As

the hay was fed in restricted amounts it was not possible to identify whether the increased consumption of the concentrate restricted calves was in order to achieve an equivalent dry matter intake to the ad libitum concentrate fed calves or whether it was an increased appetite for long fodder.

It was hoped by comparing the performance of the calves on individual nutritional treatments in each of the four houses to be able to identify house and nutrition interactions on the performance of calves. As the HL and LL treatments were based on the level of feeding achieved by the LH calves then differences in consumption of concentrates by the LH calves in each of the four houses resulted in different levels of nutrition being offered to the HL and LL treatment groups in each house. Thus, direct comparisons of the performance of the HL and LL groups from each of the four houses could not be made.

The value of 19.2 MJ/kg dry matter obtained in the metabolism trial for the metabolizable energy value of the milk replacer confirmed the figure obtained by Webster et al (1976). It was shown that this figure was unaffected by feeding either 300 or 600g of milk replacer per day and was unaffected by feeding up to 1 kg of concentrates per day in calves ranging from approximately 40 to 70 kg live weight.

The value of 9.37 MJ/kg dry matter obtained for the metabolizable energy of the concentrates was considered low with respect to the literature values of an equivalent ration and due to poor concentrate digestibility (concentrate digestibility = 70% of 80% from literature). This was considered the result of a poorly developed rumen in the young calves studied. The isolation of the metabolism trial calves may have resulted in a poorly developed rumen microflora (Smith and McAllan 1974) and lack of hay in the diet may have also caused some reduction in rumen development, although Hi Shin Kang and Leibholz (1973) found no affect

on the performance of calves when all concentrate diets were supplemented with chaffed lucerne hay. It is considered that the development of concentrate digestibility in the young calf and those factors which influence its development merits further investigation as a means of accurately predicting the food requirements of the very young calf for maintenance and production.

The values of 0.46 MJ/$kg^{0.75}$ and 12.36-13.47 MJ/kg live-weight gain obtained for the metabolizable energy requirements of the calves for maintenance and live-weight gain respectively were in good agreement with the literature values. These results confirm the validity of the metabolizable energy values obtained for the milk replacer and concentrates.

The metabolizable energy value of the milk replacer obtained during the metabolism trial was used directly in the main production trial. Allowances were made for an increase in the digestibility of the concentrates as the calves grew older and hence the metabolizable energy value of 11 MJ.ME/kg DM of an equivalent cattle cake was obtained from the literature and used in the main trial. Total metabolizable energy consumed by individual calves was calculated for the four intakes. Significant differences were found in the metabolizable energy consumption of calves on the three levels of nutrition during two of the four intakes. Lack of significance on the two remaining occasions was partly due to an increased within treatment variation in the total metabolizable energy intake. This may have been due to adjustments made in the feeding treatments offered to scouring calves during the Spring and Autumn'75 intakes.

No significant differences were found over the four intakes in the metabolizable energy required in excess of maintenance per kg of live-weight gain by calves in each of the four houses. It was found,

however, that calves in the B2 house were most efficient during three of the four intakes and that the efficiency of the calves in the A2 house was ranked third in each intake. These trends should be viewed with great caution for the maintenance requirements of the calves were assumed constant over the four intakes and also to be the same in each of the four houses. It has also been shown that the efficiency of conversion of metabolizable energy to gain decreased as live-weight gain increased. Thus the effect of house type on conversion efficiency is confounded by the overall level of performance of the calves in any one house. As the performance of calves in the A2 house was generally better than that of calves in the three other houses it was to be expected that the efficiency of energy conversion of these calves would be poorer than that of calves in the other houses with lower rates of gain.

The reduction in the efficiency of conversion of metabolizable energy to gain with increased levels of feeding is in agreement with the work of Holmes and Davey (1976). In the present work the metabolizable energy content of the gain ranged from 10.5 MJ.ME/kg gain in calves gaining at the rate of 0.3 kg/day to 18.0 MJ.ME/kg gain in calves gaining at 0.6 kg/day; an increase of 2.3 MJ.ME per 0.1 kg gain/day between the rates of 0.3 and 0.6 kg/day. A similar effect was noted in the Netherlands (Roy, 1970) when it was shown that the net availability of metabolizable energy on ad libitum feeding of milk substitute was reduced to 66% compared with the normal value of 79.5 to 84.5%. It was not stated in the latter experiment whether carcass examinations were made in an attempt to show whether the reduction of the availability of metabolizable energy was an actual reduction of the energy available or a conversion of net energy to fat rather than protein.

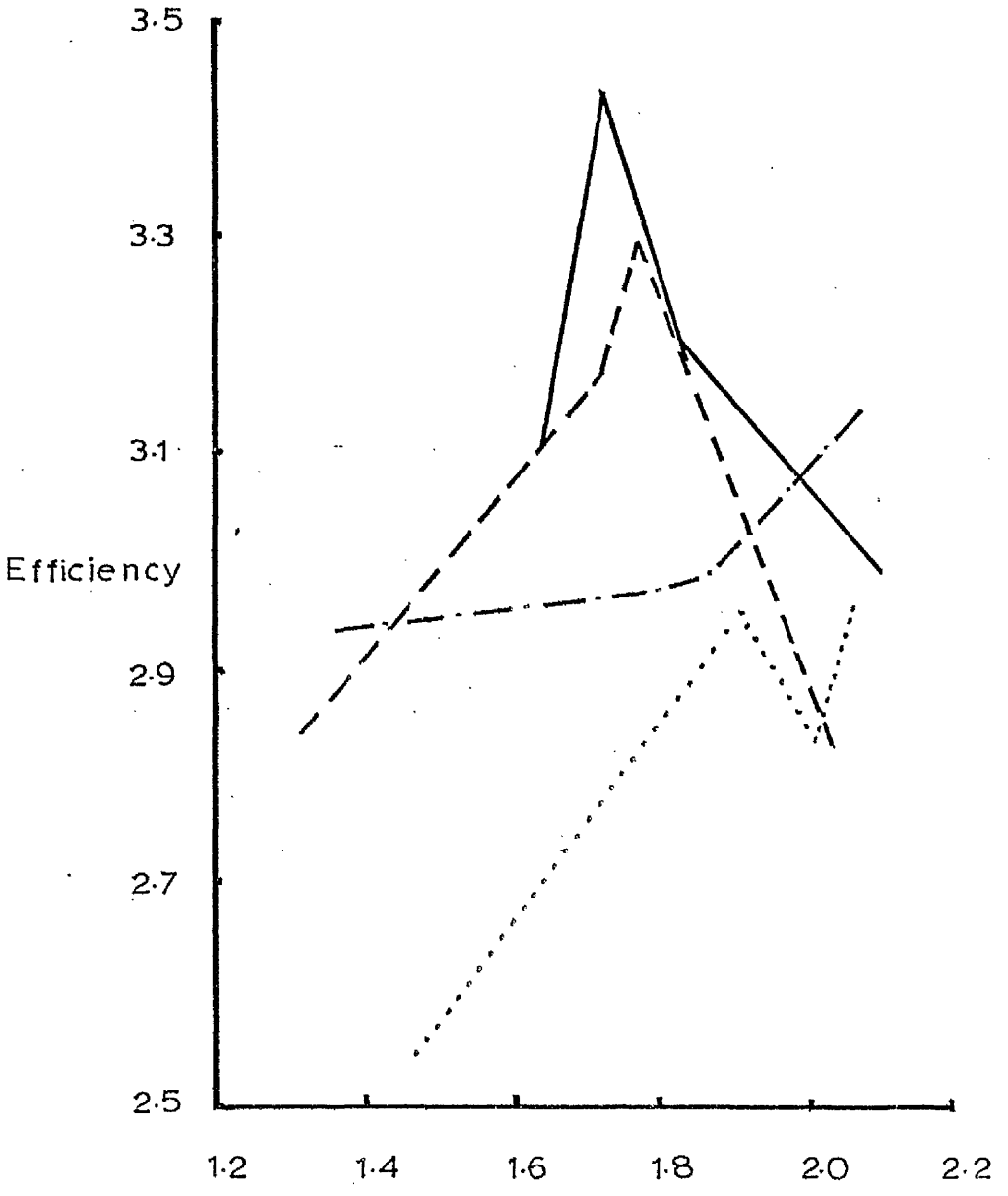
A similar argument is pertinent in the examination of the metabolizable energy per kg of live-weight gain on the four nutritional treatments. It was not possible to identify whether calves on the high nutritional treatments were depositing a high proportion of fat in the gain or whether the apparent increased metabolizable energy content of the gain was due to a reduction in the metabolizable energy content of the diet.

The efficiency of metabolizable energy conversion to gain is zero when an animal maintains itself. Above maintenance and as the rate of live-weight gain increases relative to the live weight of the animal the efficiency of energy conversion increases. It has been shown that the energy requirement of the gain increased as the rate of gain increased. It was considered, therefore, that as efficiency initially increased above maintenance but declined as the rate of gain increased then it may be possible to determine the point of maximum efficiency. As the metabolizable energy concentration of the dry matter differed on the four nutritional treatments according to the amount of milk replacer, concentrates and hay in the diet it was considered inappropriate to measure efficiency in terms of the live-weight gain per unit dry matter intake. In this instance efficiency has been expressed as live-weight gain per mega joule of metabolizable energy intake. Efficiency of food conversion versus level of feeding as a function of maintenance is shown in Figure 4.1. The data is shown for the four calf intakes and each set of data consists of four levels of feeding representing the four nutritional treatments.

The data from the Spring'74 and Autumn'74 intakes showed a peak efficiency of energy conversion at approximately 1.75 x maintenance. Data from the Spring'75 and Autumn'75 intakes did not show a similar peak in efficiency and in these two cases efficiency of energy conversion was still increasing at 2.1 x maintenance. It should be noted,

Fig 4.1.

Efficiency of metabolizable energy utilization at various levels of feeding



however, that during these latter two intakes the overall efficiency of conversion was appreciably lower than during the Spring and Autumn '74 intakes. This would suggest that the point at which the efficiency of metabolizable energy conversion to gain begins to decline is not dependent on the overall level of feeding but that efficiency declines above a level of live-weight gain at which there is a specific energy content of the gain, i.e. in this instance the point $3.3 - 3.4 \times 10^{-2}$ kg $days^{-1}$ $MJ.ME^{-1}$.

These results have shown an increase of over 100% in the metabolizable energy requirement of the gain of calves gaining close to 0.6 kg/day compared with those gaining at 0.3 kg/day. The increase in requirement was 2.3 MJ of metabolizable energy per 0.1 kg of gain between the rates of 0.3 and 0.6 kg/day. It has been stated that the reduction in efficiency of energy conversion may be an increased deposition of fat in the gain, in which case the energy content of the gain was increasing, or the energy content of the gain may have remained constant and the metabolizable energy content of the diet been reduced, as the calves grew older and rumination developed.

Roy et al (1971) showed that environment and level of nutrition may affect fat deposition in calves. Environmental effects produced a 36% difference in the perirenal fat deposition of calves. Neese and Kirchgessner (1975) found that when the feeding level of calves increased the content of lipid and energy in the carcass increased but the deposition of protein per kg of carcass remained about the same throughout the fattening period.

It was shown that the metabolizable energy value of the milk replacer did not decline when fed to calves up to 63 days of age (Section 3b). Although the metabolism trial did not show any reduction in the metabolizable energy content of the milk replacer over a period of days approximately equal to the pre-weaning trial (63 compared with

70 days), it is considered that rumination would have been more advanced in the pre-weaning trial calves. This would have occurred as a result of the earlier feeding of concentrates, the feeding of hay and the greater contact of calves with neighbouring animals during the pre-weaning trial compared with the metabolism trial. There may, therefore, have been a slight reduction in the metabolizable energy content of the milk replacer during the latter period of the pre-weaning trial. There was also a slight over estimation of the metabolizable energy content of the concentrates during the early part of the pre-weaning trial until concentrate digestibility and rumination was fully developed. It is considered that both these factors would have led to a slight over-estimation of the metabolizable energy content of the diet. In order to fully explain the discrepancy between the energy content of the gain on the high and low feeding treatments, the level of feeding would need to be implicated as reducing the metabolizable energy content of the diet. Level of feeding was not shown to affect milk replacer or concentrate digestibility over the levels of feeding studied on the metabolism trial. It is possible, however, that concentrate digestibility may have been slightly reduced on the high levels of concentrate feeding.

On balance, therefore, it is considered that the reduction in the efficiency of metabolizable energy conversion to live-weight gain recorded as the level of feeding and the daily live weight gain of the calves increased, demonstrates a greater fat deposition and not a reduction in the metabolizable energy content of the diet. The site of this fat deposition has not been identified in the present study but it may be postulated that the increased fat deposition was subcutaneous. This would have resulted in a greater total body insulation and hence a lower critical temperature of the high and medium treatment calves. The lack of total body insulation in the LL treatment calves

is in agreement with the results obtained during the post-weaning trial when it was found that upon realimentation the metabolizable energy conversion of this group was lower than the medium or high nutritional treatment groups.

The fact that the metabolizable energy content of the gain calculated from the pre-weaning trial ranged from below to above the literature values (10 - 18 MJ.ME/kg daily live-weight gain compared with 11.2 - 13.8 MJ.ME/kg live-weight gain (Holmes and Davey, 1976) and 13.47 - 12.36 MJ.ME/kg live-weight gain (Section 3b, Metabolism Trial) suggests that the composition of the gain of the climatically housed calves differed appreciably from calves reared under metabolism trial conditions. Comparing with the results of Holmes and Davey (1976) it may be postulated that the 30% increase in the metabolizable energy content of the gain of the climatically housed calves compared with those reared in metabolism chambers with a constant internal temperature of 20°C demonstrates a tendency for climatically housed calves to deposit more fat when the overall rates of gain were not very different (rates of gain = 0.61 and 0.59 kg/day for the High treatment calves of Holmes and Davey (1976) and present work respectively). Wood et al (1971) concluded that the anabolic activity of calves up to 125 kg body weight was primarily concerned with lean and bone tissue growth which could be affected by dietary feeding. The present results suggest that fat deposition may also occur especially in climatically housed calves, to an extent which is not normally encountered in calves housed in environments when the mean temperature is maintained at 20°C.

Pre-weaning levels of nutrition did not have any significant effect on the live-weight gain of the calves from weaning to sale. A small amount of compensatory growth was found in both the low and medium treatment groups when the gut fill corrected live weights were compared at weaning and at sale. The fact that a degree of compensatory growth

in a manner less efficient than the control calves was found during the trial was contrary to the consensus of opinion in the literature regarding compensatory growth. The less efficient energy conversion of the realimentating calves was considered to be the result of a higher percentage of fat in the gain of these calves compared with the controls. It was postulated that the reason for the increased deposition of fat in the LL treatment calves was the fact that these calves were severely depleted in total fat body reserves and hence were severely lacking in total body insulation. Fat deposition was, therefore, the most essential tissue to be synthesised.

Significant differences were found in the live-weight gain of the calves from arrival to sale when the milk replacer feeding treatments were set at 300 and 600g/day. There was no significant difference between the treatments when the levels were set at 400 and 600g/day. The average weights at sale of the LH and HH treatment calves when the milk replacer feeding levels were 400 and 600g/day were 152.5 and 154.0 kg respectively. These figures compare with mean live weights at sale of 134.3 and 139.8 kg for the LH and HH groups respectively when the milk replacer feeding treatments were 300 and 600g/day respectively.

When the results of the examinations of calf mortality, calf scour and overall performance were compared it would appear that there was no distinct advantage over the total duration of the trial when 600 compared to 400g of milk replacer were fed on a once daily feeding system. A distinct disadvantage was found when the level was reduced to 300g/day. Under the conditions of the trial it would appear that 400g/day was a satisfactory level of milk replacer feeding. Although this result should be viewed with caution as it was derived from only one calf intake it is in general agreement as regards raising the low level of milk replacer feeding with the results of Randall and Swannack

(1975). In this work live-weight gain and appetite were significantly reduced by feeding 340 compared with 450g of milk replacer per day. The result also casts a degree of doubt on the recommendation made by Appleman and Owen (1975) when from a review of the literature 363g/day was suggested as the level at which milk replacer should be restricted on a once daily feeding system for breeds of larger calves and proportionally less for the smaller breeds.

The examination of the conformation of the calves has shown that restrictions in nutrition not only resulted in reductions in the live weight of the calves, but produced reductions in the withers, heart girth, hooks and stifle measurements. The degree to which each measure was affected corresponded to the order in which the conformational features matured. The earliest maturing feature was the height of the withers and in descending order, heart girth, hooks and stifle. The earliest maturing feature was least affected by undernutrition. Ranked in this manner the order in which the four measures of conformation matured agreed precisely with the results of Taylor (1963).

Three of the measures of conformation related closely to skeletal development rather than soft tissue growth (withers, heart girth and hooks). It was found that the rate of growth of any one of the four measures of conformation relative to the live-weight gain of the calves was more dependent on the age of the calves than on their live weight. This result is in agreement with the work of Dickerson et al (1961) where it was found that skeletal growth continued irrespective of a level of undernutrition, although the resulting bone had a thin cortex and a large marrow cavity. Thus it can be seen, that during undernutrition, the withers measurement was least affected as it was the earliest maturing, also as the calves grew older the growth of the withers continued, although soft tissue growth and live-weight gain were retarded. A similar argument is pertinent for the growth of heart

girth and hooks although these were more retarded as they were later maturing. This therefore accounts for the tall "leggy" appearance of the restricted calves. This result should be borne in mind when it is realised that better prices can be fetched at market by the more 'rounded' calf than a calf of equal weight which may be taller and thinner.

It is considered that the method used in an attempt to determine the metabolizable energy requirements of the calves in each of the four houses for maintenance and production was inappropriate for use with young calves. In the light of the findings showing the increase in metabolizable energy required per unit of live-weight gain as the rate of gain increased it can be seen that the linear regression analysis initially considered was not correct. The fact that curvilinear regression analysis did little to reduce the residual variance is in agreement with the results of Chestnutt et al (1976). It was estimated that the gut fill of the calves in this experiment was related to the live-weight gain of the calves and that the percentage correction for gut fill ranged from 63% of the total live-weight gain in calves gaining at a rate of less than 0.3 kg/day to 30% of the gain in animals gaining at more than 0.6 kg/day. The fact that the gut fill of the calves was not taken into account when the live-weight gain of the calves was calculated will, therefore, have appreciably masked any cirvilinear response. The fact that the linear regression equations did partly represent the physiological energy utilisation can be gleaned from the effect of using the initial, mean and final metabolic live weights in the equation which on each instance did not greatly affect the maintenance term but resulted in a consistent reduction in the energy available for gain.

It is considered, therefore, that further correction of the data by allowing for gut fill may favour the curvilinear regression rather than

linear analysis. It is doubtful however whether this increased accuracy would have achieved the precision required in order to identify differences in the maintenance requirements of the calves in each of the four houses.

APPENDIX 1

Detailed drawings of the four houses are shown in Figures 1 - 12. A description of the houses is given in the text.

'A' Type Houses

The A1 and A2 houses were 18,470 mm long, by 6290 mm wide, 2,200 mm to eaves at rear and rising to 4,150 mm to the underside of purlins at the front. The buildings were divided into four cells, each 4,300 mm wide by 6,000 mm deep.

'B' Type Houses

The overall dimensions of the B1 and B2 houses were 15,270 mm long, 10,034 mm wide and 2,950 mm to the eaves. The buildings were divided into four compartments, each 3,500 mm wide by 5,250 mm deep. Each compartment had eight cubicle lying areas, with access to a 3,500 mm long by 2,500 mm wide feed stance, with feed trough and access passage. The B1 house was open fronted along the length of the feed trough. The B2 house was fully enclosed.

Floors

All floors in the 'A' type houses were constructed of 100 mm thick concrete (1 - 2 - 4) tamped finish and laid to a fall of 1 in 40 towards the front. The concrete was laid on a 500g polythene membrane on 500 mm of concrete (1 - 3 - 6) on 100 mm of hardcore. The raised cubicle beds and passage in the 'B' type houses were of a similar construction to the floors in the 'A' type houses. The polythene membrane was omitted in the feed stance and access passage area.

Walls

'A' Type Houses: the lower walls of the 'A' type houses were intended to act as a dung retaining wall. They were thus built in 290 mm thick

cavity walling to a height of 1,370 mm and in the case of the A1 house were finished to eaves height with 115 mm brickwork strengthened with 345 x 115 brick butts. The external walls of the A2 house were built to eaves height in 290 mm thick cavity walling. The internal walls in both houses were of the same construction as the external walls in the A1 house and all brickwork was flush pointed.

'B' Type Houses

The B1 house had 290 mm cavity brick, external walling, flush pointed, to a height of 1,650 mm above passage floor level of the cubicle compartment. This was topped with 115 mm brick to the roof, strengthened with 290 x 290 brick butts.

Internal divisions were of 230 mm brick, 1,450 mm high, topped with 115 mm brick to the roof. The wall between the cubicle compartment and the feed stance was 230 mm brick, 1,450 mm high.

The B2 house had 290 mm cavity brick, flush pointed, external walling, to the rear and gables. Vertical corrugated steel cladding on 50 x 100 mm timber framing above a 115 mm brick dwarf wall forms the front.

Internal divisions were of 230 mm thick brickwork as was the wall between the feed stance and cubicle house to a height of 3,000 mm.

Roof

The roof sheeting of the A1 and A2 houses was 6.3 mm thick "Monad" asbestos roofing sheets supported on Tanalised timber 63 x 200 mm purlins. Barge boards and rain water goods were fitted to the gables and eaves respectively. The roof pitch was 9°.

The sheeting of the B1 and B2 house roofs was as for the 'A' type houses, supported on 50 x 200 mm purlins, half truss formed with 2/50 x 150 rafters spaced 50 mm apart, set on 150 x 150 mm timber stanchions and braced with 50 x 100 mm struts, stanchions set at 3,750 mm centres. The roof pitch was 5°.

Ventilation

Both the A1 and A2 houses were naturally ventilated. House A1 had two courses of honeycombed brickwork with 40 mm gaps. House A2 had three 225 x 150 mm hollow tiles as ventilators. On no occasion during the four calf crops were these ventilators opened.

House A2 had a 1,000 mm deep hinged flap at the front of the building, below the timber purlin.

Houses B1 and B2 were also naturally ventilated. One hopper type window was fitted in each compartment for inlet and a 150 mm wide open ridge ran the full length of the feed stance as an air extract. The B1 house was open along the entire length of the feed trough. The B2 house had an air control flap between the cubicle house and the feed stance at roof level.

Modifications

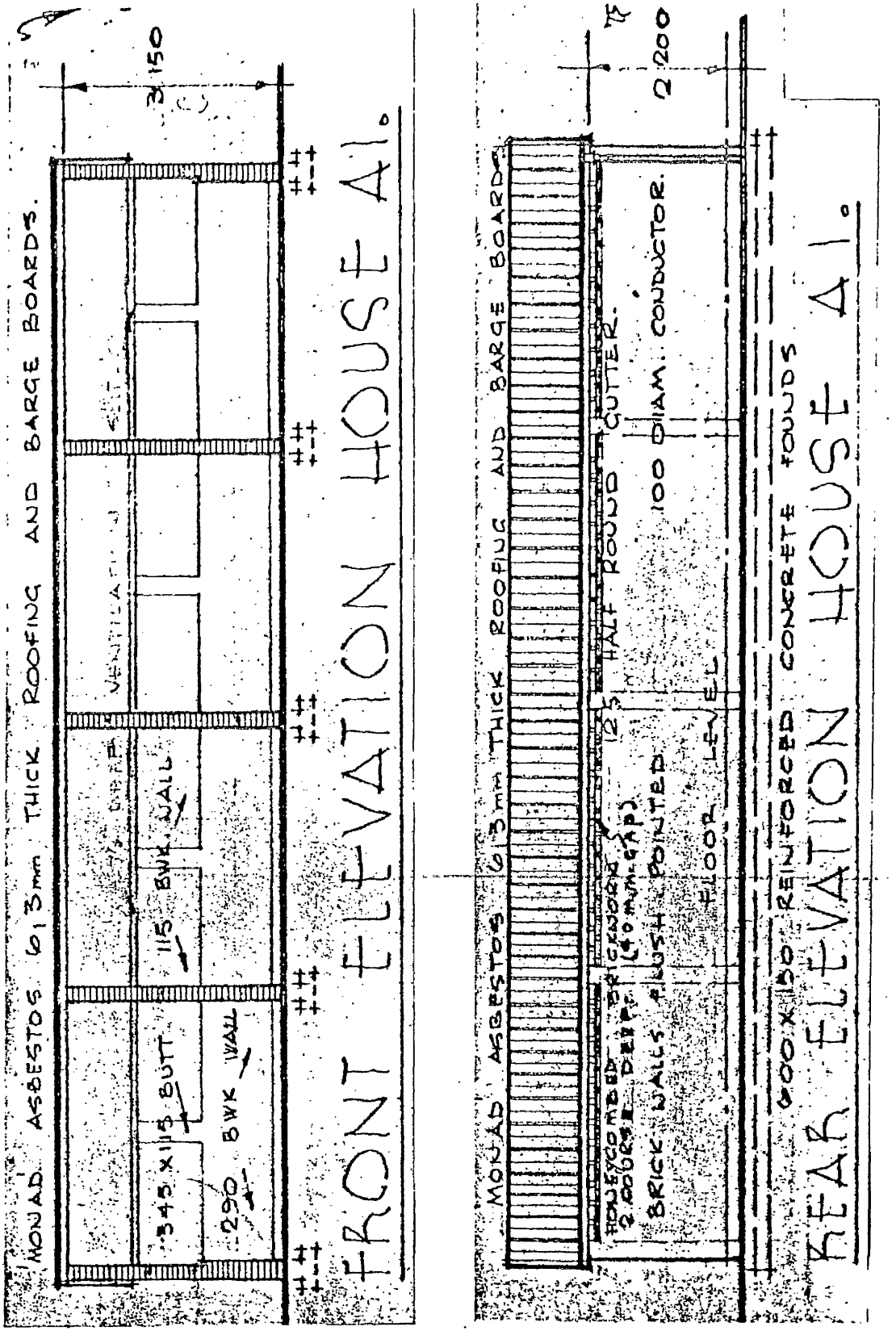
In the light of experience gained from the first crop of calves, the only modifications required were that gully traps were constructed in the access passages of the 'B' type houses. This modication was carried out in order to reduce the surface area of the run-off in the cubicle compartments.

Insulation

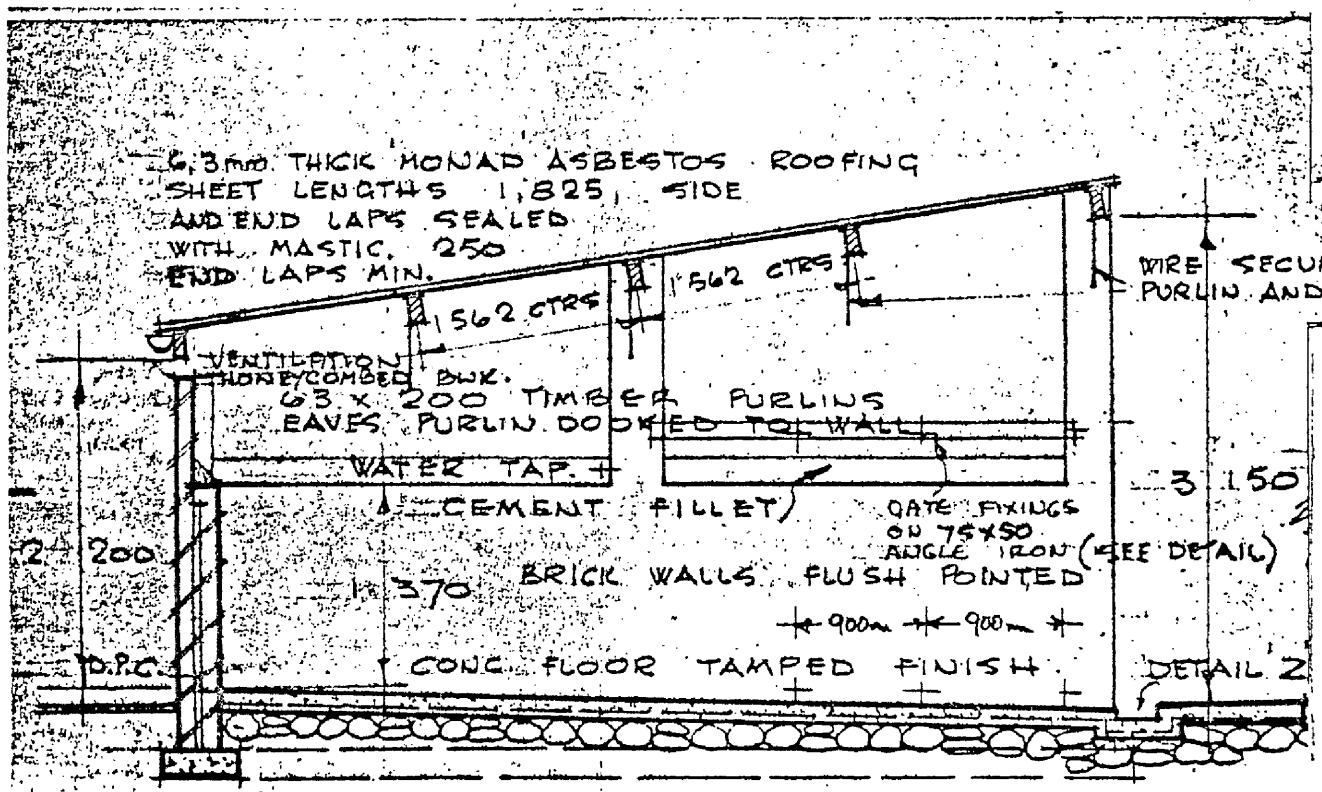
House A1 was uninsulated. House A2, besides having cavity walling had an insulated roof consisting of 50 mm glasswool, 500 guage polythene and 6.3 mm fully compressed flat asbestos sheeting.

House B1 was uninsulated. House B2 had a "sandwich" construction asbestos roof with 50 mm glass wool infill over the cubicle lying area only.

Elevations of House A1 Fig1



Sections of House A1



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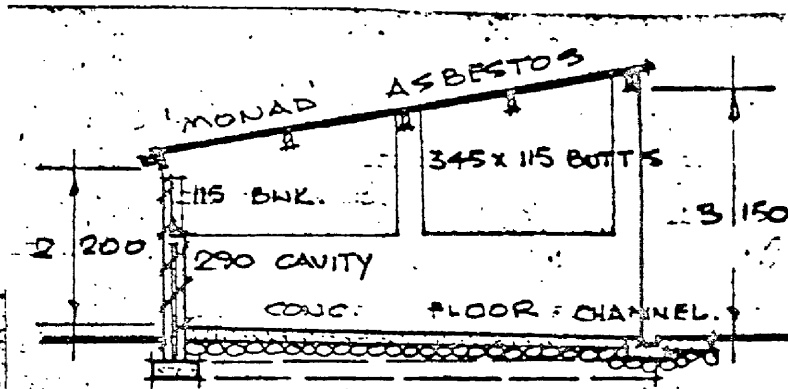

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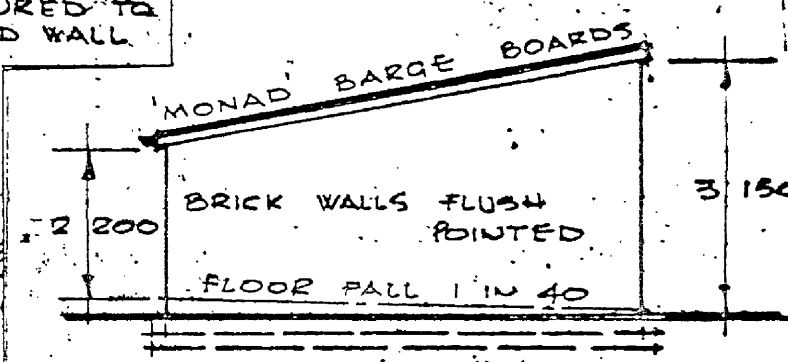
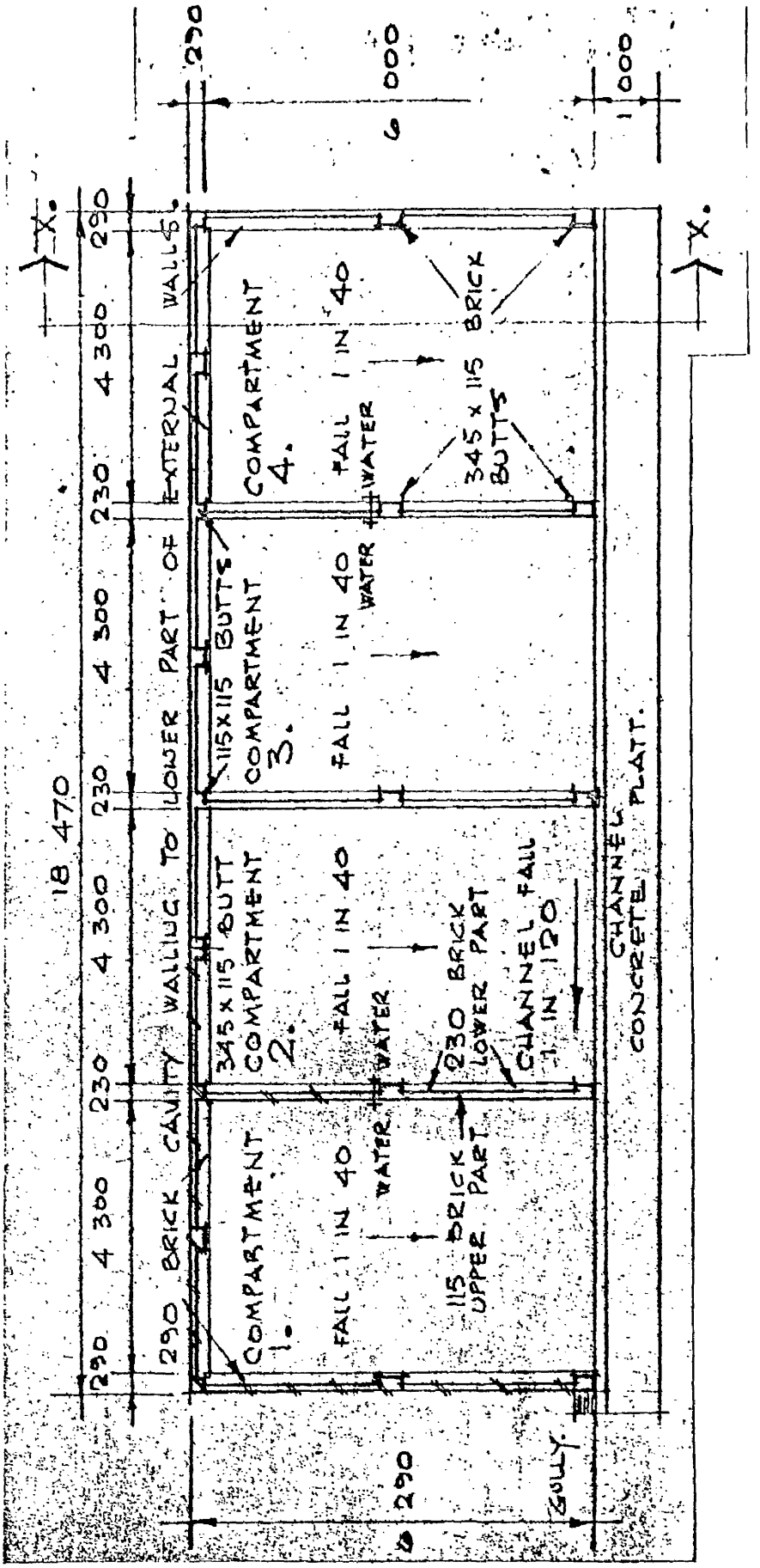


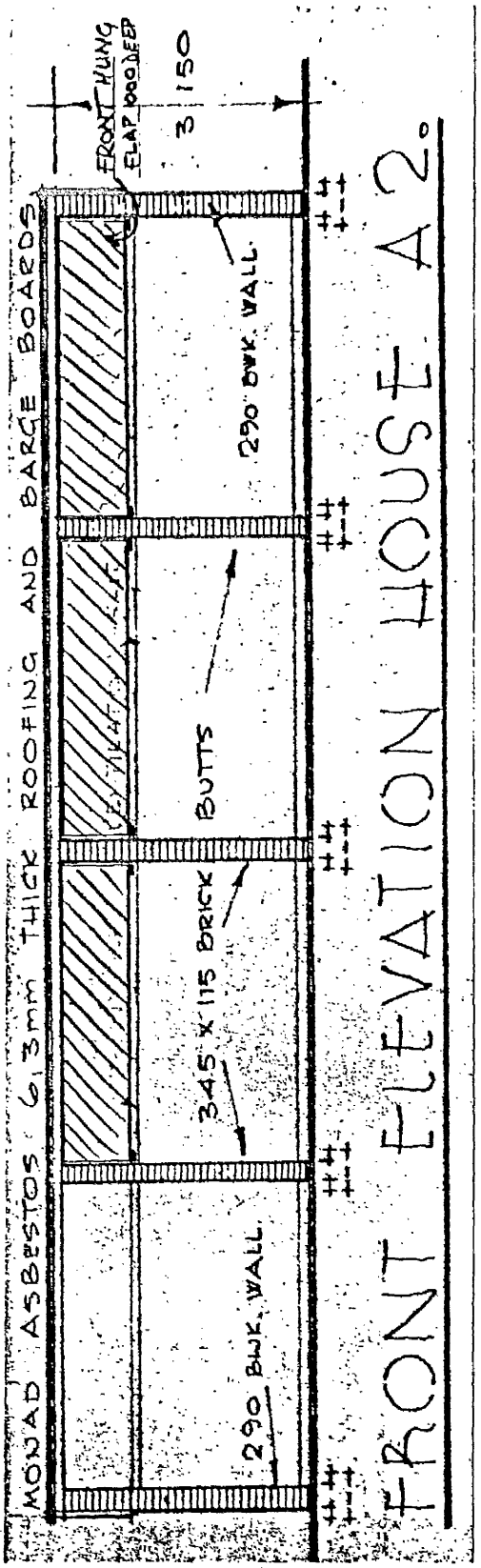
END ELEVATION.

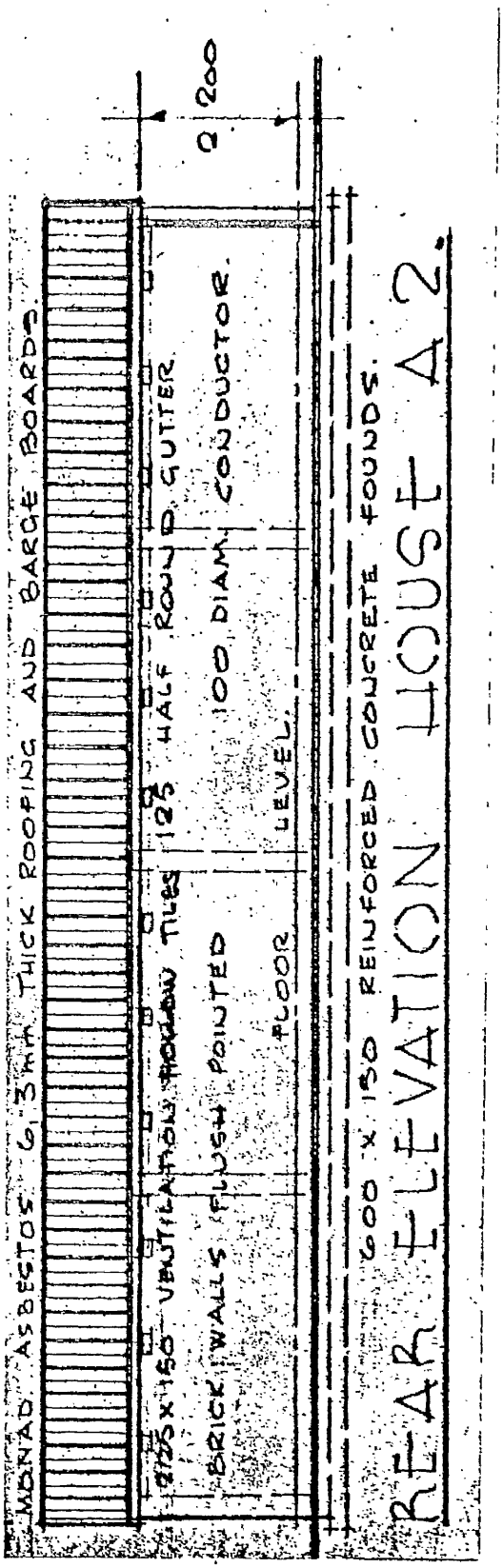
FIG 7

Plan of House A1 Fig 3

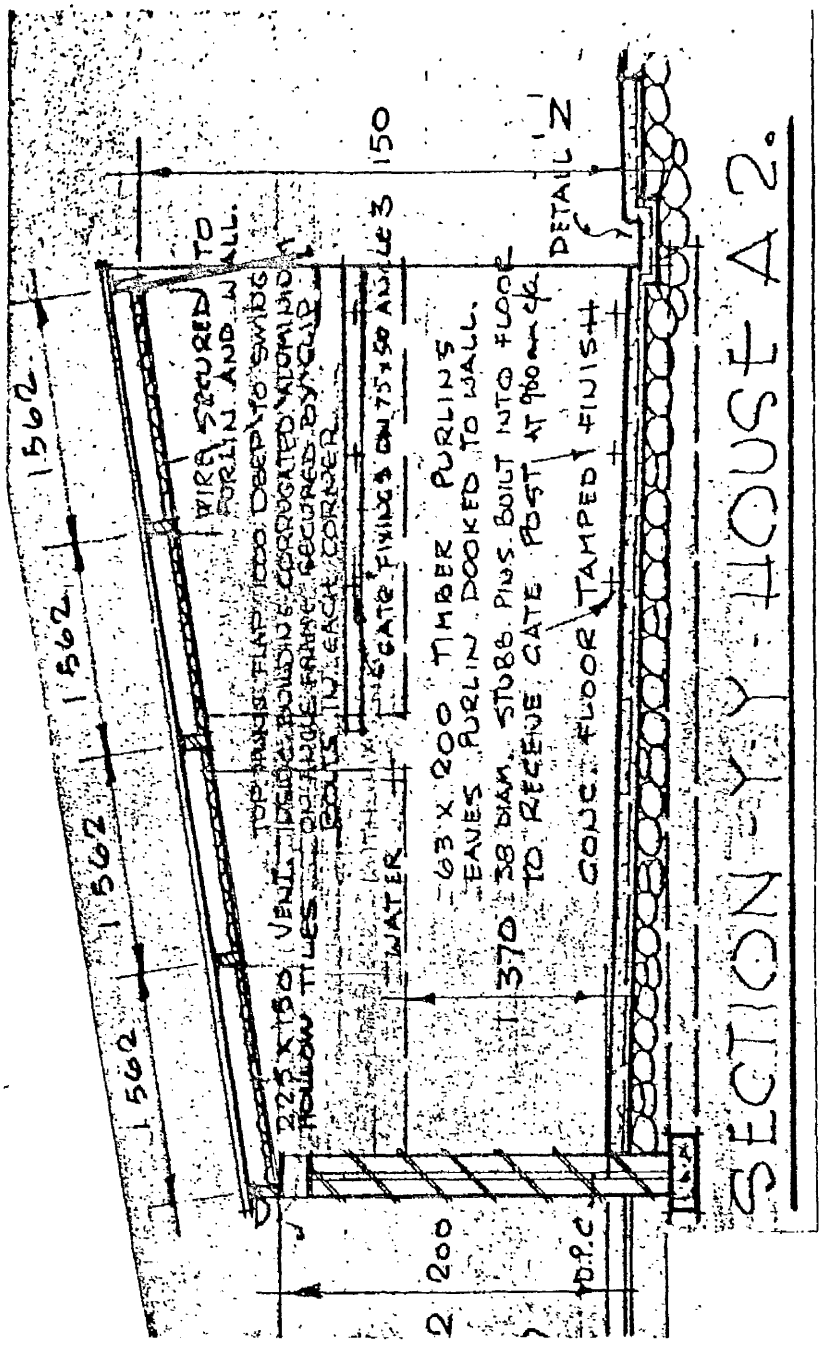


Elevations of House A 2 Fig 4

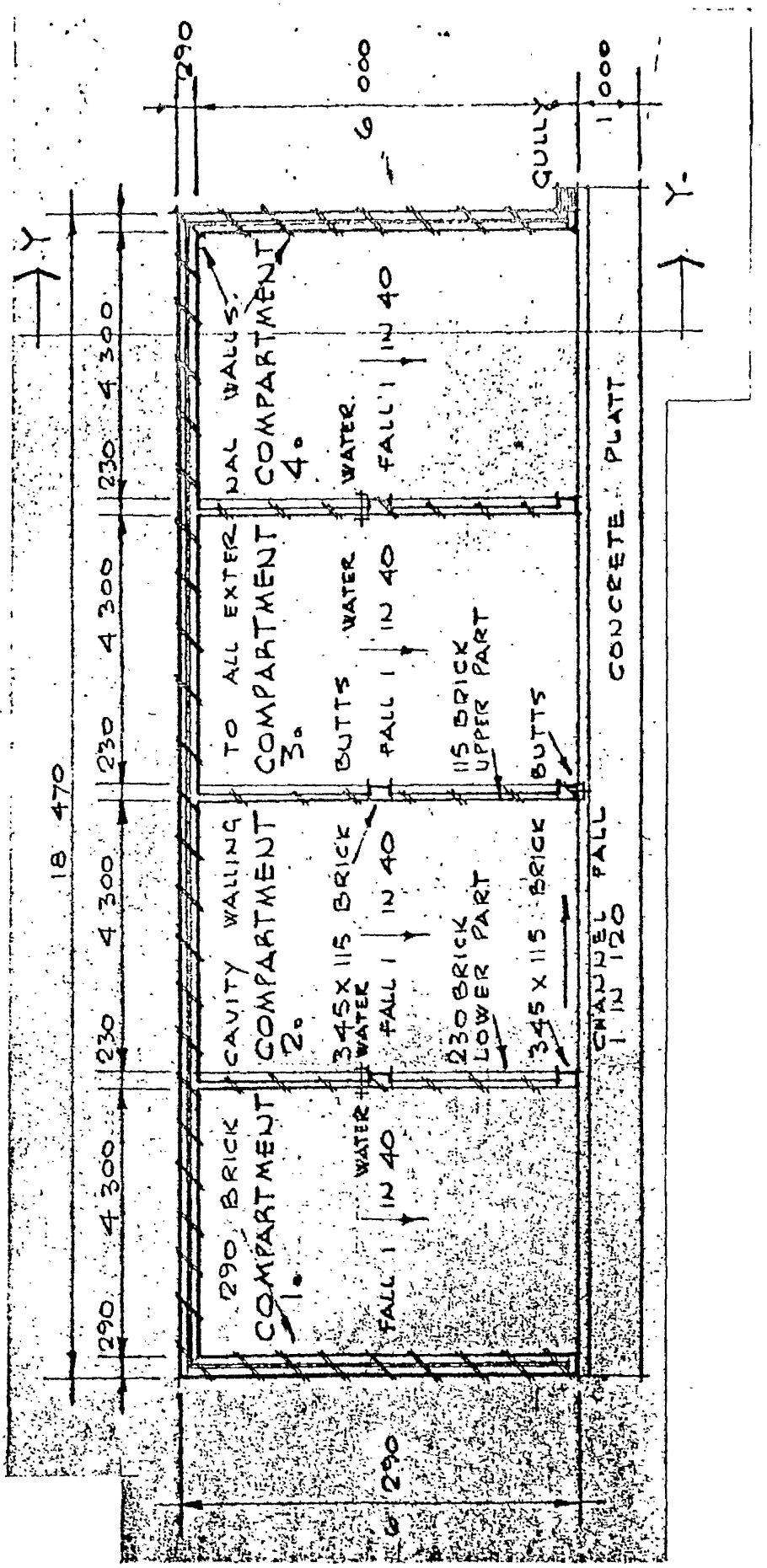




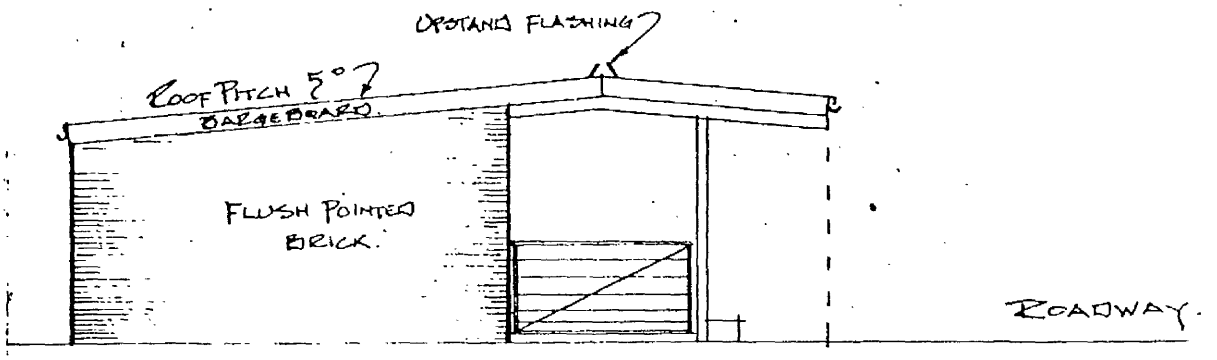
Section of House A2 Fig 5



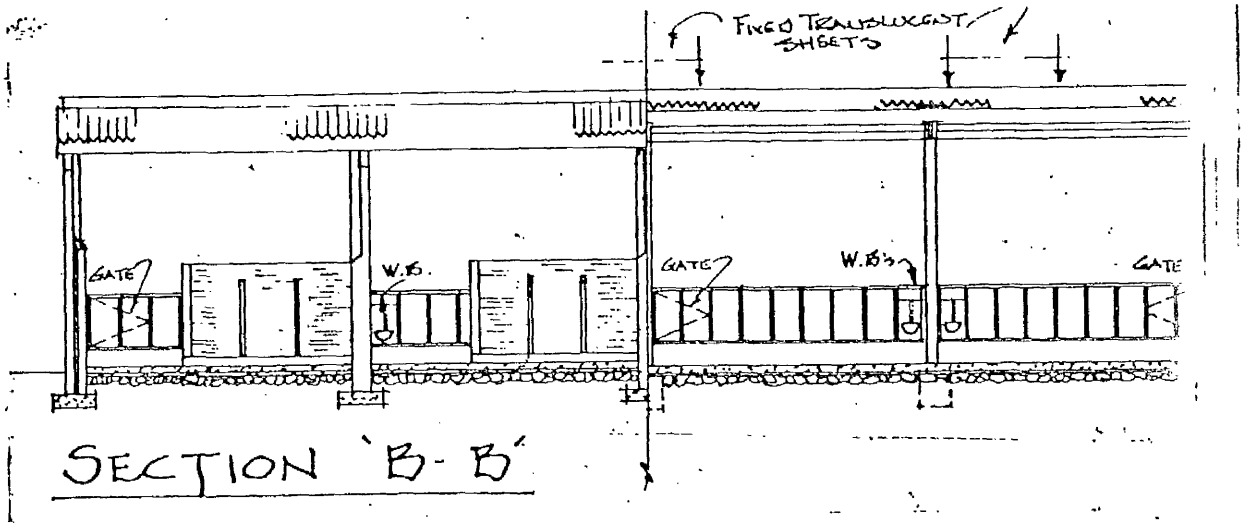
Plan of House A2 Fig 6



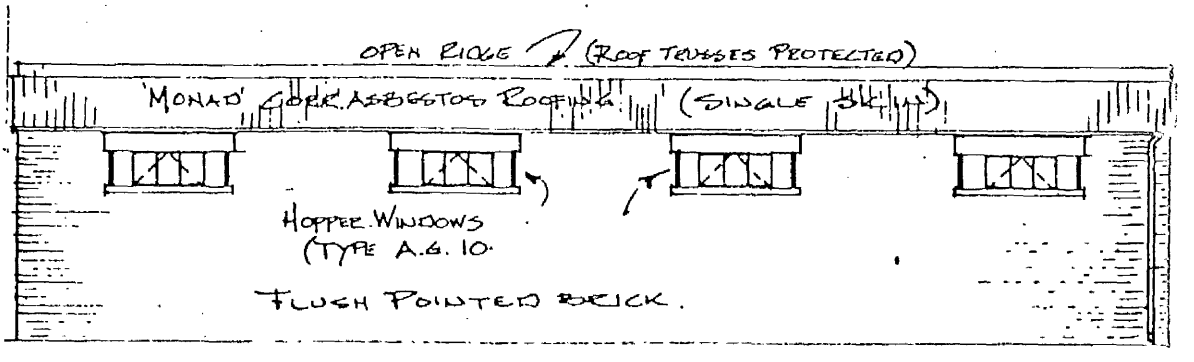
Elevations and Section of House B1



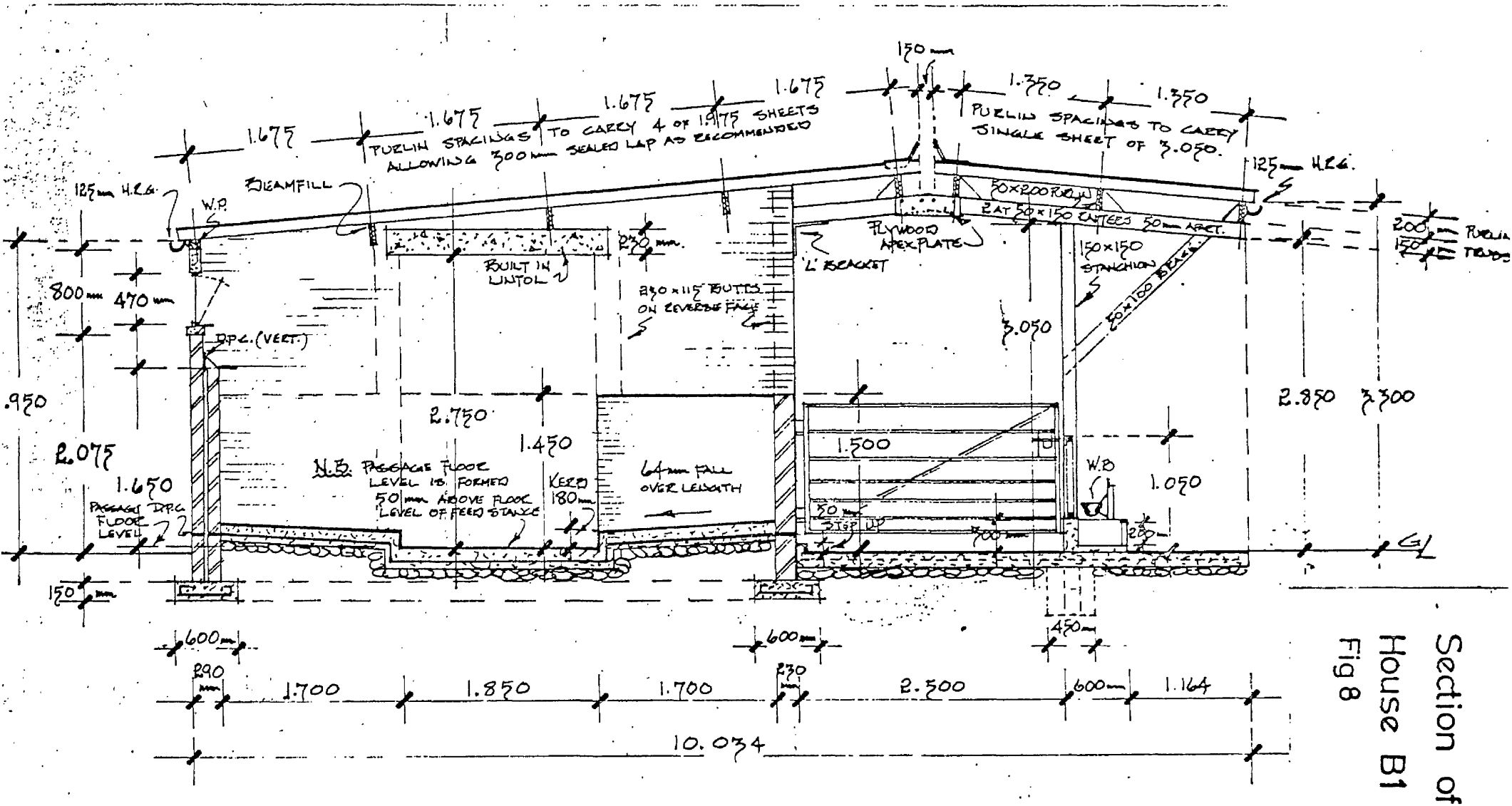
END ELEVATION



SECTION 'B-B'



REAR ELEVATION



SECTION A-A 1:50

Section of House B1
Fig 8

Plan of House B1 Fig 9

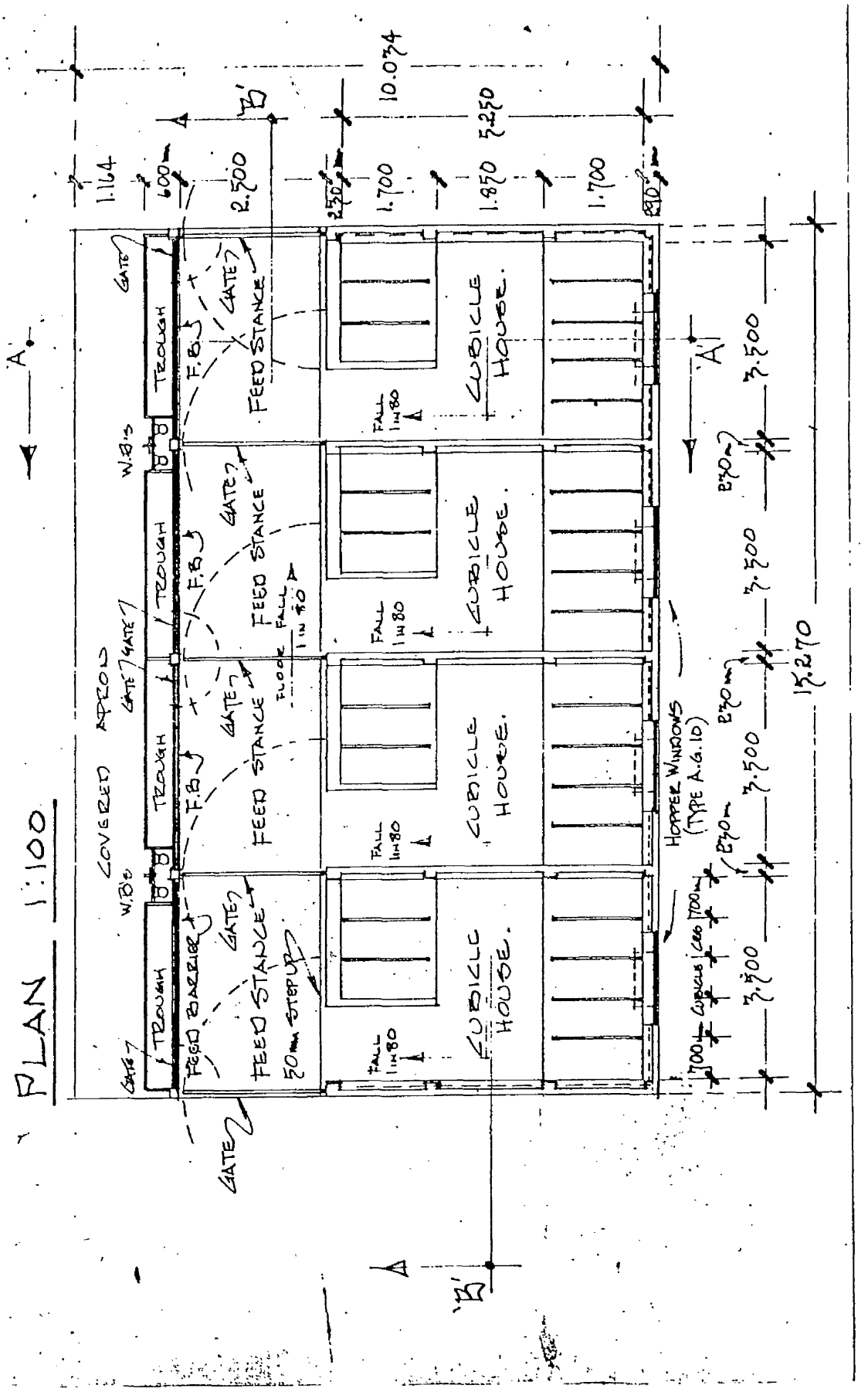
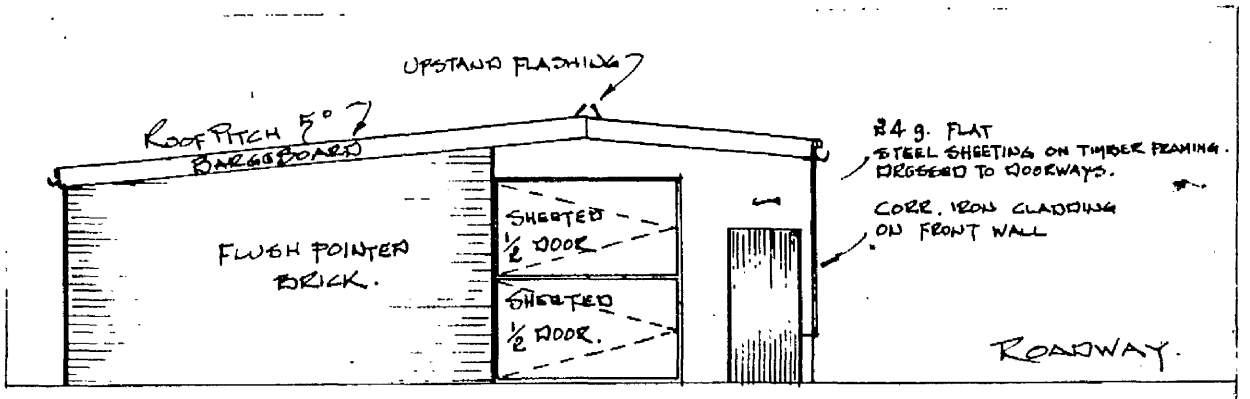


Fig 10

Elevations and Section of House B2



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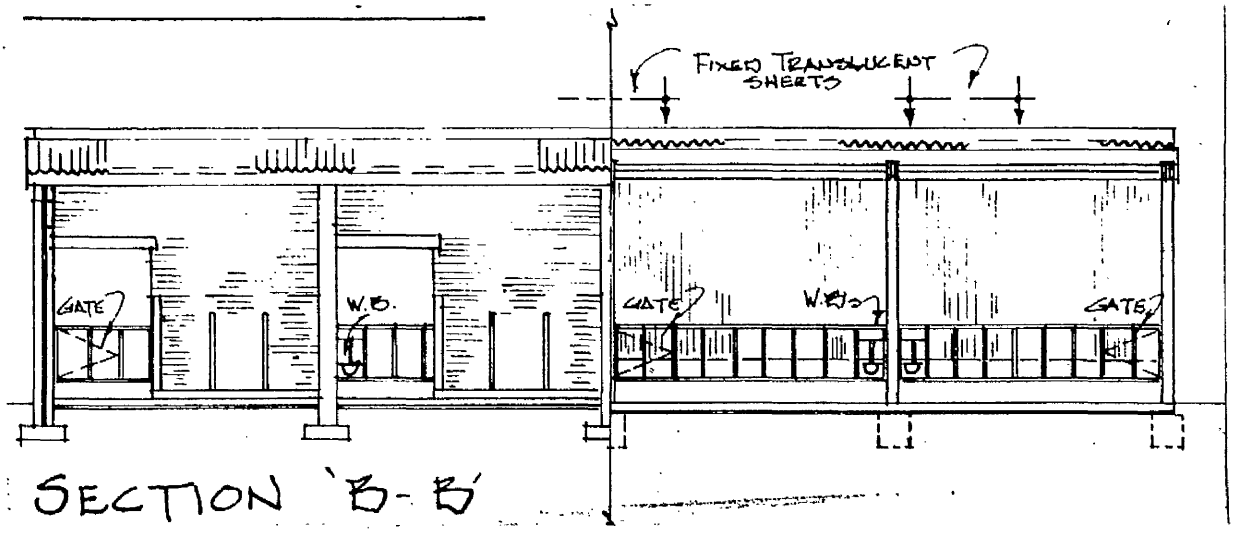

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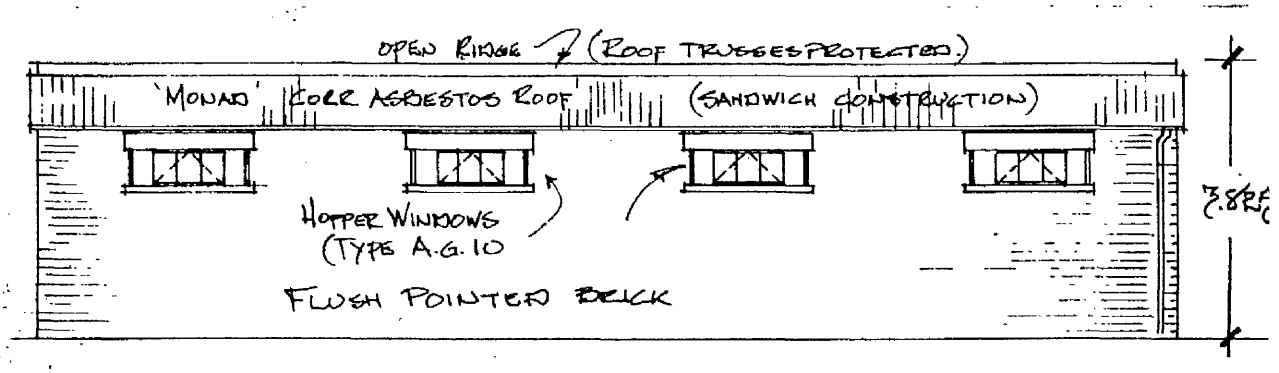

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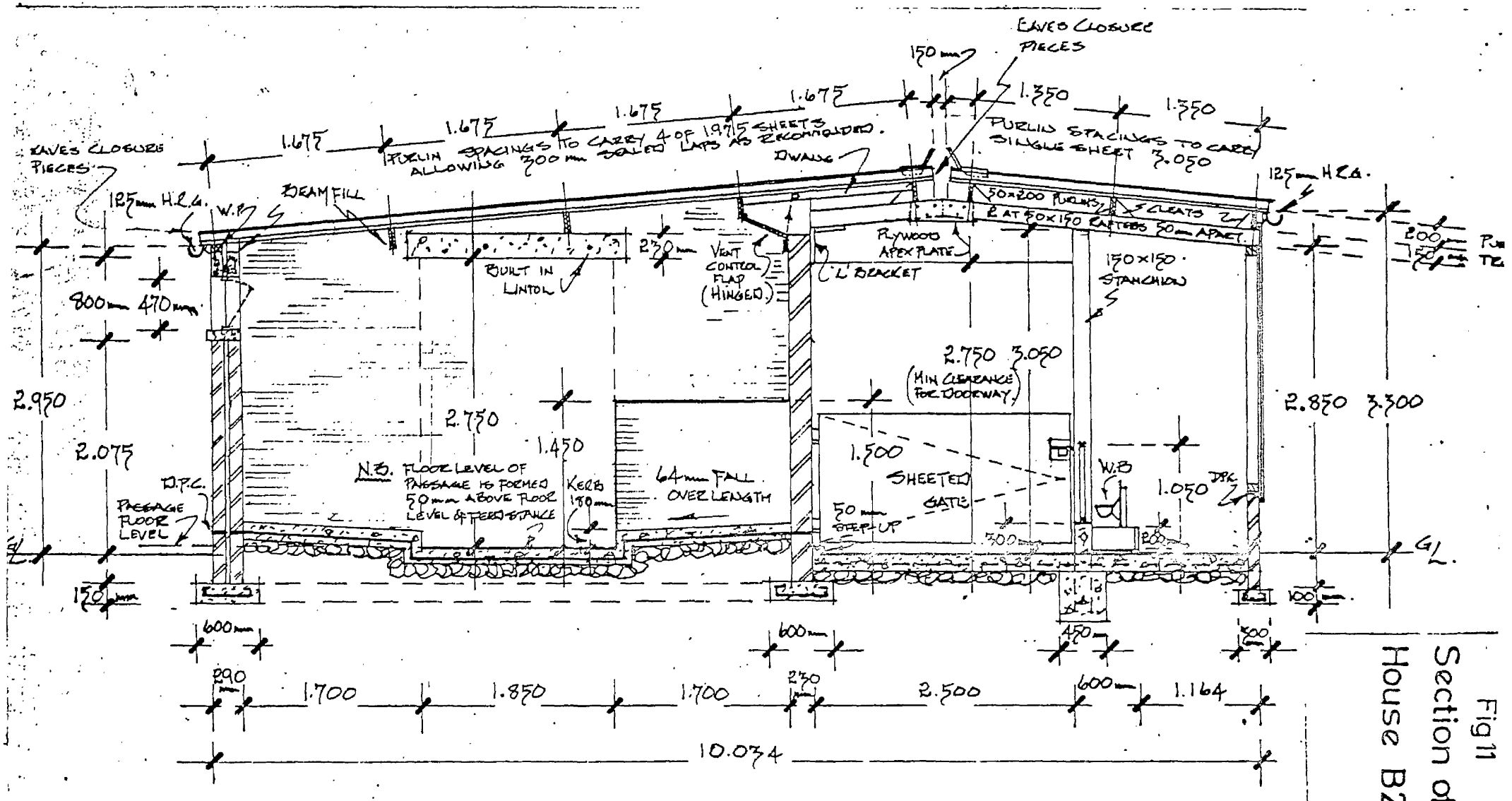
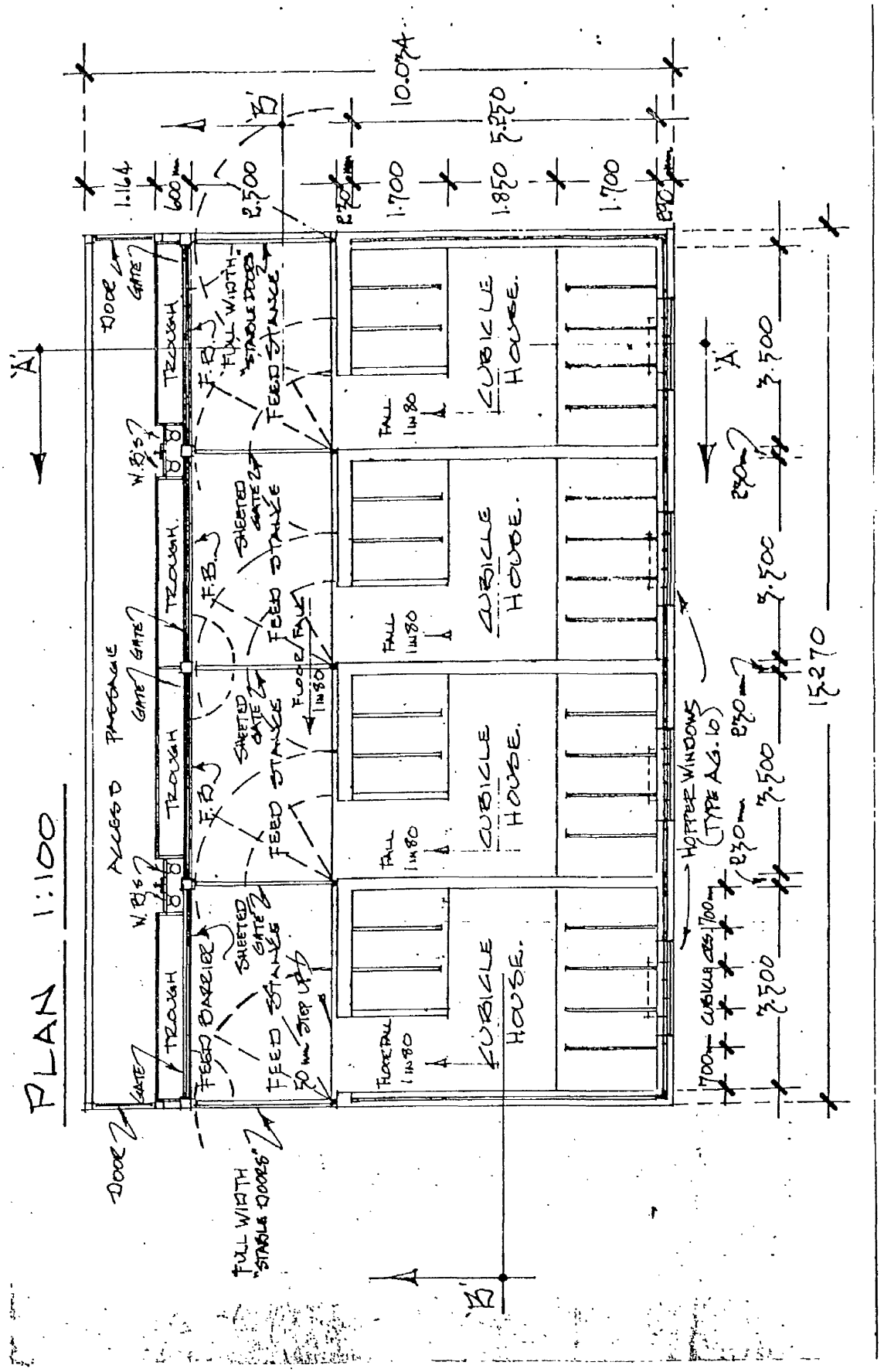


SECTION 'A-A' 1:50

Fig 11
Section of House B2

Plan of House B2 Fig 12



APPENDIX 2

Calculations to predict the live-weight gains of calves offered various levels of nutrition.

Roy (1970) has enumerated the requirements of the pre-ruminant calf for maintenance and production, fed a milk replacer containing 20% fat reconstituted to give 13.8% DM and 21 kJ.DE/g DM as:

218 kJ.DE/kg LWt for maintenance 12600.0 kJ.DE/kg gain

For ruminants k_g = 0.0435 M/D

where k_g is the efficiency with which metabolizable energy will be used for body gain and M/D is the energy concentration of the ration. (Energy Allowances and Feeding Systems for Ruminants, MAFF, H.M.S.O.)

Energy requirements do not appear to be directly related to dry matter intakes but there is undoubtedly a relationship between the metabolizable energy concentration of a diet expressed as MJ/kg and the utilization of metabolizable energy. The effect of ME concentration upon the efficiency of utilization of energy for maintenance and lactation appears to be small when the range of energy concentrations of practical diets are considered. The effect upon the efficiency of utilization for live weight gain is substantial (Report of the Working Part, MAFF, 1972).

For this reason net energies have been used in the calculations.

For a diet of 15% hay and 85% concentrates M/D = 12.6 MJ/kg (Roy 1970)

$$k_g = 0.0435 \text{ M/D}$$

$$\therefore k_g = 0.0435 \times 12.6 = 0.548$$

For a diet of 100% concentrates M/D = 13.4 MJ/kg (Roy 1970)

$$\text{hence} \quad k_g = 0.0435 \times 13.4 = 0.583$$

Hence for a diet of 15% hay and 85% concentrates and a diet of 100% concentrates metabolizable energy is used for gain with an efficiency of 54.8 and 58.3% respectively.

Concentrates

The young calf can digest concentrates with an efficiency of 82% (Roy 1970).

As only small losses of energy will occur in the urine and methane it was estimated that metabolizable energy would be approximately 95% of the digested energy.

Hence:

Gross energy x 0.82 = DE

DE x 0.95 = ME

(1a) ME x 0.548 = NE (85% concentrates)

hence DE x 0.52 = NE (85% concentrates)

(1b) DE x 0.583 = NE (100% concentrates)

DE x 0.553 = NE (100% concentrates)

Milk Replacer

The dry matter of milk replacer is 95% digestible (Roy 1970). As only small losses of energy occur in the urine, metabolizable energy will be approximately 98% of the digested energy (Roy 1970).

Hence:

Gross energy x 0.95 = DE

(2) DE x 0.98 = ME

ME x 0.85 = NE (Nutrient Requirements of Farm Livestock, ARC Publication, 1965)

the assumption was made here that the utilisation of the ME of milk replacer is equivalent to that of whole milk.

$\therefore$ DE x 0.85 x 0.98 = NE

Milk replacer has 21 kJ DE/g DM

$\therefore$ NE/g DM of milk replacer = 21 x 0.833 =

17.49 kJ/g DM

12600 kJ DE are required per kg of gain in the young calf (Roy 1970).

Thus from (2) 12600 x 0.85 = 10710 kJ of NE are required per kg gain (3).

A diet containing 100% concentrates has an M/D of 13.4 MJ/kg

A diet containing 85% concentrates + hay has an M/D of 12.6 MJ/kg.

From equations (1a) and (1b) these two diets supply:-

13.4 x 0.583 = 7.81 kJ NE/g DM (100% concentrates)

12.6 x 0.548 = 6.90 kJ NE/g DM (85% concentrates)

From equation (3) 10710 kJ of NE are required/kg gain.

thus for gains of 0.25 and 0.20 kg, 2677 and 2142 KJ NE are required respectively.

To support gains of 0.25 and 0.20 kg the requirement for concentrates would be:

$\frac{2677}{7.81}$ and $\frac{2142}{7.81}$ = 342 and 274g of concentrate DM for gains of 0.25 and 0.20 respectively

@ 90% DM = 380 and 304g of concentrates

It was estimated that calves arriving at the unit would weigh approximately 40 kg. The DE requirement for maintenance of these calves = 8.736 MJ.

$\therefore$ NE requirement for maintenance

= 8.736 x 0.85 x 0.98 = 7.131 MJ NE

Having calculated the maintenance requirement and the concentrate consumption equivalent to gains of 0.25 and 0.20 kg/day it was required to calculate the gains which may be envisaged from a mixed ration of concentrates and milk replacer. Upon the result of these calculations it could then be decided whether some calves could be restricted in levels of intake equivalent to that which would produce live-weight gains of 0.25 or 0.20 kg/day.

From the graph of concentrate intake versus milk replacer Fig 3a.3 the likely range of concentrate consumption may be calculated for a 40 kg calf receiving various levels of milk replacer.

Consider intakes of 400 and 600g of milk replacer per day. The range of concentrates intakes which may be expected for 40 kg calves receiving these two levels of milk replacer are:

Level of milk replacer	Range of concentrate consumption
600g/day	410-350 g/day
400g/day	460-450 g/day

In order to calculate expected live-weight gains and whether calves receiving an allowance restricted by a concentrate consumption equivalent that which would produce a gain of 0.25 or 0.20 kg/day compared with the ad lib consumption of other calves, the minimum levels of consumption ranges have been used.

The four treatments considered were:-

T1 = high milk replacer + concentrates ad libitum

T2 = low milk replacer + concentrates ad libitum (xg/day)

T3 = low milk replacer + (x - 380)g concentrates/day

T4 = high milk replacer + (x - 380)g concentrates/day

treatments T3 and T4 being restricted by 0.25 kg/day gain.

Hence daily treatment intakes envisaged:-

T1 = 600g MR + 350g/day concentrates

T2 = 400g MR + 450g/day concentrates

T3 = 400g MR + (450 - 380) g concentrates

T4 = 600g MR + (450 - 380) g concentrates

∴ Total ME supplied:

using ME/g of milk replacer DM = 17.49 kJ/g.DM

ME/g of concentrate DM = 7.81 kJ/g.DM

then ME in the fresh for milk replacer of 95% DM and concentrates of 85% DM.

= 16.62 and 6.64 kJ/g respectively.

The total NE intake from the four treatments are shown in Table 1.

Table 1

Net Energy (kJ) Supplied by Four Rations

Ration		Net Energy kJ/g	g of fresh/day	kJ NE supplied
T_1	Milk	16.62	600	9972
	Concentrates	6.64	350	2324
	Total		-	12296
T_2	Milk	16.62	400	6648
	Concentrates	6.64	450	2988
	Total		-	9636
T_3	Milk	16.62	400	6648
	Concentrates	6.64	70	465
	Total		-	7113
T_4	Milk	16.62	600	9972
	Concentrates	6.64	70	465
	Total		-	10437

From the previously calculated NE requirement for maintenance and gain of a 40 kg calf of 7.13 MJ and 10.71 MJ respectively, the gains expected from the four treatments in Table 1 may be calculated:

T_1 supplies Maintenance + 0.48 kg/day

T_2 supplies Maintenance + 0.23 kg/day

T_3 supplies 0.99 x Maintenance

T_4 supplies Maintenance + 0.31 kg/day

In the foregoing discussion the restricted level of concentrates fed to Treatments T_3 and T_4 was based on the ad libitum concentrate consumption of calves receiving 400g of milk replacer per day. It was considered that the ad libitum concentrate consumption of calves offered a low level

of milk replacer would be greater then that of calves receiving the high level of milk replacer, thus basing the restriction on the consumption of the high milk replacer group would restrict T_3 and T_4 even more severely. This was not considered practicable. Imposing a restriction equivalent to 0.20 kg/day then the expected live-weight gain would be as calculated from Table 2.

Table 2

Net Energy Supplied by Two Rations to Restrict Calves by 0.20 kg of Gain Per Day

Ration		Net Energy kJ/g	g of fresh/day	kJ NE supplied
T_3	Milk	16.62	400	6648
	Concentrates	6.64	146	969
	Total			7617
T_4	Milk	16.62	600	9972
	Concentrates	6.64	146	969
	Total			10941

The requirement of a 40 kg calf for maintenance and production = 7.13 and 10.71 MJ respectively.

Hence:

T_3 supplies Maintenance + 0.05 kg/day

T_4 supplies Maintenance + 0.35 kg/day

Second Approach

The calculation of live-weight gains of calves offered four levels of nutrition. The treatments considered were two levels of milk replacer offered once daily (600 and 400g/day) and two levels of concentrate feeding (ad libitum and restricted). These formed four treatments, viz:

T_1 = 600g milk replacer per day + concentrates ad libitum

T_2 = 400g milk replacer per day + concentrates ad libitum

T_3 = 400g milk replacer per day + concentrates restricted

T_4 = 600g milk replacer per day + concentrates restricted

The restriction in concentrate intake was calculated to be equal in terms of the supply of metabolizable energy, to the difference in metabolizable energy supplied by the two levels of milk replacer feeding.

Let the subscripts MR and C refer to the metabolizable energy supplied per gramme of milk replacer and concentrates respectively in MJ/day offered to the calves. The total ME supplied by the four treatments equals:-

$T_1 = H_{MR} + P_C$ where H = 600g milk replacer/day and P = ad libitum concentrate intake in g/day

$T_2 = 0.66\ H_{MR} + Y_C$ where 0.66 H = 400 g milk replacer/day and Y = ad libitum concentrate intake in g/day

$T_3 = 0.66\ H_{MR} + Y_C - Z_C$ where Z = restriction in concentrate intake in g/day

$T_4 = H_{MR} + Y_C - Z_C$

if Z_C equals ($H_{MR} - 0.66\ H_{MR} = 0.33\ H_{MR}$) then T_4 may be rearranged:

$T_4 = H_{MR} + Y_C - 0.33\ H_{MR}$

$= 0.66\ H_{MR} + Y_C$

A comparison of the ME intake from T_2 and T_4 shows that both treatments supply equivalent quantities of ME per day. Of the total ME intake supplied by both treatments, T_4 supplies a greater proportion of the total in the form of milk replacer compared with T_2 more ME is supplied by concentrates compared with T_4.

The difference in energy supplied by the two levels of milk replacer in terms of metabolizable energy equals:

(600 - 400) x 19.551 = 3910.2 kJ ME (Milk replacer = 95% DM)

21 kJ DE/g DM and DE x 0.98 = ME (see Appendix 1)

Concentrates have M/D of 13.4 MJ/kg DM at 85% DM = 11.39 MJ/g concentrates.

Hence:

$$\text{concentrate restriction} = \frac{3910.2}{11.39} = 343 \text{ g of concentrates}$$

Using the expected ad libitum concentrate intakes of 350 and 450 g/day for 40 kg calves consuming 600 and 400g/day of milk replacer (see previous discussion) then the total NE supplied by the rations is as shown in Table 3.

Table 3

Total NE Supplied by the Four Nutritional Treatments

Ration		Net Energy kJ/g	g of fresh/day	kJ NE supplied
T_1	Milk	16.62	600	9972
	Concentrates	6.64	350	2324
	Total			12296
T_2	Milk	16.62	400	6648
	Concentrates	6.64	450	2988
	Total			9636
T_3	Milk	16.62	400	6648
	Concentrates	6.64	107	710
	Total			7358
T_4	Milk	16.62	600	9972
	Concentrates	6.64	107	710
	Total			10682

From the NE requirement for maintenance and gain of a 40 kg calf of 7.13 and 10.71 MJ respectively the gains expected from the four treatments in Table 3 may be calculated:

T_1 supplies M + 0.48 kg/day

T_2 supplies M + 0.23 kg/day

T_3 supplies M + 0.02 kg/day

T_4 supplies M + 0.33 kg/day

APPENDIX 3

Example of the statistical analysis carried out on the performance data of the calves.

Weight gain per day from arrival to weaning, Spring'74.

A total of 119 values were analysed. Nine values were missing as a result of calf mortality. The daily weight gain of the calves was calculated from:

$$\frac{\text{weaning weight - arrival weight}}{\text{days from arrival to weaning}}$$

The analysis of variance was carried out as follows:-

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	Fratio	Significance level
House (H)	3	0.01302	0.00434	0.61	N.S.
Cells (D)	3	0.017285	0.05762	8.16	***
House x Cells	9	0.23270	0.02586	3.66	*
Milk (M)	1	0.12520	0.12520	17.73	***
Concentrates (C)	1	0.12654	0.12654	17.92	***
M x C	1	0.03419	0.03419	4.84	**
H x M	3	0.03805	0.01268	1.79	N.S.
H x C	3	0.02101	0.00700	0.99	N.S.
H x M x C	3	0.00257	0.00086	0.12	N.S.
D x M	3	0.00592	0.00197	0.28	N.S.
D x C	3	0.01224	0.00408	0.58	N.S.
D x M x C	3	0.04599	0.01529	2.17	N.S.
H x D x M	9	0.08423	0.00936	1.33	N.S.
H x D x C	9	0.02297	0.00255	0.36	N.S.
H x D x M x C	9	0.07708	0.00856	1.21	N.S.
Error	55	0.38844	0.00706		
Total	118	1.40290			

The values of the nine missing calves were estimated by a missing plot technique.

APPENDIX A

CONFORMATION

Individual Coefficients Obtained in the Linear Regression Analyses of Live-Weight Gain Versus Conformational Parameter

Period 1

		L.L.	S.E.	H.L.	S.E.	L.H.	S.E.	H.H.	S.E.
Heart Girth	c	-29.78	13.6	-57.33	12.3	-78.81	19.0	-87.06	10.9
	m	0.912	0.168	1.28	0.145	1.57	0.213	1.65	0.127
Hooks	c	-56.41	11.8	-48.87	15.4	-62.99	13.1	-48.33	10.5
	m	5.62	0.659	5.36	0.819	6.05	0.698	5.36	0.549
Stifle	c	-19.27	21.2	-43.68	10.0	-41.93	9.38	-56.75	15.0
	m	1.28	0.431	1.801	0.189	1.78	0.181	2.04	0.276
Withers	c	-71.28	31.0	-81.35	31.0	-104.13	27.9	-118.36	30.2
	m	1.55	0.418	1.76	0.411	2.03	0.368	2.26	0.396
		n = 20		n = 25		n = 26		n = 28	

CONFORMATION

Individual Coefficients Obtained in the Linear Regression Analyses of Live-Weight Gain Versus Conformational Parameter

Period 2

		L.L.	S.E.	H.L.	S.E.	L.H.	S.E.	H.H.	S.E.
Heart Girth	c	-106.32	19.6	-101.77	24.3	-122.46	22.1	-41.88	29.1
	m	1.912	0.223	1.858	0.257	2.107	±0.236	1.27	0.305
Hooks	c	-63.16	11.6	-69.86	19.6	-87.64	14.2	-30.55	19.3
	m	6.31	0.587	6.77	0.925	7.61	0.665	5.06	0.89
Stifle	c	-24.29	12.8	-19.04	25.6	-83.45	16.9	-5.35	25.0
	m	1.580	0.236	1.53	0.423	2.69	0.287	1.39	0.409
Withers	c	-78.68	37.1	-112.36	40.8	-211.55	45.8	-108.38	41.9
	m	1.79	0.476	2.304	0.505	3.55	0.568	2.29	0.512
		n = 19		n = 25		n = 24		n = 29	

CONFORMATION

Individual Coefficients Obtained in the Linear Regression Analyses of Live-Weight Gain Versus Conformational Parameter

Period 3

		L.L.	S.E.	H.L.	S.E.	L.H.	S.E.	H.H.	S.E.
Heart Girth	c	-82.74	30.4	-112.83	19.6	-178.9	17.4	-162.65	25.2
	m	1.64	0.305	2.01	0.189	2.65	0.167	2.501	0.238
Hooks	c	-112.7	27.7	-87.65	20.5	-117.96	21.2	-74.26	21.4
	m	8.68	1.24	7.65	0.854	8.90	0.878	7.205	0.875
Stifle	c	-50.9	19.1	-81.41	25.3	-66.91	29.9	-77.56	28.0
	m	2.177	0.315	2.75	0.393	2.60	0.475	2.75	0.430
Withers	c	-194.0	55.0	-96.23	49.7	-179.8	49.4	-157.59	52.7
	m	3.37	0.674	2.27	0.587	3.27	0.585	3.00	0.610
		n = 19		n = 25		n = 24		n = 29	

Section 5

Bibliography

Ackerman, R.A., Thomas, E.Q., Thayne, W.V. and Butcher, D.F., 1969. J. Dairy Sci. 52: 1869-1872.

Adam, T. 1965. Nutr. Abst. Rev. 35: 4, 1142.

Agriculture, 1971, 73: 323.

Alexander, G., Williams, D., 1968. J.Physiol. 198: 251-276.

Alexander, G., Bell, A.W. and Hales, J.R.S., 1973. J.Physiol. 234: 65-77

Alexander, G., Bonnett, J.W. and Gemmell, R.T., 1975. J.Physiol. 244: 223-234.

Alexander, R.H., 1969. Laboratory Practice. 18: No. 1

Amos, D.R., and Brink, D.R. 1977. J. Anim. Sci. 44: 1. 136-140.

Anderson, A.W., Barlott, P.J., 1973. Can. J. Anim. Sci. 53: 4. 767.

Ap-Solami, M.T.H. and Sinclair, K.B., 1977. Vet. Rec. 100: 93.

Appleman, R.D. and Owen, F.G., 1970. Transactions of the American Society of Agricultural Engineers. Paper No. 70: 355.

Appleman, R.D. and Owen, F.G., 1975. J.Dairy Sci. 58: 447-464.

Asai, T., 1973. Japanese J. of Vet. Sci. 35: 239-252.

Bailey, C.B., 1964. Can. J. Anim. Sci. 44: 68.

Bartlett, 1949, Biometrics, 5: 207.

Bell, A.W., Gardener, J.W. and Thompson, G.E., 1974. Br. J. Nutr. 32: 471.

Bianca, W. 1959. J.Agri. Sci. 52: 296.

Bianca, W. and Blaxter, K.L. 1961. Festschr, 8th int. tierzuchtkongr, Hamburg. 1: 113-147.

Blaxter, K.L. and Wood, W.A. 1951. Brit. J. Nutr. 51: 29-55.

Blaxter, K.L. 1961. Symposium on Energy Metabolism, E.A.A.P. Publication No. 10.

Blaxter, K.L., 1962. Energy Metabolism of Ruminants. Hutchison Scientific and Technical Press, London. pg. 198.

Blaxter, K.L., Joyce, J.P., Wainman, F.W., 1963. Nature. 198: 4885-1115.

Blaxter, K.L., 1967. The Energy Metabolism of Ruminants, 2nd. ed. Hutchinson, London.

Bourne, F.J. 1974. British Cattle Veterinary Association, Stoneleigh, May, 1974.

Burt, A.W.A., 1968. Anim. Prod. 10: 113-116.

Butterfield, R.M. and Berg, R.A., 1966a. Res. Vet. Sci. 7: 326.

Butterfield, R.M. and Berg, R.A., 1966b. Proc. Aust. Soc. Anim. Prod. 6: 298.

Butterfield, R.M. and Johnson, E.R., 1968. Growth and Development of Ruminals. Proceedings of the 14th Nottingham Easter School.

Chestnutt, D.M.B., Marsh, R., Wilson, J.G., Stewart, T.A., McCullough, T.A. and Callain, T., 1975. Anim. Prod. 21: 109-119.

Christopherson, R.J. and Milligan, L.P., 1973. Can. J. Anim. Sci. 53: 4. 767.

Christopherson, R.J., 1976. Can. J. Anim. Sci. 56: 201-212.

Clench, B.F., 1972. Agriculture. 79: 143.

Coop, J.E., 1962. J.Agric. Sci. 58: 182.

Crabtree, R.M., Kay, M. and Webster, A.J.F., 1976. Anim. Prod. 22. 1. 135-164.

Davis, A.V., Woodward, R.S. and Rusoff, L.L., 1970. J.Dairy Sci. 53: 674.

Demchenko, P.V., 1969. Energy Metabolism of Farm Animals. E.A.A.P. Publication No. 12.

Dickerson, J.W.T. and McConee, R.A., 1961. Br. J. Nutr. 15: 567.

Draper, N.R. and Smith, H. 1966, in Applied Regression Analysis. John Whyley and Sons. pp. 104-127.

Drew, Bridget, 1975. Agricultural Development and Advisory Service Development Report. South East Region Summary of Experiments, 1975.

Drori, D., Levy, D., Folman, Y, and Holzer, Z, 1974. J. Anim. Sci. 38: 3. 654-660.

Edwards, R.A., 1977. Proceedings of the 62nd British Society of Animal Production. Winter Meeting Paper 25.

Van Es, A.J.H, Nyjkamp, H.J., Van Weerden, E.J. and Van Hellemond, K.K., 1969. E.A.A.P. Publication No. 12. Ed. Blaxter, K.L., Kielanowski, J. and Grota Thorbek.

Everitt, G.C. 1972, Proc. N.Z. Soc. Anim. Prod. 32: 20-25.

Everitt, G.C., Evans, S.T. and Franks, M., 1969. Proc. N.Z. Soc. Anim. Prod. 29: 147-163.

Fairweather, L., Sliwa Kipling, I.A., 1968. A.J. Metric Handbook. The Architectural Press Ltd.

Feenstra, A., 1973. From Buildings Association Journal, pg. 42.

Fisher, E.W., 1972, J. Dairy Sci. 55: 703.

Fisher, A.V., 1975. Livestock Prod. Sci. 2: 357-366.

Fisher, E.W. and Martinez, A.A., 1975, in Perinatal Ill Health in Calves. Ed. J.M. Rutter. Commission of the European Communities.

Forbes, E.B., 1933. J.Agric. Res. 46. 753-770.

Forbes, T.J. and Robinson, J.J. 1969. Anim. Prod. 11: 389.

Fox, D.G., Johnson, R.R., Preston, R.L., Docherty, T.R. and Klosterman, E.W., 1972. J.Anim. Sci. 34: 2. 310-318.

Fuller, M.F. and Cadenhead, A., 1969. Energy Metabolism of Farm Animals. E.A.A.P. Publication, No. 12.

Garrill, A.D.L. and Nicholson, J.W.G., 1969. Can. J. Anim. Sci. 49: 305-313.

Gay, C.C., Anderson, N., Fisher, E.W. and McEwan, A.D., 1965. Vet. Rec. 77. No. 5. 149.

Gay, C.C., Fisher, E.W. and McEwan, 1965b. Vet. Rec. 77. No. 34. 994.

Gemmell, R.T., Bell, A.W. and Alexander, G. American J. Anat. 1972. 133: 2. 143-146.

Godfrey, N.W. 1961. J. Agric. Sci. 57: 177.

Godfrey, N.W. 1961. J. Agric. Sci. Cam. 57: 173-175.

Gonzalez-Kimones, R., Blaxter, K.L., 1962. Brit. J. Nutr. 16: 199.

Graham, N. McC. 1964. Aust. J. Agric. Res. 15: 113-126.

Hardy, R., 1972. Experimental Husbandry Ministry of Agriculture, Fisheries and Food. 22: 89.

Hartman, D.A., Everett, R.W., Slack, S.T. and Warner, R.G. 1974. J.Dairy Sci. 57: 576-578.

Hironaka, R. and Konub, G.C. 1973. Can. J. Anim. Sci. 53: 709-715.

Hi Shin Kang and Leibholz, J., 1973. Anim. Prod. 16: 195-203.

Hodgson, J. 1971a, Anim. Prod. 13: 15-24.

Hodgson, J. 1971b, Anim. Prod. 13: 25-36.

Hodgson, J. 1971c, Anim. Prod. 13: 449.

Hodgson, J. 1971d, Anim. Prod. 13: 581-592.

Hodgson, J. 1971e, Anim. Prod. 13: 593-597.

Holmes, C.W., McLean, N.R., 1974. Proc. N.Z. Soc. Anim. Prod. 34: 132.

Holmes, C.W. and Davey, A.W.F., 1976. Anim. Prod. 23: 45-53.

Huber, J.T., 1969. J. Dairy Sci. 52: 1303-1315.

Irwin, V.C.R., 1974a, Vet. Rec. 94: 105-106.

Irwin, V.C.R., 1974b, Vet. Rec. 94: 406.

Johansson and Hildeman, S.E., 1954. Anim. Breed Abstr. 22: 1.

Johnson, F.T.C. and Elliot, R.C., 1972a, Rhod. J. Agric. Res. 10: 119.

Johnson, P.T.C. and Elliot, R.C., 1972b, Rhod. J. Agric. Res. 10: 125.

Johnson, P.T.C. and Elliot, R.C., 1972c, Rhod. J. Agric. Res. 10: 135.

Jones, M.E., Hugh, 1972. Ministry of Agriculture, Fisheries and Food, Paper read at the World Association for Buiatrics Congress, London, 31st July.

Jorgenson, L.J., Jorgenson, N.A., Schingoethe, D.J. and Owens, M.J., 1969. J. Dairy Sci. 52: 932.

Kennedy, P.M., Christopherson, R.J. and Milligan, L.P. 1976. Br. J. Nutr. 36: 231.

Kermack, K.A. and Haldane, J.B.S., 1950. Biometrika, 37: 30.

Kesler, E.M., Fonning, M. and Knodte, B. 1951. J. Anim. Sci. 10: 969.

Kilkenny, J.B. and Rutter, J.M., 1975. Perinatal Ill Health in Calves. Ed. J.M. Rutter, Commission of the European Communities.

Laird, R., 1954. M.Sc. Thesis, Ohio State University.

Lambourne, L.J., 1962. Proc. N.Z. Soc. of Anim. Prod. 21: 92.

Langlands, J.P., Corbett, J.L., McDonald, I. and Fuller, J.D., 1963. Anim. Prod. Sci. 1: 1-9.

Large, R.V., 1964. Anim. Prod. 6: 169-178.

Leaver, J.D. and Yarrow, N.H., 1972a. Anim. Prod. 14: 155-159.

Leaver, J.D., and Yarrow, N.H., 1972b. Anim. Prod. 14: 161-165.

Ledger, H.P., 1973. Proceedings of the III World Conference of Animal Production. R.L. Reid, Sydney University Press.

Leibholtz, Jane, 1975. Animal Prod. 20: 93-100.

Leibholtz, Jane, 1975. Aust. J. Agric. Res. 26: 623-633.

Leibholtz, Jane, 1975. Aust. J. Agric. Res. 26: 1081-91.

Levy, D., Folman, Y., Holzer, Z., and Droxi, D., 1971. J. Anim. Sci. 33: 5, 1078-1085.

Lineweaver, J.A. and Hafez, E.S.E., 1969. J. Dairy Sci. 52: 2001-2006.

Lodge, G.A. and Lister, E.E. 1973. Can. J. Anim. Sci. 53: 307-316.

Logan, E.F. and Penhale, W.J., 1971. Vet. Rec. 89: 628-632.

Logan, E.F., Penhale, W.J. and Jones, R.A., 1972. Res. Vet. Sci. 1972. 14: 394-397.

Logan, E.F. 1974. Vet. Rec. 94: 367-370.

Lonsdale, C.R. and Taylor, J.C. 1969. J. Agric. Sci. Camb. 73: 483-488.

Martig, J., Ross, P.H., Nicolet, J. and Steck, F. 1976. Livestock Production Sci. 3: 285-294.

Martin, S.W., Swabe, C.W. and Franti, C.E. 1975. Amer. J. Vet. Res. 36: 8, 1099-1114.

McEwan, A.D., Fisher, E.W., Selman, I.E. and Penhale, W.J., 1970. Clin. Chim. Acta 27, 155-163.

McEwan, D., Jenkinson, Noble, R.C., Thompson, G.E., 1968. J. Physiol. 195: 639.

Meuler, U. Ter, Molner, S. and Gunther, K.D. 1975. Zeitschrift für Tierernährungund, Futter Mittelbunde 35: 5, 228-242.

Milligan, J.D. and Grieve, C.M. 1970. Can. J. Anim, Sci. 50: 147-155.

Mitchell, C.D., 1972a, Farm Building Research and Development Studies, 2: 3-19.

Mitchell, C.D., 1972b, Farm Building Research and Development Studies, 3: 19-39.

Mitchell, C.D. and Broadbent, P.J. 1973. Anim. Prod. 17: 245-256.

Mitchell, C.D. 1976. Calf Housing Handbook, Scottish Farm Buildings Investigation Unit. Scottaspress Publishers Limited, Aberdeen.

Mitchell, J.H.L. 1972. J.Agric. Sci. Camb. 78: 417-423.

Moose, M.C., Ross, C.V. and Pfander, W.H., 1969. J.Anim. Sci. 29: 619.

Morgan, J.H.L., 1972. J.Agric. Sci. Camb. 78: 417-423.

Mound, B.A., 1971. Agricultural Development and Advisory Service, Drayton Report.

Mount, 1974. Heat Loss from Animals and Man. Proceedings of the 20th Easter School in Agricultural Science, University of Nottingham 1973.

Mullen, P.A., 1964. Animal Breeding Abstracts. 33: 3. 387.

Murley, W.R. and Calvahouse, E.W. 1958. J. Dairy Sci. 41: 977.

Neese, K.R., and Kirchgessner, M. 1975. Zuchtungskunde 47 (3) 207-217.

Olbrich, S.E., Marts, F.A., Johnson, H.D., Phillips, S.W., Lippincott, A.C. and Hilderbrand, E.S., 1972. J. Anim. Sci. 34: 64.

Osborne, A.D., 1975 in Perinatal Ill-Health in Calves. Commission of the European Communities, First Seminar on Pathology.

Owen, F, Plum, M. and Harris, L., 1965. J. Dairy Sci. 48: 824.

Pettyjohn, J.S., Everett, J.P. Jr. and MacKrie, R.D., 1963. J. Dairy Sci. 46: 710-714.

Penhale, W.J., Logan, E.F., Selman, I.E., Fisher, E.W. and McEwan, A.D. 1973. Ann. Rech. Veter. 4: 235.

Pointer, C.G. 1969. Paper given to the A.D.A. Conference, Reading. Feb. 1970.

Porter, J.W.G. 1969. Proc. Nutr. Soc. 28: 115.

Prenatal and Postnatal Mortality in Cattle, 1968. Publication 1685. National Academy of Sciences, Washington, D.C.

Radcliffe, J.C. and White, B.R. 1972. Proc. Aust. Soc. Anim. Prod. 9: 309.

Randall, E.M. and Svennack, K.P. 1975. Experimental Husbandry. 28: 44-52.

Rowen, A.M. 1967. Scientific Information Published by the National Renderers Association.

Rowen, A.M. 1972. Proceedings of the II International Milk Replacer Symposium. 19-30.

Raven, A.M. 1972. J. Sci. Fd. Agric. 23: 517-526.

Reardon, T.F. and Everitt, G.C. 1972. N.Z. Soc. Anim. Prod. 32: 26-38.

Roy, J.H.B., 1964. Vet. Record, 76: 511.

Roy, J.H.B., 1969. Proc. Nutr. Soc. 28: 161.

Roy, J.H.B., Stobo, I.J.F., Gaston, H.J., Gandorton, P. and Shotton, S.M. 1971. Brit. J. Nutr. 26: 363.

Roy, J.H.B., Stobo, I.J.F., Gaston, H.J., Gandorton, P., Shotton, S.M. and Thompson, S.Y., 1971. Br. J. Nutr. 26: 353.

Roy, J.H.B. and Tennouth, 1972. Proc. Nutr. Soc. 31: 53.

Roy, J.H.B., and Stobo, I.J.F., 1974. Digestion and Metabolism in the Ruminant, Proc. IV. Int. Symp. on Ruminant Physiology Ed. I.W. McDonald and A.C.I. Warner.

Sainsbury, D.W.B., 1967. Animal Health and Housing, 243 Bailliere, Tindall and Cassell.

Santhirasegaram, K. and Watts, J.I. 1970. Proc. Aust. Soc. Anim. Prod. 8: 258.

Saubidet, C., Lopez and Verde, L.S. 1976. Anim. Prod. 22: 61-69.

Seebeck, R.M., 1973. J. Agric. Sci. Camb. 80: 411-423.

Seebeck, R.M. and Tulloh, N.M. 1968a. Aust. J. Agric. Res. 19: 477-95.

Seebeck, R.M. and Tulloh, N.M. 1968b. Aust. J. Agric. Res. 19: 673-88.

Slee, J.J. 1972. J. Physiol. 227: 51-70.

Slee, J.J. 1974. Anim. Prod. 19: 201-210.

Smith, E.H. 1973. in Proc. Nat. Dairy Housing Conf. Spec. Pub. 01-73 Amer. Soc. Agr. Eng. 154.

Smith, H. Williams 1962. J. of Pathology and Bacteriology. 84: 147-168.

Smith, R.H. and McAllan, A.B. 1974. Br. J. Nutr. 31: 27.

Snedecor, G.W. and Cochran, W.G. 1972. in Statistical Methods. The Iowa State University Press.

Solovev, F.A. 1955. Veterinariya Moscow. 32: 11. 78-83.

Spoicher, J.A. and Hopp, 1973. J. Amer. Vet. and Med. Association 162: 6. 463-466.

Srinivasan, G. and Martin, T.G. 1974. J. Anim. Sci. 39: 5. 966.

Steel, R.G.D. and Torrie, J.H. 1960. Principles and Procedures in Statistics. McGraw-Hill Book Co. Inc. New York. 366-387.

Stiles, H.P., Grieve, D.G., Butler, D.G., Willoughby, R.A. 1974. J.Anim. Sci. 54: 73-78.

Stobo, I.J.F., Roy, J.H.B. and Gaston, H.J. 1966. Br. J. Nutr. 20: 171.

Stobo, I.J.F., Roy, J.H.B. and Gaston, H.J. 1966. Br. J. Nutr. 20: 189.

Stott, G.H., Wierama, F., Menoloo, B.E. and Radwanski, F.R. 1976. J.Dairy Sci. 59: 7.

Strickland, M.J. 1968. Exptl. Husbandry. 17: 1.

Taylor, St. C.S. 1962. Anim. Prod. 4: 1. 144.

Taylor, St. C.S. 1963. Anim. Prod. 5: 1. 105.

Thomas, L.H. 1973. Vet. Record. 93: 384-388.

Thompson, G.E. and Clough, D.P. 1972. Quarterly Journal of Experimental Physiology. 57: 192-198.

Thompson, G.E. and Boll, A.W. 1976. Biol. of the Neonate. 810.

Touchberry, R.W. and Lunch, J.C. 1950. J. Dairy Sci. 33: 72-80.

Turner, P.J. 1974. High Mowthorpe Farm Review Agricultural Development and Advisory Service.

Vermorel, M., Bouvier, J.C., Thuvend, P. and Toulec, R. 1974. E.A.A.P. Publication No. 14. ed. K.H. Menke, H.J. Lentzsch. and J.R. Reichl.

Vet. Record 1964. 76. No. 41. 1139-1143.

Wardrop, I.D. 1966. Aust. J. Agric. Res. 17: 375-85.

Warner, R.G., Flatt, W.P., 1965. Physiology of Digestion in the Ruminant. Ed. R.W. Dougherty Butterworths.

Warren, W.P., Marts, F.A., Asay, K.H., Hildebrand, E.S., Payne, C.G. and Vogt, J.R. 1974. J. Anim. Sci. 39: 93.

Watt, B.K. and Merrill, 1963. Composition of Foods. Agricultural Handbook No. 8 Agriculture Research Service United States Dept. of Agriculture.

Watt, J.G. 1965. Vet. Record. 77 : 49. 1974.

Webster, A.J.F., Hicks, A.M. and Hays, F.L., 1969. Can. J. Physiol. and Pharmacy. 47: 553-562.

Webster, A.J.F., Chlumecky, J. and Young, B.A. 1970. Can. J. Anim. Sci. 50: 89-100.

Webster, A.J.F. 1974. In Environmental Physiology Edited by Robertshaw. Butterworths University Park Press.

Webster, A.J.F. 1974. Heat Loss from Animals and Man. Proceedings of the 20th Easter School in Agricultural Science, University of Nottingham, 1973.

Webster, A.J.F., Brockway, J.M. and Smith, J.S. 1974. Anim. Prod. 127-139.

Webster, A.J.F., Gordon, J.G. and Smith, J.S. 1976. Anim. Prod. 23: 35-42.

Westra, 1975. M.Sc. Thesis, University of Alberta.

White, B.R. and Radcliffe, J.C. 1970. Proc. Aust. Soc. Anim, Prod. 8: 247.

Wickes, R.B., White, B.R., Lewis, D.H. and Radcliffe, J.C. 1972. Proc. Aust. Soc. Anim. Prod. 9.

Widdowson, E.M. and McCance, R.A. 1960. Proc. R. Soc. B. 152: 188.

Widdowson, E.M. 1968. Growth and Development of Mammals, Proceedings of the 14th Easter School in Agricultural Science. G.A.Lodge and G.E. Lamming, Butterworth.

Williams, E.J. 1959. Regression Analysis 198. John Wiley and Sons, New York and London.

Williams, P.P. and Dinusson, W.E. 1972. J. Anim. Sci. 34: 469.

Williams Smith, H. 1975. in Perinatal Ill Health in Calves. Ed. J.M. Rutter. Proceedings of the first seminar in Pathology 1975. C.E.C. programme of co-ordination of research in beef production.

Wood, A.S., Bayley, H.S. and Macleod, G.K. 1971. J. Dairy Sci. 54: 405.

Wood, T.B. and Capstick, J.W. 1926. J. Agric. Sci. 16: 325.

Young, B.A. and Christopherson, R.J. 1974. Proc. of the International Livestock Environmental Symposium. American Society of Agricultural Engineers. 75.

Young, B.A. 1975. Can. J. Anim. Sci. 55: 619-625.