NUTRITION OF THE LACTATING BEEF COW

by

Stuart H. Somerville

A dissertation submitted to the University of Edinburgh
in fulfilment of the requirements for the
degree of Doctor of Philosophy.

Edinburgh June 1977

DECLARATION

This thesis was composed by the undersigned and is a report of the work undertaken by him on an original line of research.

All sources of information are shown in the text and listed in the Bibliography, and all assistance given is indicated and acknowledged.

None of the work reported has been presented for any other degree or professional qualification.

CONTENTS

LIST OF DIAGRAMS AND FIGURES APPEARING IN TEXT

Page No.

ACKNOWLEDGEMENTS

I am indebted to the Department of Agriculture and Fisheries for Scotland for the award of a Post-Graduate Studentship.

I wish to express my sincere gratitude to the many people who assisted me in the preparation of this thesis;

Professor F.W.H. Elsley, my supervisor, for making available the necessary resources and facilities and for his general advice and assistance;

Dr. B.G. Lowman who suggested the original line of research and for his invaluable help and encouragement throughout;

Dr. J.H.D. Prescott, and his predecessor Mr. K.V. Runcie, and the members of the Animal Production Advisory and Development Department for their assistance with both the care of the experimental animals and the preparation of this thesis;

Dr. R.A. Edwards and the staff of the Advisory Nutrition Department of The Edinburgh School of Agriculture for carrying out the analyses of the feeds and milks, and for general guidance given;

Mr. G. Jolly and the staff of the Agricultural Research Council Unit of Statistics for their guidance, advice and assistance with statistical analyses;

Mr. A. Whithorn and the staff of the Computer Services Department of The Edinburgh School of Agriculture for their assistance with data preparation;

My late brother-in-law, Mr. A. Maclean, and Mr. R.A. Finlayson who prepared all the diagrams and figures;

My mother and my wife for their patience, help and encouragement, and Mrs. F. Anderson who typed the final manuscript.

THESIS SUMMARY

The primary purpose of this thesis was to examine the evidence relating to the effect of nutrition on the performance of single-suckled beef cows and to determine experimentally the response of autumn-calving Hereford cross British Friesian cows to three levels of energy intake during lactation.

The different methods available for measuring the milk production of beef cows were discussed on the basis of information reported in the literature and two of the methods, machine-milking twice a day and a calf-suckling technique compared experimentally. It was concluded that the calf-suckling technique described is the more reliable and precise method of measuring milk production.

Two experiments were reported in each of which 36 beef cows were offered individually either 175 per cent of their estimated energy requirement for maintenance (high), 125 per cent (medium), or 90 per cent (low), during the first 150 days of lactation. The rations offered consisted of grass silage and a barley-based concentrate supplement.

The estimated 150-day cumulative milk yields of beef cows in their second lactation, measured by a calf-suckling technique, were 1385 kg, 1274 kg and 1197 kg ($P < 0.01$) on the high, medium and low planes of nutrition respectively. The corresponding figures for live-weight loss between parturition and 150 days *post partum* were 31 kg, 87 kg and 139 kg ($P < 0.001$). The results demonstrated that energy deficient beef cows will attempt to sustain milk production by mobilising body reserves. It was also demonstrated that the growth rate of a suckled calf is sensitive to a reduction in milk intake during its first 150 days of life, but the weaning weights of autumn-born calves appeared unaffected by the plane of nutrition received by their dams during the winter.

The implications of the results and areas of future research were discussed.

GENERAL INTRODUCTION

In any discussion of the relative efficiencies of different types of livestock production, reference is usually made to the inefficiency of production from single-suckled beef cows. The main contributory factor is the low average annual output of less than one weaned calf per cow relative to the high input of feed required to maintain the suckler cow throughout the year. It has been estimated, for example, that the suckler cow may consume between 85 and 93 per cent of the total energy required to produce a weaned calf (Baker and Barker 1972).

Many suckler cows graze hill and upland areas during the summer months and these areas have limited potential for food production. Apart from suckler cows, usually hill and upland areas can only be utilised for sheep or deer production which are also inefficient methods of producing food for human consumption. During the winter months, however, beef cows are largely dependent on feed supplies produced on land which could be utilised for more efficient forms of animal or crop production.

The amount of feed required to maintain a suckler cow, particularly during the winter, also has a major impact on the profitability of suckled calf production. The Meat and Livestock Commission (MLC) annually record the physical and financial performance of over 400 suckler herds distributed throughout the United Kingdom. Their records (eg MLC 1975) reveal that, on average, the cost of feeding a suckler cow during the winter accounts for more than 50 per cent of the total variable costs of suckled calf production.

The annual physical output of a suckler herd, ie the total weight of weaned calf produced, is a function of the reproductive performance of the cows and the mortality, birth-weight, age at weaning and weight gain between birth and weaning of the calves. Quantitative data are required on the effect of nutrition of the cow on these parameters measured over a number of successive production cycles, because, despite its biological and economic significance for suckled calf production, the nutrition of the suckler cow has been the subject of very little detailed investigation.

Most of the information specifically relating to nutrition of the beef cow has been derived from investigations undertaken in Australasia and North America, where in the past, suckled calf production has assumed a greater economic and political significance than in the United Kingdom. Many of these studies lacked the precision necessary to characterise accurately the relationship between nutrition of the cow and the physical and economic performance of suckled calf production. In addition, it may be inappropriate to apply, in this country, feeding and management recommendations based on these studies because the genotypes involved, environmental conditions, feeds utilised and systems of suckled calf production can differ markedly from those which obtain in the United Kingdom.

Studies of dairy cow nutrition have probably had the most significant influence on the current feed recommendations for beef cows. At the present time, the estimated nutrient requirements of beef cows used in ration formulation are based on the requirements considered appropriate for dairy cows which have been reported by Evans (1960), The Agricultural Research Council (ARC 1965) and the Ministry of Agriculture Fisheries and Food (MAFF 1975). These nutrient requirements have been derived from numerous feeding trials involving dairy cows and the evidence has been reviewed by Blaxter (1956), Burt (1957), Broster (1971, 1972a, 1972b) and Wiktorsson (1971) among others. The dairy cows used in these studies had higher feed intakes and substantially higher milk yields than the limited experimental evidence suggests can be expected from beef cows. Consequently, the response of beef cows to different planes of nutrition may differ from the response recorded in dairy cows. Moreover, with beef cows, the effect of plane of nutrition on milk yield is not the main issue. The important criteria are, a) the response of the suckled calf in terms of its health, growth rate, and consumption of supplementary feed to any differences in the quantity and/or quality of the milk it consumes, as a result of a change in the plane of nutrition of the dam; and b) the response of the cow in terms of its reproductive performance.

Even if experimentation demonstrates that the nutrient requirements assumed for dairy cows are appropriate for beef cows, when suitably modified to allow for differences in live-weight and milk output, their practical application as feeding standards has definite limitations. In order to apply these standards to lactating cows, knowledge is required of the quantity of milk produced and its composition. In dairy cows, the measurement of milk yield and quality presents little difficulty in practice. The suckled calf producer, however, has no means of assessing the milk output of beef cows in practice.

Furthermore, unlike many dairy cows, beef cows are rarely offered sufficient feed to supply their estimated nutrient requirements during the winter. Systems of suckled calf production have been developed which exploit the capacity of beef cows to store surplus energy in the form of body reserves of fat. The cow is allowed to accumulate these reserves during the grazing season at relatively low cost. During the winter the reserves are depleted to supply a proportion of the cow's energy requirement, thus permitting a reduction in the amount and cost of winter feed required. It is necessary to take account of the annual repletion and depletion of body reserves when assessing the nutrient requirements of beef cows.

Since there was little information available relating to beef cow nutrition, and since much of the existing information was considered inapplicable, in 1970 The Edinburgh School of Agriculture initiated a research programme designed to investigate nutrition of the autumn-calving, single-suckled beef cow. A specific objective of the programme was to provide information on which to base feeding and management recommendations for suckler herds.

The lack of information on the nutritional requirements of beef cows has been recognised by other workers in the United Kingdom. In Ireland, Drennan has investigated the effect of summer stocking rate (Drennan 1971) and plane of nutrition in late pregnancy (Drennan 1974) on the performance of spring-calving beef cows. Workers at the North of Scotland College of Agriculture have evaluated energy and protein supplements for straw-based diets for winter feeding beef cows (Ball, Broadbent and Dodsworth 1971) and studied the effects of underfeeding autumn- and winter-calving beef cows (Economides *et al* 1973; Miller, Economides, Trigg and Topps 1974; Topps, Economides and Miller 1974). Baker and his co-workers at the Grassland Research Institute have examined the relationship between cow size and the efficiency of suckled calf production (Baker and Barker 1972) and the effect of level of milk consumption on the herbage intake and growth rate of spring-born calves (Le Du and Baker 1974, 1975). Additionally, group-feeding trials with beef cows are undertaken by the Agricultural Development and Advisory Service on experimental husbandry farms (eg Powell 1974).

In this thesis, two experiments undertaken at The Edinburgh School of Agriculture are reported. As these formed part of a series of experiments a brief description of the previous work is appropriate at this stage.

The first major investigation undertaken at Edinburgh involved a traditional crossbred suckler cow, the Scottish Blue-Grey, which is the product of a mating between a White Shorthorn bull and a Galloway cow. The purpose of the investigation was to examine the response of autumn-calving Blue-Grey cows to three planes of nutrition during lactation. Twenty-four individually fed cows were involved in the investigation which was conducted in three successive winters.

A preliminary study had revealed considerable variation in the milk yield and live-weight changes of Blue-Grey cows at similar levels of nutrition. Therefore, a changeover design was used in the main investigation with the influence of nutrition assessed on a within cow basis. Milk yields were measured by machine-milking the cows twice daily and their calves were removed at birth and reared separately. This method of milking was adopted for two main reasons. Firstly, machine-milking facilitated accurate measurement of yield and representative sampling for the determination of milk composition, and secondly, the influence of such factors as the sex, breed and birth-weight of the calf on the responses recorded in the cows was removed.

Throughout this thesis reference will be made to the "Blue-Grey investigation", the results of which have not yet been published.

During the course of the Blue-Grey investigation the importance of changes in the level of a cow's body reserves of fat and the limitations of live-weight as a criterion of the response of a cow to different planes of nutrition became apparent. While live-weight changes are a crude measure of changes in the level of a cow's body reserves, the information provided is of limited value particularly when the changes of different cows are compared. The implications of a 50 kg weight loss in a 500 kg cow with adequate body reserves are different from a 50 kg weight loss in a 500 kg cow with low levels of body reserves. The techniques available for measuring the body condition of cows were considered and, because none of the methods appeared suitable, a method of describing the body condition of cattle was developed. The method has been reported by Lowman, Scott and Somerville (1973).

On completion of the Blue-Grey investigation, a second study was initiated. This study was designed to investigate the response of autumn-calving Hereford cross British Friesian cows to three planes of nutrition during lactation.

A criticism levelled at the Blue-Grey investigation was that the response to different planes of nutrition recorded in these machine-milked cows may have been at variance with the response that would have been recorded had the cows been suckling calves as in commercial practice. This led to a reconsideration of the available methods of measuring the milk yield of beef cows, and in this thesis the various methods are reviewed.

One method (the calf-suckling technique) involves the weighing of a calf before and after suckling to determine its milk intake, and hence the milk production of the dam. This technique satisfies the requirement of allowing the cows to be maintained under conditions more closely resembling commercial practice, while still enabling the measurement of milk production. A calf-suckling technique was developed following observations of the natural suckling frequency of beef cows (see Appendix I) and a preliminary investigation of the problems associated with this method of measuring milk production.

In the first of the two experiments described in this thesis, the response of machine-milked and calf-suckling beef cows was compared at three levels of nutrition during lactation. The comparison of the two methods of milking was secondary, however, and the primary purpose of the experiment was to provide information on the influence of nutrition on the performance of lactating beef cows.

In the second experiment the milk yields of the cows were measured exclusively by a calf-suckling technique for reasons which will be discussed in a subsequent section.

The two experiments to be reported represent the first and second "year" of a three-year experiment. Eventually the three years' data will be combined and analysed and evaluated as a single investigation, but in this thesis the two experiments will be described separately.

In addition to the main investigation, a concurrent study was undertaken which involved a small group of cows, older than those involved in the main investigation and with lower levels of body reserves at calving at the beginning of the first experimental period. These older cows were also involved in a study of the two methods of milking and the effect of nutrition during lactation on the performance of calf-suckling beef cows. The results have been reported

(Somerville, Lowman and Edwards 1976), and submitted for publication. The complete manuscript is reproduced in Appendix 2.

To date, the research work at Edinburgh has been concerned exclusively with nutrition of suckler cows during lactation. Ideally, information is required on the effect of nutrition over the lifetime of the cow, but as has been pointed out by Broster (1972a), the difficulties encountered in such studies are considerable. It is recognised, however, that the influence of nutrition during lactation will be affected by the previous nutrition of the cow from the point in time it was conceived to the parturition preceding the lactation under consideration. Unfortunately, the deficiencies of relatively short-term nutritional studies have to be accepted when the available resources are limited. Future work at Edinburgh will examine the influence of nutrition in late lactation and prior to parturition and be concerned with the interactions between levels of nutrition at different stages of the reproductive cycle, but this thesis is concerned only with nutrition during lactation. Furthermore, a change-over design was adopted in the experiments and thus it was not possible to examine the effects of the different levels of nutrition applied during successive lactations in all cows. The limitations imposed by a changeover design and the reasons for adopting this type of experimental design are discussed in Appendix 3.

Suckler cow nutrition has only recently received the attention of research workers in this country and is a relatively new area of research. In any new area of research in animal production, problems arise which require the development of new experimental techniques, although in most instances existing techniques can be adapted from other areas of animal research. The adaptation of the sheep condition scoring system for cattle is a case in point. Many technical problems were encountered in the research programme undertaken at Edinburgh. A discussion of the problems involved in suckler cow experimentation, and an appraisal of the techniques employed in the two experiments are presented in Appendix 3.

Priority was given to the influence of nutrition during lactation in the research programme because the early part of lactation was considered to be the most important phase of the production cycle of a beef cow. It is during this period that the suckled calf is largely dependent for maintenance and growth on milk produced by the dam. Furthermore, the cow has to conceive for a subsequent cycle during early lactation if an annual production cycle is to be maintained.

The limited amount of published data relating to the milk yield of beef cows and on nutritional and non-nutritional factors affecting the lactation performance of beef cows are reviewed in this thesis. No attempt has been made to review in detail the considerable amount of data relating to the influence of nutrition on the lactation performance of dairy cows. There are several excellent reviews available on the subject (see Blaxter 1949, 1956; Burt 1956, 1957; Rook 1961; Balch 1972; Broster 1971, 1972a, 1972b), although much of the data discussed are not relevant to beef cows. The information relating to the influence of nutrition on the fertility of beef cows is briefly reviewed.

To summarise - two of a series of experiments are reported. Both experiments were designed to investigate the response of autumn-calving suckler cows to three planes of nutrition during lactation. Considerable emphasis is placed on the experimental techniques involved, particularly the development of a suitable technique for measuring the milk yield of beef cows. The literature relating to methods of measuring the milk yield of beef cows, the yield and composition of milk produced by beef cows, and the effect of nutrition on the performance of beef cows is reviewed. The experimental results are discussed in relation to their implications for commercial suckled calf production.

REVIEW OF LITERATURE

1. METHODS OF MEASURING THE MILK PRODUCTION OF BEEF COWS

INTRODUCTION

A number of different methods have been devised to measure the milk production of beef cows. These methods can be classified under the following headings although the precise procedures adopted by different workers have varied in detail:

1.1 The calf-suckling technique
1.2 Machine or hand-milking
1.3 The oxytocin technique
1.4 Estimation from calf body-water turnover
1.5 Estimation from calf growth rate

Few authors have commented on the possible sources of error associated with the different methods, but a limited number of experiments have been reported in which two or more methods of measuring the milk production of beef cows were compared. These studies provide valuable information on the levels of milk production recorded using different methods of measurement.

In this section the five methods used to measure the milk production of beef cows are described and their relative merits discussed. Since measuring the milk production of non-dairy breeds of sheep has presented essentially the same problem, reference is made to the literature relating to methods of measuring the milk production of ewes.

To prevent any confusion arising from the terminology employed in this and subsequent sections, it is necessary to define the terms "beef cow" and "suckler cow". In this thesis the terms are considered synonymous and a beef or suckler cow is defined as a cow maintained solely for the production of a suckled calf. Since pure-bred dairy cows are rarely used for suckled calf production, except when multiple suckling systems are employed, most beef/suckler cows are either of a pure beef breed or are the product of a cross between two beef breeds, or between a beef breed and a dairy breed.

1.1 THE CALF-SUCKLING TECHNIQUE

Description

The calf-suckling technique has been the most frequently used method of measuring the milk production of beef cows. Essentially, the method involves weighing a calf before and after suckling, after a period of separation from its dam. The difference between the pre- and post-suckling weights is assumed to represent the weight of milk consumed by the calf, and hence the milk production of the dam.

The precise procedure adopted by different workers has varied in detail but usually daily milk yield has been measured at either weekly or monthly intervals by summing the milk intakes of the calf determined at two or three sucklings during a 24 hr period. Walker and Pos (1963), Totusek, Arnett, Holland and Whiteman (1973) and Economides *et al* (1973) segregated calves from their dams during the period of lactation under study except when suckling was permitted. Walker and Pos permitted cows to suckle their calves at 05.00 hr and 15.30 hr and recorded milk intakes at every suckling. Totusek *et al* permitted suckling at 06.00 hr and 18.00 hr and recorded milk intakes on six days a week, and Economides *et al* permitted suckling at 08.00 hr and 16.00 hr but only recorded milk intakes on two days each week.

Other workers have allowed the cows and calves to remain together except immediately before and during the period when milk yield estimates were made (Drewry, Brown and Honea 1959; Dawson, Cook and Knapp 1960; Neville 1962; Bond *et al* 1964; Furr and Nelson 1964; Melton, Riggs, Nelson and Cartwright 1967; Gleddie and Berg 1968; Deutscher and Whiteman 1971; Kropp *et al* 1973). The procedure adopted by Drewry, Brown and Honea (1959) is fairly typical of the procedures adopted by these workers. Drewry, Brown and Honea separated calves from their dams at 15.00 hr and permitted suckling at 18.00 hr on the day before milk yield was to be estimated. The calves were then separated from their dams until the following morning at 06.00 hr when suckling was permitted and the milk intake of the calf determined. Following a further period of separation, another suckling was permitted at 16.00 hr and milk intake again determined. The sum of the two milk intakes was assumed to represent the daily milk production of the cow. Table R.1 summarises the procedures used by other workers who have used this method.

TABLE R.1: Numbers of sucklings and intervals between sucklings used in the calf-suckling technique

Preliminary period of separation (hr)	Number of sucklings in 24 hr period	Intervals between sucklings (hr)	Author(s)
12	[1]NR	NR	Bond *et al* (1964)
NR	3	8	Dawson *et al* (1960)
NR	3	6	[2]Deutscher & Whiteman (1971)
12	2	10	Drewry *et al* (1959)
NR	3	8	[2]Furr & Nelson (1964)
12	4	NR	Gleddie & Berg (1968)
12	2	12	Melton *et al* (1967)
16	2	8	Neville (1962)
NR	4	6	Kropp *et al* (1973)

[1]NR - not reported

[2]Until calves were 6-8 weeks old only; thereafter two sucklings at 12 hr intervals were used.

Despite the extensive application of the calf-suckling technique, few authors have referred to the possible sources of error involved in the technique. The errors associated with measuring the milk yield of ewes by the lamb-suckling technique have received more attention, however, and several authors have discussed factors affecting the accuracy and reliability of the method (Wallace 1948; Barnicoat, Logan and Grant 1949; Coombe, Wardrop and Tribe 1960; Robinson, Foster and Forbes 1968). The similarity between the calf and lamb-suckling techniques is such that the same factors are likely to affect the reliability of both methods. These are:

a) the frequency of suckling permitted
b) achieving a satisfactory milk let-down
c) the accuracy of weighing
d) the frequency of yield determinations

a) <u>The frequency of suckling permitted</u>

The usual procedure in the calf-suckling technique is to measure the milk intake of the calf at two or three sucklings during a 24 hr period with equal intervals of 8 or 12 hr between sucklings. There is some evidence which suggests that, under natural conditions, calves are suckled more frequently and thus the intervals between sucklings are shorter than is usual in the calf-suckling technique.

The natural suckling behaviour of cattle has been studied by Hutchison *et al* (1962) in Tanganyika, Walker (1962) in New Zealand, and Johnstone-Wallace and Kennedy (1944), Peterson and Woolfolk (1955) and Drewry, Brown and Honea (1959) in the USA. Ewbank (1969) has reported the frequency of suckling in single-suckled Hereford cows under English field conditions. These studies indicate that, in general, cows suckle their calves between three and eight times per 24 hr under natural conditions.

Ewbank (1969) and Peterson and Woolfolk (1955) reported an approximately equal distribution of sucklings between "day" and "night" but Drewry, Brown and Honea (1959) stated that, unless disturbed, the suckling of calves during the night was negligible. Schake and Riggs (1969) in a study of the behaviour of lactating beef cows in a North American drylot found that the total time devoted to suckling at night was only 7.7 min. compared to 84 min. during the day, with intervals between sucklings twice as long at night. Thus, the evidence suggests that, in general, calves are suckled more frequently under natural conditions than the two or three times per 24 hr commonly used in the calf-suckling technique, but the evidence relating to the distribution of sucklings during a 24 hr period is contradictory.

In the calf-suckling technique, if the interval between sucklings was reduced by permitting a suckling frequency comparable to that observed under natural conditions, several problems emerge. A number of workers (Owen 1957; Coombe, Wardrop and Tribe 1960; Robinson, Foster and Forbes 1968) have commented on the tedious and time-consuming nature of the lamb-suckling technique and the same criticism can be levelled at the calf-suckling technique. More frequent sucklings during the period of yield estimation would increase the time involved and hence the resources required to record milk production.

With respect to measuring the milk production of grazing ewes, Barnicoat, Logan and Grant (1949) pointed out that the interval between sucklings which is used is a compromise between allowing the ewe sufficient time to graze and allowing the lamb sufficient opportunity to suckle. Similarly, when measuring the milk production of grazing beef cows, the cow would have less opportunity to graze if the intervals between sucklings were reduced. It can also be argued that more frequent collection of beef cows, unaccustomed to having their normal behavioural pattern disturbed, may introduce a stress factor at suckling. It is known that stress inhibits the normal milk-ejection reflex (Cowie and Folley 1961; Svendsen 1974) and this would result in the calf-suckling technique underestimating milk production.

Although not referred to by any authors, the use of shorter intervals between sucklings would be expected to reduce the milk intake of the calf at each suckling. Consequently, accurate measurement of the weight increase of the calf at each suckling would present a greater technical problem.

On the basis of the foregoing discussion it appears that allowing cows to suckle their calves as frequently in the calf-suckling technique as they would under natural conditions presents practical and technical problems. Particularly with housed cattle however, provided the inconvenience and cost incurred is acceptable, there appears to be no reason why four sucklings per day at equal six-hour intervals could not be used.

Chow, Riggs and Schake (1967) have assessed the effect of different frequencies of suckling and intervals between sucklings on the quality and quantity of milk produced by beef cows, and Wallace (1948) and Munro and Inkson (1957) have studied the effect in ewes. Chow, Schake and Riggs studied frequencies of suckling of six, four, three, two, one and one a day at invervals between sucklings of 4, 6, 8, 12, 17 and 24 hr respectively. The mean 24 hr milk yield at all frequencies differed significantly ($P < 0.01$). The lowest yield was obtained with one suckling a day at a 17 hr interval (2.6 kg) and the highest with two sucklings a day at a 12 hr interval between sucklings (6.4 kg). Chow, Riggs and Schake concluded that two tests a day at 12 hr intervals appeared adequate to estimate, effectively, the milk yield of the Hereford cows used in their study. This appears a surprising conclusion in view of the results reported but in the absence of a more detailed description of the procedures than is provided, the justification for this conclusion cannot be assessed. Furthermore, the cows used averaged 69 days *post partum* at the start of the study and two sucklings a day at 12 hr intervals may not provide an accurate estimate of milk production during the first two months of lactation when Gifford (1949, 1953), Walker and Pos (1963), and Totusek *et al* (1973) have shown that higher milk yields can be expected than in later lactation.

A number of workers have observed that the young single-suckled calf is unable to consume all the milk the dam is capable of producing in early lactation (Gifford 1949, 1953; Drewry, Brown and Honea 1959; Research Investigations and Field Trials 1972-73) and Christian, Hauser and Chapman (1965) have suggested that the milk intake of a suckled calf may be reduced if it has only restricted access to its dam. There are no reports in the literature of studies designed to test this hypothesis and it is not clear whether permitting fewer sucklings than would normally occur under natural conditions reduces the appetite of a suckled calf for milk.

It is possible that reducing the frequency of milk removal may have a direct effect on the amount of milk available to the calf. It is well known that dairy cows milked three or four times a day produce higher milk yields than when milked twice a day (see review by Elliot 1959a). Traditionally, this effect was ascribed to a decline in the rate of milk secretion associated with the rise in intramammary pressure that occurs with increasing intervals between milkings but Elliot (1959b) in a review of the experimental evidence concluded that an interval of up to 16 hr between milkings has no effect on milk secretion rate. Benson and Folley (1957) proposed that the effect of higher frequencies of milking on milk yield was attributable to an increased production of oxytocic hormone caused by more frequent stimulation. Elliot (1961), however, found that when two halves of the same udder were milked either two or three times a day, the udder halves which were milked three times produced, on average, 12 per cent more milk than the halves milked only twice. Elliot concluded that the effect of higher frequencies of milking on yield was attributable to some local cell effect in the udder, activated either by differences in the amount of residual milk or by long-term effects of differences in milk accumulation.

The implications of this for measuring the milk production of beef cows by the calf-suckling technique are not clear, but, particularly when calves are segregated from their dams during lactation and only two sucklings a day are permitted (eg Walker and Pos 1963; Totusek *et al* 1973; Economides *et al* 1973), it is possible that the milk production of the cow will be less than had the more frequent sucklings which are reported to occur under natural conditions been permitted.

A number of workers have reported significant positive correlations between the milk intake and growth rate of suckled calves (see Table R.2 on page 50). Thus, if permitting fewer sucklings than occur under natural conditions either reduces the appetite of a suckled calf for milk and/or reduces the amount of milk available to the calf, these calves would be expected to have lower growth rates than contemporaries maintained under a natural suckling régime. Economides *et al* (1973) did not report the growth rates of their calves but Totusek *et al* (1973) recorded lower weight gains in calves involved in the calf-suckling technique than they claimed were normally observed under pasture conditions. This they ascribed to a number of factors but they suggested that methods of measuring milk production which involve disturbing the normal grazing and behaviour-patterns of beef cows and their calves are likely to provide an underestimate of true milk production.

Only Walker and Pos (1963) have directly compared the growth rates of calves involved in the calf-suckling technique with the growth rates of a control group of calves run normally with their dams. Walker and Pos reported that there was "very little difference" between the growth rates of calves involved in the calf-suckling technique and control calves. From this they concluded that the calves involved in the calf-suckling technique were obtaining as much milk as those run normally with their dams.

It is possible that permitting fewer sucklings in the calf-suckling technique than occur under natural conditions only influences the potential milk intake of a suckled calf in early lactation, and only then if the milk production of the dam approaches the maximum intake of the calf. The effect on milk production of the cow is more difficult to assess because Hutchison *et al* (1962) and Walker (1962) have suggested that there is an interaction between frequency of suckling and level of milk production, and the appetite of the calf is a third factor to be considered.

b) Achieving a satisfactory milk let-down

Hammond, Mason and Robinson (1971), Foley, Bath, Dickinson and Tucker (1972) and Svendsen (1974) have described the milk-ejection reflex and have pointed out that any pain, excitement or undue stress will inhibit the normal release of oxytocin and the consequent ejection of milk. The presentation of the calf to its dam is a potent stimulus to the release of oxytocin (Foley *et al* 1972) and, provided beef cows are handled carefully and without undue excitement, when milk production is measured by the calf-suckling technique it seems likely that a satisfactory milk let-down will occur.

c) The accuracy of weighing

Most workers who have studied the pattern of milk production during lactation in beef cows have found that, after an initial rise, milk production declines throughout the remainder of lactation (eg Gifford 1949, 1953; Walker and Pos 1963; Totusek *et al* 1973). Therefore, as lactation proceeds the milk intake of the calf decreases as its live-weight increases and the accurate measurement of the gain in weight of the calf during suckling becomes increasingly difficult.

This can be demonstrated using the data of Totusek *et al* (1973) who recorded mean daily milk yields of approximately 6.8, 6.5 and 5.6 kg at 70, 112 and 210 days after calving respectively. From the data provided relating to the live-weight gain of the calves involved and assuming a calf birth-weight of 35 kg, and an equal intake of milk at each suckling, it can be calculated that the milk intake of the calves and, therefore, the weight changes at each of the two sucklings a day represented 4.2, 3.1 and 1.7 per cent of the live-weight of the calf at 70, 112 and 210 days of age respectively.

Specialised weighing equipment is necessary to record, accurately, weight changes of less than 2 per cent but few authors have referred to the type of weighing equipment used in the calf-suckling technique. Wilson *et al* (1971), however, reported that they obtained pre- and post-suckling calf weights to the nearest 45 g on "specially-built scales".

Yates, Macfarlane and Ellis (1971) pointed out that defecation and/or urination between the pre- and post-suckling weighings would result in an underestimate of a calf's milk intake. In the lamb-suckling technique it has been reported that, provided the lambs were roused for a few minutes before they were weighed before suckling, defecation and urination did not present a problem (Wallace 1948; Robinson, Foster and Forbes 1968). In the calf-suckling technique, Economides *et al* (1973) stated that calves did not defecate or urinate during suckling and they claimed that the weighing procedure proved highly satisfactory for the purpose of estimating milk consumption.

d) Frequency of yield determinations

When the calf-suckling technique has been used to measure the milk production of beef cows, the frequency of recording has varied from daily (Walker and Pos 1963) to as little as one day every two months (Drewry, Brown and Honea 1959; Neville 1962). In general, when cows and calves have been allowed to remain together between yield estimates, milk yield has been recorded less frequently than when cows and calves were segregated.

Rutledge, Robison, Ahlschwede and Legates (1972) and Totusek *et al* (1973) have examined the number of estimates required to assess the milk production of beef cows by the calf-suckling technique. Rutledge *et al* (1972) tested the use of regression equations to predict total lactation yield with two or three daily yield estimates made at different stages of lactation as the independent variables. In two sets of independent data they obtained correlation coefficients in excess of 0.90 between observed and predicted yield. The observed yield, however, was itself subject to error since it was based on only once weekly or once monthly estimates.

Totusek *et al* (1973) compared 210-day cumulative milk yields calculated on the basis of measurements made on six days each week, with 210-day cumulative milk yields calculated on the basis of measurements made at different frequencies and at different stages of lactation. Totusek *et al* reported that daily yield measurements made at either weekly or monthly intervals could be used to estimate 210-day yield with an error of less than one per cent. Yields calculated on the basis of measurements made on four or five selected days also provided a satisfactory estimate of 210-day yield, although the error increased to approximately four per cent.

Before definite conclusions can be reached on the extent of sampling required to predict total milk yield with varying degrees of precision, detailed studies are required of the day-to-day variation in milk yield and the pattern of milk production of beef cows of different genotypes maintained under a variety of nutritional régimes and in different environments.

Sampling for determination of milk composition

It is well documented that there is a progressive increase in the butter fat content of the milk produced by dairy cows during the process of milking and that the first drawn milk can contain as little as one per cent and the last drawn as much as ten per cent (see reviews by Rook 1961; Balch 1972). This must be taken into account in order to obtain representative samples of the milk produced.

When measuring the milk production of beef cows by the calf-suckling technique, the collection of a milk sample representative of the milk consumed by the calf has presented problems. For this reason, few of the workers who have used the calf-suckling technique have attempted to determine milk composition. Melton *et al* (1967) collected milk samples from one or two quarters of the udder on three occasions during the period of lactation under study. The quarter or quarters of the udder were completely milked out by hand following an intramuscular injection of oxytocin. Dawson, Cook and Knapp (1960) obtained milk samples once a week by hand-milking, "after suckling but before the quarter was milked out". Kropp *et al* (1973) collected milk samples on three occasions during lactation. After being separated from their calves for a period of six hours, the cows were tranquilised and given intramuscular injections of oxytocin prior to machine-milking.

It is unlikely that the samples of milk obtained by these procedures were representative of the milk either available for consumption by the calf or that the calf would have consumed. Unfortunately, these workers have not reported the relationship between the amount of milk obtained for sampling and the amount of milk consumed by the calf at approximately the same stage of lactation.

Conclusions

Probably the biggest single criticism of the calf-suckling technique is that it is both tedious and time-consuming. This is possibly one of the main reasons why fewer sucklings are undertaken with this technique than are reported to occur under natural conditions although other factors have to be considered, particularly when measuring the milk production of beef cows maintained under grazing conditions. Permitting fewer sucklings in the calf-suckling technique than occur under natural conditions may result in the method providing an underestimate of milk production.

It is probably the tedious and time-consuming nature of the method which has deterred most workers from recording milk yield at more frequent intervals during lactation than they have done, and only Walker and Pos (1963) have used the method to measure milk yield every day. More regular recording would necessitate, however, more frequent disturbance of the normal behavioural pattern of the cows and this may influence milk production, particularly in cows unaccustomed to being handled.

The accurate measurement of the weight increase of a calf at suckling requires specialised weighing equipment but defecation and/or urination during suckling do not appear to constitute a problem.

When the calf-suckling technique is used, the collection of milk samples, representative of the milk consumed by the calf, presents difficulties and the procedures reported in the literature do not appear satisfactory.

1.2 MACHINE-MILKING

Description

Machine-milking, without any artificial stimulation of milk let-down, was one of the earliest methods used to measure the milk production of beef cows. Dawson, Cook and Knapp (1960) have reported the findings of a study conducted between 1915 and 1919 which involved machine-milking beef cows, and since then the method has been used by Cole and Johansson (1933), Abadia and Brinks (1972), Economides *et al* (1973), and B.G. Lowman and R.A. Edwards (personal communication).

The usual procedure when this method is used involves removing calves at or near birth, and thereafter machine-milking the cows twice a day. Essentially the cows are treated in a similar manner to dairy cows and standard milking equipment has been used.

Serwanja, Welch and Kidder (1969) allowed the calves to remain with their dams and machine-milked one half of the udder presumably while the calf was allowed to suck the other side, although this was not specified. They estimated daily milk yield one day a month using this procedure and thus the amount of time involved and manpower required was less than in the more usual procedure which involves machine-milking cows twice every day.

Hand-milking, although a more laborious method than machine-milking, has been used by a number of workers. Pearson *et al* (1968) removed calves within 72 hr of birth and hand-milked beef cows twice a day, while Gifford (1949, 1953), Christian, Hauser and Chapman (1965) and Totusek *et al* (1973) hand-milked one half of the udder while the calf sucked the other side. This half-udder technique is generally preferred because it eliminates the need to handle the cows except when yield estimates are made. When calves have been removed at birth and the cows either hand or machine-milked twice a day, the amount of milk produced has been recorded at every milking. Usually milk yield has been recorded at monthly intervals when the half-udder technique has been employed.

Ideally the quantity and composition of the milk obtained by machine or hand-milking a beef cow should be the same as that which would have been consumed by a suckled calf. There is some evidence which indicates that this may not be the case.

Appetite of calf

It has been suggested that beef cows are capable of producing more milk in early lactation than a suckled calf can consume, and that the appetite of the calf may limit the milk production of the cow in early lactation (Gifford 1949, 1953; Drewry, Brown and Honea 1959; Research Investigations and Field Trials 1972-73).

Workers at the North of Scotland College of Agriculture (Research Investigations and Field Trials 1970-71 and 1972-73) measured the milk production of 16 beef cows by the calf-suckling technique but, during the first month of lactation, any excess milk, ie milk not consumed by the calf, was removed by machine-milking and weighed. It was found that the calves consumed, on average, only 64 per cent of the total milk produced by their dams during the first month of lactation, with a range of 43 to 91 per cent. Plum and Harris (1971) reported that calves suckled by Holstein cows (managed as beef cows) were unable to consume all the milk available to them until they were approximately three months of age. The levels of milk production reported by the workers at the North of Scotland College of Agriculture (Research

Investigations and Field Trials 1970-71 and 1972-73) and by Plum and Harris (1971) for the cows involved in these two studies were higher, however, than most other reported estimates of the level of milk production of beef cows which are described in a subsequent section. Brumby, Walker and Gallagher (1963) considered that a young calf's appetite for milk was probably in excess of the level of milk production that many beef cows were capable of attaining.

There is little detailed information in the literature on the appetite of a suckled calf for milk at different ages and, because the appetite of a calf is closely related to its weight (Roy 1970), the maximum milk intake of suckled calves at different weights. Neville (1962) noted in a study involving 135 lactations, that seven suckled calves had a daily milk intake in excess of 9.0 kg in early lactation, and Brumby, Walker and Gallagher (1963) reported that the calves involved in their study had an average daily milk intake in excess of 7.25 kg during their first six weeks of life. Roy (1970) quotes figures of 6.3, 7.9 and 10.3 kg for the maximum daily milk intake of pail-fed calves at 30, 40 and 50 kg live-weight respectively.

Economides *et al* (1973) offered seven cows the same level of nutrition and measured the milk production of three cows by machine-milking and four by the calf-suckling technique. The numbers of cows involved were too few to warrant statistical analysis, but Economides *et al* observed that the daily milk yield of the machine-milked cows was appreciably higher than that of the calf-suckling cows at the beginning of the period of lactation recorded (approximately 10 days after calving). The difference between the mean daily milk yield of the machine-milked cows and that of the calf-suckling cows decreased as lactation progressed, and by approximately 35 days after calving the daily milk yield of the two groups was similar.

Serwanja, Welch and Kidder (1969) measured the milk production of 21 Aberdeen Angus cows by the calf-suckling technique one day a month, and the following day by machine-milking. The average daily milk yield in the first eight months of lactation was not significantly affected by method of milking and was 6.7 and 6.6 kg for the calf-suckling and machine-milking methods respectively. The first yield estimate was not made until approximately two weeks after calving, however, and there was a closer relationship between the yields recorded using the two methods in the fourth to eighth month of lactation than in the first, second and third.

On the basis of the evidence cited it appears probable that some beef cows will be genetically capable of producing more milk in early lactation than a young suckled calf can consume, but that many beef cows either for genetic, nutritional or environmental reasons are not. Thus, machine or hand-milking may provide an overestimate of the milk production of beef cows under certain circumstances, particularly in early lactation.

Milking stimulus

Totusek *et al* (1973) measured the milk production of 24 beef cows by the calf-suckling technique (six days a week) and by hand-milking one half of the udder while the calf sucked the other side (one day a week). The mean 210-day lactation yield determined by the calf-suckling technique was 27 per cent higher than the yield recorded by hand-milking and Totusek *et al* suggested that the calf-suckling technique provided a more precise estimate of milk yield than did hand-milking, probably because the stimulus of the calf resulted in a greater release of oxytocin.

The need to stimulate the release of oxytocin to obtain a satisfactory milk-ejection reflex has already been mentioned in relation to the calf-suckling technique where it was concluded that the stimulus of the cow's own calf would be sufficient to elicit the milk-ejection reflex.

In an attempt to ensure a satisfactory milk-ejection reflex some workers have allowed the calf to suck one side of the udder while the other side has been machine or hand-milked (eg Gifford 1949, 1953; Christian, Hauser and Chapman 1965; Totusek *et al* 1973). If cows are machine or hand-milked without the presence of their calf (eg Cole and Johansson 1933; Dawson, Cook and Knapp 1960; Pearson *et al* 1968; Abadia and Brinks 1972; Economides *et al* 1973), external stimuli such as washing and massaging of the udder are required to elicit the milk-ejection reflex. The reflex can also be conditioned to stimuli associated with the milking routine such as feeding, the noise of buckets and the presence of the milker.

Failure to elicit a satisfactory milk-ejection reflex, either because of inadequate stimulation or because of inhibition of the reflex caused by stress, will result in an incomplete removal of milk in the udder. In dairy cows, the incomplete removal of the secreted milk has been shown to cause a slowing in the rate of milk secretion (Turner 1955; Wheelock, Rook and Dodd 1965a) which in turn is associated with poor lactation persistency (Elliot 1959b). Partial or complete failure to elicit the milk-ejection reflex when beef cows are machine or hand-milked will result in an underestimate of milk production at that milking, and this is likely to be associated with poor lactation persistency where calves have been removed at birth and the cows hand or machine-milked throughout lactation.

Economides *et al* (1973) used cows which had been adapted to machine-milking prior to the beginning of their study and apparently obtained a satisfactory milk-ejection reflex. In an interim report of the same study (Economides *et al* 1971), however, they reported that one machine-milked cow responded differently to different stockmen, and this implies that individual milkers are more successful than others at initiating milk-ejection in certain cows.

Cole and Johansson (1933) recorded shorter lactation lengths in machine-milked Aberdeen Angus cows than in Holstein cows maintained under the same conditions. This they considered to be an inherent characteristic of the particular Aberdeen Angus cows involved in their study.

Abadia and Brinks (1972) recorded an average lactation length of only 93 days in 68 Hereford heifers which were machine-milked from calving to 150 days *post partum* or "until lactation essentially ceased". This implies that a satisfactory milk-ejection reflex was not obtained in all the heifers involved in this study and that this resulted in premature drying-off.

Pearson *et al* (1968) considered that the lower yields they obtained by hand-milking cows of the Blanco Orejinegro breed (a Colombian Criollo breed of cattle) compared to Jersey cross contemporaries was as much due to the refusal to eject milk as to the absence of milk in the udder. Pearson *et al* concluded that while hand-milking provides a crude indication of the lactation performance of beef cows, it appears that the suckled calf can obtain more milk than can be removed by hand-milking.

The premature drying-off recorded by Cole and Johansson (1933) and Abadia and Brinks (1972) is an extreme case of poor lactation persistency but, although failure to achieve regularly a satisfactory milk-ejection reflex may have been the causal factor, other factors including inadequate nutrition and bacterial infection of the udder may have been involved.

Even should the stimuli associated with hand or machine-milking elicit the milk-ejection reflex, it has been suggested by Pearson *et al* (1968) and Totusek *et al* (1973) that the degree of stimulation may not be as great as that received by a cow suckling her own calf.

In dairy cows, Walsh (1974) has examined the effect on milk yield of a suckling stimulus *versus* the stimuli associated with machine-milking. Between parturition and 100 days *post partum* (early lactation), 12 cows were machine-milked while a further 12 were suckled, each by four calves. All cows were machine-milked between 100 and 230 days *post partum* and thereafter, until the end of lactation (late lactation), the early lactation treatments were repeated. The suckling cows produced more milk than the machine-milked cows in both early and late lactation (11.3 and 7.7 per cent respectively). Walsh considered that, while the increase in yield of the suckling cows in early lactation could be attributed to either the degree of milking stimulus, the degree of udder evacuation or the lower incidence of mammary infection, the increase in yield in late lactation was attributable to the greater degree of milking stimulus received by the suckling cows. In this experiment, each cow was suckled by four calves and the amount of stimulation received by a cow may depend on the number of calves suckled. In sheep it is generally accepted that ewes suckling two lambs produce more milk than those suckling only one (Barnicoat, Logan and Grant 1949; Starke 1953; Davies 1963) and that this may be partly a reflection of the additional stimulation received (Wallace 1948; Treacher 1967).

It appears that the amount of milk voided by a beef cow will depend upon the degree of stimulation received at milking and the absence of stress. Thus, machine-milking beef cows may not remove the same quantity of milk as would a suckling calf.

Bacterial infections of udder

It is well established that an infection of pathogenic bacteria in an individual quarter of the udder normally depresses the milk yield of that quarter, the effect varying from a few per cent of production to complete cessation of secretion (Wheelock and Dodd 1969). Bacterial infection of the udder will also influence the composition of the milk produced (Rook 1961; Foley *et al* 1972).

Bacterial infections of the udder are a greater problem in machine-milked cows than in suckling cows and Walsh (1974) reported an incidence of infected quarters of 29.2 per cent in machine-milked cows compared to only 2.1 per cent in suckling contemporaries.

Weighing, sampling, frequency of milk removal and recording

When milk production is measured by hand or machine-milking the accurate weighing and collection of representative samples of the milk produced presents little difficulty. It is essential, however, to obtain aliquot samples of the milk produced for the determination of composition, particularly when the intervals between milkings are unequal.

The possible effect of using longer intervals between milkings than occur under natural suckling conditions has been discussed in relation to the calf-suckling technique although the effect (if any) that the appetite of the calf has on milk production is removed by hand or machine-milking throughout lactation.

When calves have been removed soon after birth and the cows either hand or machine-milked twice a day thereafter, the milk produced has been recorded at every milking. When calves have been allowed to remain with their dams and the half-udder technique used, yield estimates have been made less frequently. In the absence of data relating to the pattern of milk production during lactation obtained by the half-udder technique and the day-to-day variation in milk yield, it is not possible to assess the extent of sampling required to estimate total lactation yield with varying degrees of accuracy.

Conclusions

Machine-milking is a convenient and relatively inexpensive method of measuring the milk production of beef cows, particularly when large numbers of animals are involved. Hand-milking is less convenient and more time-consuming than machine-milking, but both methods are suitable for cows maintained under either housed or grazing conditions and facilitate continuous recording, accurate weighing and representative sampling of the milk produced.

Machine-milking will provide an overestimate of milk production in early lactation in situations where a satisfactory milk-ejection reflex is obtained and the potential milk yield of the cow is greater than the appetite of the calf for milk. This may not be a disadvantage if the purpose of a particular study is to determine the milk yield of beef cows without the possible limitation imposed on milk output by the appetite of the calf.

There is evidence which indicates that the stimuli associated with machine or hand-milking may be less than the stimuli associated with suckling, and that as a consequence machine or hand-milking may provide an underestimate of the milk production of beef cows. Furthermore, many beef cows are unaccustomed to being handled and the milk-ejection reflex of individual cows may be inhibited by stress.

1.3 THE OXYTOCIN TECHNIQUE

Description

The role of the oxytocin in the milk-ejection reflex has been described by Foley *et al* (1972) and Svendsen (1974), and a number of workers have used commercial preparations of the hormone, injected either intravenously or intramuscularly, to facilitate milk removal when measuring the milk production of both beef cows and sheep.

This method, usually referred to as the oxytocin technique, attempts to measure the rate of milk secretion during a period of 6 to 12 hours. The normal procedure is as follows: The cow is separated from her calf, injected with 2 cc of oxytocin and milked. The cow and calf remain separated and at the end of a period of usually 6 or 12 hr the cow is again injected with oxytocin and milked. The amount of milk obtained at the second milking represents the amount of milk secreted during the 6 or 12 hr interval between milkings.

Different workers have used different methods of milk removal following injections of oxytocin. Milk has been removed by machine-milking (Schwulst, Sumption, Swiger and Arthaud 1966), machine-milking and hand-stripping (Anthony *et al* 1959), and metal catheters (Lamond, Holmes and Haydock 1969).

The accuracy and reliability of the oxytocin technique have been discussed in relation to measuring the milk production of sheep (Barnicoat, Logan and Grant 1949; McCance 1959; Coombe, Wardrop and Tribe 1960; Robinson, Foster and Forbes 1968) and beef cows (Schwulst *et al* 1966; Lamond, Holmes and Haydock 1969).

In dairy cows, it has been shown that after the completion of milking, a variable amount of milk remains in the udder (Elliot 1959a) and is normally 10 to 25 per cent of the total amount of milk present in the mammary gland just before milking commences (Johansson 1952). Most of this milk can be removed if oxytocin is injected and the cow is milked again (Foley *et al* 1972) and the quantities carried over to the next milking are small (Wheelock and Dodd 1969). If the udder is emptied to the same extent at the beginning and end of a period of known length using injections of oxytocin, the amount of milk secreted can be measured and from this, the rate of milk secretion calculated.

In beef cows, it is assumed that the rate of milk secretion observed is representative of the amount of milk consumed by the calf because, over a period of weeks the rate of milk secretion of the cow must equal the rate of milk removal (Wheelock and Dodd 1969) by the suckled calf. Milk secretion will be measured, accurately, by the oxytocin technique only if:

a) the udder is emptied to the same extent at the beginning and end of the period during which milk secretion rate is measured, and

b) the rate of secretion is unaffected by injection of oxytocin.

a) Emptying of the udder

The rate of milk secretion will be imprecisely estimated if different amounts of residual milk are present in the udder at the beginning and end of the test-period.

Almost complete emptying of the udder in response to injections of oxytocin has been claimed in sheep (McCance 1959; Coombe, Wardrop and Tribe 1960) and in beef cows (Anthony *et al* 1959; Lamond, Holmes and Haydock 1969). Anthony *et al* (1959) stated that by careful hand-stripping most beef cows could be milked out in five minutes following injections of oxytocin. Schwulst *et al* (1966), however, found that certain individual beef cows were unresponsive to injections of oxytocin. Schwulst *et al* reported that on several occasions, even after a second injection of oxytocin, certain cows appeared to have milk remaining in their udders and in one instance they confirmed this by allowing a cow to suckle her calf. The cow had not displayed any signs of nervousness during milking but yielded nearly 3 kg of milk in response to the stimulus of the calf. Schwulst *et al* concluded that this cow was not responsive to the effects of exogenous oxytocin and that the oxytocin technique was not a useful method of measuring the milk production of beef cows.

Barnicoat, Logan and Grant (1949) in an early attempt to use the oxytocin technique with ewes reported that while 82 per cent of the ewes tested yielded on average 94 per cent of the milk accumulated in the udder during a 6 hr interval, apparently oxytocin had little effect on the other 18 per cent which yielded only 75 per cent or less. Their method of measuring residual milk was not described, but because of incomplete emptying of the udder they considered the oxytocin technique unsatisfactory.

More recently, Butterworth *et al* (1968) have encountered a similar problem with variation between ewes in their response to oxytocin. After injecting ewes with oxytocin and hand-milking, they determined the residual milk remaining in the udder by weighing lambs before and after suckling. It was found that the quantity of milk obtained by hand-milking, expressed as a percentage of total milk obtained by hand-milking and the lamb-suckling technique, varied widely from ewe to ewe with a range of from 50 to 88 per cent and a mean of 75 per cent.

b) *Effect on rate of milk secretion*

To inject higher levels of oxytocin into a cow than are physiologically normal may influence milk secretion either directly, or indirectly by abnormally emptying the udder. The effect of using injections of oxytocin to completely empty the udder has been reviewed by Elliot (1959b). Most of the experimental evidence discussed by Elliot indicates that higher rates of milk secretion than are normal follow emptying of the udder by oxytocin. In two studies, however, no effect was observed and in one, a decline in secretion rate was reported. Elliot is critical of the methodology employed in all the experiments discussed and concluded that there was insufficient evidence to show whether complete removal of residual milk by oxytocin injections has any effect on milk secretion rate.

More recently, Morag (1968) found that when oxytocin was injected between milkings and a normal milking routine adopted, milk yield was depressed. When the residual milk was removed at the end of each milking by a further injection of oxytocin, however, Morag found that milk yield increased. Wheelock and Dodd (1969) in a brief review of the subject concluded that there was a lack of information concerning the action of oxytocin in cows, but it does appear that injecting oxytocin to completely empty the udder may increase the rate of milk secretion in the following interval.

There is general agreement in the literature, however, that the milk produced following injections of oxytocin differs in composition from normal milk (Wheelock, Rook and Dodd 1965b; Lane, Dill, Armstrong and Switzer 1970; Graf, Randy and Elliot 1970).

Diurnal variations in secretion rate

When measuring the milk yield of beef cows by the oxytocin technique, the assumption is made that the rate of milk secretion observed during the 6 or 12 hr test period is representative of the average rate of secretion over a 24 hr period. This assumption will only be valid if there is no diurnal variation in the rate of milk secretion. Despite an extensive search of the literature there appears to be little published data on this subject in cows, although there is evidence which shows that when equal intervals occur between milkings, more milk is voided at the morning milking than at the evening milking (eg Everett and Wadell 1970). However, the amount of milk voided may not be equivalent to the amount of milk secreted if variable amounts of residual milk remain in the udder after each milking.

Donker and Dalton (1955) and Ǐotsov (1956) observed a diurnal variation in the rate of milk secretion of cows and they recorded higher rates of secretion during the day than at night. Donker and Dalton (1955) found, however, that the difference in milk secretion rate between day and night was less than two per cent, and Lamond, Holmes and Haydock (1969) reported that the time of day milk secretion rate was recorded did not affect the hourly rate of secretion observed.

It appears that calculating milk secretion rate for a 24 hr period, based on the secretion rate observed during a 6 or 12 hr period, may be subject to error because of diurnal variation but that the magnitude of the error is likely to be small.

Effect of length of period of measurement

It has already been mentioned that milk secretion rate is constant up to 16 hr after milk removal (Elliot 1959b). Thus, provided milk secretion rate is measured during a period of less than 16 hr, the length of the period should not affect the hourly rate of milk secretion observed.

Comparison of the oxytocin and calf-suckling techniques

A limited number of studies have been reported in which the calf-suckling technique and the oxytocin technique have been used concurrently to measure the milk production of beef cows.

Gleddie and Berg (1968) found that in the first month of lactation, milk yield recorded by oxytocin technique was, on average, 18 per cent greater than the yield recorded by the calf-suckling technique. Wilson *et al* (1971) measured the milk production of beef cows by the calf-suckling technique and the oxytocin technique in two adjacent 12 hr periods. Milk yields were recorded every two weeks using this procedure and the mean yield recorded by the oxytocin technique was 28 per cent higher than that recorded by the calf-suckling technique. Schwulst *et al* (1966) also observed a non-significant trend towards higher milk yields when the oxytocin technique was used. Lam, Lamond, Hill and Loadholt (1969), however, reported that the calf-suckling technique and oxytocin technique provided similar estimates of the milk production of 18 Hereford cows.

In ewes, McCance (1959) found that there was a tendency for the oxytocin technique to provide higher estimates of milk yield than the lamb-suckling technique and Coombe, Wardrop and Tribe (1960) reported that the oxytocin technique gave significantly ($P < 0.01$) higher yields than the lamb-suckling technique during a lactation period of 10 weeks.

In general, the oxytocin technique appears to give a higher estimate of milk production than the calf-suckling technique. It cannot be concluded from this, however, that the oxytocin technique gives an overestimate of milk production because evidence was discussed in an earlier section which indicated that the possible sources of error involved in the calf-suckling technique would tend to result in this method providing an underestimate of milk production.

In early lactation, the oxytocin technique and the calf-suckling technique may not measure the same trait. If the appetite of the calf for milk, and hence the rate of milk removal, is less than the initial rate of milk secretion of the cow after calving, milk will accumulate in the udder. The accumulation of milk in the udder will result in a decline in the rate of milk secretion (Turner 1955; Wheelock, Rook and Dodd 1965a) until it equals the rate of milk removal by the calf. If, however, the udder is almost completely emptied by injecting oxytocin, the inhibiting effect of residual milk is removed. This may, temporarily, arrest the decline in milk secretion rate or stimulate milk secretion in the succeeding interval although there is no evidence in the literature to substantiate or disprove this theory.

Conclusions

After a cow is machine or hand-milked or suckled by a calf, a variable amount of residual milk remains in the udder. Usually, most of this residual milk will be removed if oxytocin is injected and the cow is milked again, and thus the use of oxytocin simply to facilitate milk removal will provide an overestimate of milk production. The oxytocin technique, however, attempts to measure milk secretion rate during a 6 to 12 hr period by emptying the udder to the same extent at the beginning and end of the period of measurement.

The oxytocin technique is more convenient and less time-consuming than the calf-suckling technique and facilitates accurate weighing and the collection of representative samples of the milk obtained. There is some evidence to suggest, however, that individual cows are unresponsive to injections of oxytocin. Furthermore, emptying the udder using oxytocin affects the composition of the milk produced and may increase the rate of milk secretion in the subsequent period.

1.4 ESTIMATION FROM CALF BODY-WATER TURNOVER

Description

A group of Australian workers have developed a method of estimating the milk intake of suckled calves, and hence milk production of the dam, using tritiated water (TOH) dilution. The method is based on the assumption that the only water consumed by a young pre-ruminant calf is consumed in the form of milk. The application of this method is restricted, therefore, to situations where calves can be prevented from consuming water, and foods other than milk, or to situations where it can be confidently expected that only milk will be consumed.

Milk contains approximately 85 per cent water (Yates, Macfarlane and Ellis 1971) and the burning, ie oxidation, of the hydrogen in the milk-solids yields a volume of water near to that of the solids themselves, so that measurement of water turnover in the young calf provides a close estimate of milk intake (Macfarlane, Howard and Siebert 1969). Water turnover can be determined by measurement of the dilution, by incoming water, of TOH injected into the calf (Macfarlane and Howard 1970).

Procedure

The procedure used to determine the body-water content and water turnover of calves, suckled by beef cows at pasture, has been described by Yates, Macfarlane and Ellis (1971). The cows and calves are brought into yards and separated. Then, after 2 hr to allow equilibration of milk in the stomach, a blank blood sample is collected from each calf. An intramuscular injection of TOH is given at a dosage rate of 100 μCi at the beginning of the sampling period which is gradually increased to 900 μCi during the eight-week period as the calves become heavier.

The calves remain separated from their dams for 2 hr, without water, to allow equilibration between the TOH and body-water. A sample of equilibrated blood is then collected from each calf and the cows and calves are returned to their grazing area. This procedure was repeated at 14-day intervals during the first eight weeks of lactation.

Measurement of water turnover

By measuring the decline in the activity of the injected tritium, ie its dilution, the water turnover and hence the milk intake of the calf can be calculated. Springhall (1968) has described the method of calculating the rate of water turnover. The total radioactivity injected is determined from the volume and the count of the administered TOH solution. This total activity, divided by the count of the water recovered at equilibrium, gives the estimate of the TOH space. The biological half-life of the TOH is derived by the conventional experimental decay equation from the decline in the tritium count of the body fluids in the interval between samplings. The turnover rate may then be calculated from half the product of the TOH space and the reciprocal of the half-life.

There are several problems and possible sources of inaccuracy associated with this method of measuring the milk yield of beef cows.

Accuracy of estimation

In the estimation of TOH space it is assumed that there are no losses of TOH before it has time to mix completely with the body-water, and that the TOH has mixed completely with the body-water by the time the blood sample is withdrawn for assay. Springhall (1968) has estimated that in adult cattle the pre-equilibration losses of TOH are less than two per cent and it seems unlikely that this constitutes a major source or error. Yates, Macfarlane and Ellis (1971) reported that 2 hr was sufficient to allow equilibration between TOH and body-water in young calves.

Any exchange between the injected tritium and labile hyrdrogen present in the body tissues will result in an overestimate of the TOH space which in turn will result in an overestimate of milk intake. Exchange between tritium and hydrogen in the tissues seems to be one to two per cent (Macfarlane, Howard and Siebert 1969). Two other possible sources of error in the measurement of water turnover in the calf are associated with obtaining an accurate count of the level of activity in the samples and the prevention of contamination of the samples by atmospheric water during the drying process.

When Macfarlane, Howard and Siebert (1969) bottle-fed lambs a known quantity of milk, the correlation between their intake and estimated intake by TOH dilution was high ($r = +0.96$). The actual volume of milk ingested was five per cent greater than the turnover of TOH because of the ash, carbon, nitrogen and phosphorus component that was not measured as water.

Application

The biggest single limitation of this method is that it can only be applied when milk represents the only source of water ingested by the suckled calf. This precludes the application of the method in most situations because calves may begin to ingest small quantities of grass and, providing it is palatable, dry food at about seven days of age (Roy 1970). The age at which calves begin to consume solid food, however, will be influenced by their level of milk intake (Hodgson 1971).

There is no information in the literature relating to the free water intake of suckled calves, but it is known that if water is offered to pail-fed dairy calves given liquid diets, the amount of water consumed will be influenced by the dry matter content of the liquid diet (Roy 1970). Pettyjohn, Everett and Mochrie (1963) found that seven to eight-week old calves consumed 2.3 kg free water per day when they were offered milk substitute *ad libitum*, reconstituted to give a dry matter of 15 per cent which approximates to the dry matter content of cow's milk.

The water intake of young calves is also influenced by environmental temperature (Roy 1970), and in hot weather free water may be ingested by suckled calves, although this seems to be in small quantities, at least in the first half of the lactation (Macfarlane and Howard 1970).

Conclusions

Macfarlane, Howard and Siebert (1969) have claimed that two advantages of using TOH to estimate the milk production of beef cows are that the cow and calf remain undisturbed during the important phase of early lactation, and that the technique provides an integral picture of milk intake in which the week becomes the unit of measured time, rather than 2 or 4 hr of milk measurement. This method is also more convenient and less time-consuming than the calf-suckling technique, machine or hand-milking and the oxytocin tehcnique, and facilitates continuous measurement of milk production. In addition to providing an estimate of milk intake,the use of labelled water permits estimation of the body-solids content.

The dilution of TOH is used to measure the rate of water turnover in the young calf when it is assumed that milk is the only source of ingested water. Therefore, it is only appropriate to use the method to measure milk production during the first 8 to 12 weeks of lactation, and even then only if the calf does not consume any water other than that consumed in milk. Calves may consume solid food and free water before they are eight weeks of age, however, and the method will provide a progressively less accurate estimate of milk production during the period of measurement as the calves become older and their intake of solid food and free water increase.

When beef cows and their calves are on pasture, it is obviously not possible to prevent calves from consuming grass and under housed conditions it may be difficult to prevent calves having access to food and water on offer to their dams. Even were it possible to prevent the ingestion of solid food and free water during the period of measurement, this may not be desirable. The growth rate of the calves will be affected and, under natural conditions, calves usually have access to solid food and free water from birth onwards.

1.5 ESTIMATION FROM CALF GROWTH RATE

An indirect method of estimating the milk production of suckling ewes has been proposed by Wallace (1948) and Owen (1957), and has been the subject of an investigation by Robinson, Foster and Forbes (1969). The method uses the relationship between milk production of the ewes and body-weight increase of the lamb.

Totusek *et al* (1973) refer to a similar method of measuring the milk production of beef cows. In the first instance, milk production is measured using one of the other techniques described (usually the calf-suckling technique) and the corresponding body-weight gains of the calf recorded. These data are then used to establish the relationship between the two traits. After the relationship has been established, it can be used to estimate milk production of the dam using data relating to the body-weight of the suckled calf. The equation defining the relationship can only be used to estimate milk production in conditions similar to those under which the data on which it was based were collected (Robinson, Foster and Forbes 1969).

This method is based on the assumption that a close relationship exists between the milk intake and growth rate of a suckled calf. A number of workers have reported high correlations between the milk intake and body-weight increase of suckled calves in early lactation, but that these decline as lactation progresses and the calf becomes older (Table R.2). The correlation coefficients presented in Table R.2 are all positive with one exception, and it should be noted that most workers have calculated simple correlations between the traits, although Neville (1962) calculated partial correlations, holding year, sex of calf and plane of nutrition of the dam constant. The decline in the

TABLE R.2: Correlations between the milk intake and average daily weight gain of suckled calves reported in the literature

Stage of lactation (days *post partum*)	Correlation coefficient	Author(s)
1 to 42	0.78	Brumby, Walker and Gallagher 1963
43 - 84	0.79	
85 - 168	0.31	
1 - 172	[1]0.15; -0.31; 0.53	Furr and Nelson 1964
1 - 150	0.84	Gleddie and Berg 1968
1 - 30	0.60	Gifford 1949
31 - 60	0.71	
61 - 90	0.52	
91 - 120	0.35	
1 - 238	0.64	Heyns 1960
1 - 170	0.76	Jeffery and Berg 1971
1 - 179	0.78	
1 - 220	0.67 to 0.81	Klett, Mason and Riggs 1965
64 - 92	0.58	Melton *et al* 1967
93 - 124	0.38	
125 - 154	0.01	
1 - 60	0.74	Neville 1962
61 - 120	0.63	
121 - 180	0.59	
181 - 240	0.66	
1 - 30	0.49	Rutledge, Robison and Legates 1970
31 - 60	0.38	
61 - 90	0.36	
91 - 120	0.38	
121 - 150	0.37	
151 - 180	0.29	
1 - 35	0.58	Schwulst *et al* 1966
1 - 35	0.58	Totusek *et al* 1973
1 - 72	0.83	
1 - 112	0.82	
1 - 210	0.80	
19 - 203	0.63	Wilson *et al* 1971
0 - 120	[2]0.68	Wistrand and Riggs 1966

[1]three different groups of calves
[2]correlation between milk intake and weight of calf at end of period

relation between milk intake and body-weight gain of the calf as lactation progresses indicates that body-weight gain of a calf is an increasingly inaccurate index of the milk yield of the dam.

Even in the first two months of lactation the data presented in Table R.2 show that, in general, only 35 to 65 per cent of the variation in the body-weight gain of the calf is accounted for by differences in milk intake. Length of measurement period, sex and genotype of calf, weight of the contents of the alimentary tract, environment and disease may all influence the observed weight changes of a suckled calf at a particular level of milk intake. It may be possible to take account of some of these factors and improve the accuracy of prediction by defining the relationship between milk intake and body-weight gain during a period of standard length, for each sex and genotype of calf, and in the same environment as the relationship is to be used to estimate milk yield. Nevertheless, factors such as ill-health of the calf and defecation or urination before weighings in some calves but not in others cannot be accounted for and may introduce a source of inaccuracy when the method is used.

Robinson, Foster and Forbes (1969) state that the accuracy of estimating the milk yield of ewes using the body-weight data of lambs is dependent upon the degree to which the lambs are prevented from consuming supplementary food. To prevent young calves from consuming supplementary food presents problems because at pasture, grass is always available to the calves and when housed, although the calves may not be directly offered supplementary food, they may have access to food on offer to their dams. A further problem arises because it is well established that the development of solid food intake in calves is influenced by their level of milk intake (Burt and Bell 1962; Hodgson 1971) and that more solid food will be eaten earlier and in greater quantities if less milk is available. Thus, the milk intake and solid food intake of a calf may be inversely related and if solid food is consumed by the calf, the use of equations of calf growth rate will provide an inaccurate estimate of milk production.

The correlations presented in Table R.2 have been derived in situations where variable amounts of solid food may have been consumed by the calves and had the calves been prevented from consuming solid food, higher correlations would be expected between milk intake and body-weight gain. In certain situations it may be possible to measure the solid food intake of calves and, by including this as an independent variable in the relationship between intake and body-weight gain, improve the precision with which milk intake is estimated.

An additional problem with the method referred to by Yates, Macfarlane and Ellis (1971) is that cross-suckling may occur, ie calves may be suckled by cows other than their own dams, which will introduce an obvious source of error when equations of calf growth rate are used to estimate milk production.

The method is more convenient and less time-consuming, however, than the other methods used to measure the milk production of beef cows. After the relationship between milk intake and body-weight gain has been established, all that the method involves is the weighing of calves and the application of the equation.

Conclusions

The body-weight gain of a suckled calf is influenced by a number of interacting factors of which milk intake is only one. Correlations between the milk intake and body-weight gain of suckled calves, reported in the literature, indicate that it is only appropriate to use body-weight gains of a calf to estimate milk production of the dam during the first two months of lactation.

Even in early lactation the correlations reported suggest that equations of calf growth are unlikely to provide any more than a rough estimate of milk production and problems associated with the method include preventing the consumption of supplementary food, ill-health of the calf affecting the relationship between milk intake and body-weight gain, and cross-suckling. The method may be sufficiently accurate, however, to enable a genetically uniform population of beef cows maintained under identical conditions to be ranked on the basis of their milk yield.

GENERAL CONCLUSIONS

It is evident that there are potential sources of inaccuracy associated with all the currently available methods of measuring the milk production of beef cows.

The calf-suckling technique, equations of calf growth and dilution techniques attempt to measure the milk production of beef cows by estimating the milk intake of the suckling calf, whereas machine or hand-milking and the oxytocin technique enable direct measurement of milk production.

Machine or hand-milking and the oxytocin technique both have the disadvantage that they require the separation of the calf from the cow, which is not a normal procedure in beef-cow husbandry. The presence of a suckling calf may influence the level of milk production of a beef cow and the calf-suckling technique provides an estimate of milk production under conditions more closely resembling those obtaining under normal systems of management. The method is laborious, however, and the use of longer intervals between sucklings than occur under natural conditions may result in an underestimate of milk production.

Estimations on the basis of calf growth or calf body-water turnover provide an indirect estimate of milk production, but both methods can only be used in the early part of lactation. The two methods are based on the assumption that the calves do not consume solid food during the period of measurement and this assumption may not be valid in many circumstances.

The specific objective of a particular investigation and the degree of precision required will influence the choice of method of measurement.

2. THE EFFECT OF NUTRITION ON THE LACTATION PERFORMANCE OF BEEF COWS

INTRODUCTION

There is very little detailed information available with respect to the effect of nutrition on the lactation performance of beef cows. Furthermore, much of the information that does exist has been derived from short-term feeding trials and few experimenters have attempted to examine the interactions between levels of nutrition imposed in different phases of the production cycle, or the interactions between different levels of nutrition and non-nutritional factors which may influence milk production.

In this section, the information in the literature relating to the effect of nutrition on the lactation performance of beef cows is briefly reviewed. In many studies, the levels of feeding have not been defined in terms of energy and protein but were quantified in terms of the level of supplement fed and designated high or low. The interpretation of the results of these studies is difficult and thus, only the results of studies in which the levels of feeding are defined will be discussed here.

To provide a background to the discussion, Table R.3 has been compiled to show the general levels of milk production which have been reported for beef cows. These levels of milk production represent the results of a number of studies conducted in various locations, with diverse systems of management, different levels of feeding and using different methods of measuring milk production. The number of estimates made of milk yield also varied and some workers estimated daily milk yield on only three occasions during the period of lactation under study (e.g. Drewry, Brown and Honea 1959; Dunn, Wiltbank, Zimmerman and Ingalls

1965), while others recorded milk production every day (eg Walker and Pos 1963; Abadia and Brinks 1972).

Table R.3 is not intended to show breed differences but it was convenient to present the levels of milk production in relation to the breeds of cow involved because the primary purpose of many of the studies was to identify breed differences in milk production. In many reports, the total milk yield of the cow during the period of lactation under study was not quoted. While in some of these studies it was possible to calculate an estimate of total lactation yield from the information provided, in others this was not possible and only daily milk yields at specific stages of lactation are presented in Table R.3.

To this author's knowledge, there are only four published reports of studies undertaken in the British Isles which present information on the milk production of beef cows and most of the work on this subject has been undertaken in North America. It may be inappropriate to assume that the levels of milk production reported for beef cows in North American range or drylot conditions are of the same magnitude as those of beef cows in the British Isles.

Most of the studies summarised in Table R.3 have shown levels of daily milk yield of the order of 4 to 6 kg a day and similar levels of production have been observed under British conditions by McCarrick and Crowley (1967), Drennan (1971) and B.G. Lowman and R.A. Edwards (personal communication). Economides *et al* (1973), however, recorded a daily milk yield of 8.3 kg in six machine-milked beef heifers, although in a group of calf-suckling heifers they recorded a daily yield of 6.0 kg.

Some reported estimates of the composition of the milk produced by beef cows are presented in Table R.4. The reported values for butter

TABLE R.3: Milk yield of beef cows

Location	Breed(s)	No.	Method	Stage of lactation	Lact. yield	Daily yield	Author(s)
						(kg)	
Colorado	H	68	MM	0- 93	379	4.1	Abadia & Brinks 1972
New Zealand	BSh AA & H	40	-	0-244	679	2.8	Barton 1959
Maryland	AA	54	CST	0-150	1205[1,2]	8.0[1,2]	Bond *et al* 1964
USSR	H	78	-	0-245[1]	1322	5.4[1]	Černov 1969
USSR	AA	64	-	0-245[1]	1225	5.0[1]	Černov 1969
Texas	H	10	(MM-0 (CST	69+		4.4-7.5[5]) 2.6-6.4[5])	Chow *et al* 1967
Wisconsin	H	88	HM	0-240	957	4.0	Christian *et al* 1965
Wisconsin	AA	20	MM	0-251	1413	5.6	Cole & Johansson 1933
Beltsville	BSh	61	CST	0-250	1993	8.0	[3]Dawson *et al* 1960
Manhattan	BSh	42	MM	0-298	2205	7.4	[4]Dawson *et al* 1960
Oklahoma	AA	41	CST	0-200	795	4.0	Deutscher & Whiteman 197
Oklahoma	AAxHol	31	CST	0-200	1136	5.7	Deutscher & Whiteman 197
Florida	AA	119	CST	-	-	2.6	Dickey *et al* 1970
Florida	H	105	CST	-	-	2.6	Dickey *et al* 1970
Ireland	HxSh	96	CST	79-186	-	6.7[1,7]	Drennan 1971
Arkansas	AA	47	CST	(15[1] (75[1] (165[1]	- - -	6.4) 7.3) 4.1)	Drewry *et al* 1959
Arkansas	AA	122	CST	(53 (81 (109	- - -	7.5)[2] 6.5) 4.1)	Dunn *et al* 1965
Arkansas	H	118	CST	(53 (81 (109	- - -	6.2)[2] 5.3) 3.6	Dunn *et al* 1965
Scotland	HxDSh	6	MM	61-133	-	8.3[1,2]	Economides *et al* 1973
Scotland	HxDSh	4	CST	46-118	-	6.0[1]	Economides *et al* 1973
Oklahoma	H	107	CST	63-254	-	3.1[1,2]	Furr & Nelson 1964
East Africa	Az	568	MM	0-239	830	3.5	Galukande *et al* 1962
Arkansas	H AA & Sh	82	HM-HU	0-245[2]	686[1]	2.8[1]	Gifford 1949
Arkansas	H AA & Sh	54	HM-HU	0-244	680	2.8	Gifford 1953
Pennsylvania	AAxHol	24	0-MM	77-200	-	4.3[2,6]	Gillooly *et al* 1967
Canada	H Gal AA ChxAA AAxGal	42	0-MM	25-150[1]	-	6.4	Gleddie & Berg 1968
South Africa	Af	24	CST	0-238	1312	5.5	Heyns 1960
Wisconsin	H	245	(HM&MM) -HU	0-240	1055[2]	4.4[2]	Hohenboken *et al* 1972

TABLE R.3: Milk yield of beef cows (cont)

Location	Breed(s)	No.	Method	Stage of lactation	Lact. yield	Daily yield	Author(s)
					(kg)		
Canada	H AA Gal	377	O-MM	(115 (175	- -	5.8) 4.4)	Jeffery *et al* 1971a
Texas	H	15	O-MM	0-245[1]	715[1]	2.9	Klett *et al* 1965
Texas	AA	15	O-MM	0-245[1]	956[1]	3.9	Klett *et al* 1965
Oklahoma	H	42	CST	0-234[1]	1252[2]	5.2[2]	Kropp *et al* 1973
Oklahoma	HxHol	42	CST	0-234[1]	1993[2]	8.3[2]	Kropp *et al* 1973
Kenya	Bor	164	CST	0-252	1127	4.5	Lampkin & Lampkin 1960
Scotland	ShxGal	70	MM	0-150	806[2]	5.4	Lowman & Edwards 1974
Ireland	HxSh	50	-	0- 42	635[2]	5.3[2]	McCarrick & Crowley 1967
Kenya	Sam	82	HM	0-139	517	3.7	McKay 1957
Arizona	BrSwxH	12	CST	(85 (135 (180	- - -	8.6) 6.0) 5.2)	McGinty & Frerichs 1971
Arizona	H	12	CST	(85 (135 (180	- - -	4.0) 4.1) 3.3)	McGinty & Frerichs 1971
Texas	AA	15	CST	62-237	664[1]	3.8	Melton *et al* 1967
Texas	Ch	15	CST	62-237	784[1]	4.5	Melton *et al* 1967
Texas	H	15	CST	66-241	581[1]	3.3	Melton *et al* 1967
Georgia	H	129	CST	0-240[1]	1023[2]	4.3[2]	Neville 1962
Colombia	BIO	(1357	HM)	0- 93	310	3.3	Pearson *et al* 1968
Colombia	BIOxJ			0-169	690	4.1	Pearson *et al* 1968
Nebraska	Hol	42	CST	0-155	1760	11.4	Plum & Harris 1971
Oklahoma	H	80	-	-	-	4.3[2]	Renbarger *et al* 1964
Louisiana	AA Bra & AAxBra	-	CST	-	-	6.0[1]	Reynolds *et al* 1967
Carolina	H	279	CST	0-205	1033	5.0	Rutledge *et al* 1971
Texas	H	-	CST	-	-	3.7[2]	Schake *et al* 1966
Virginia	AA	21	CST	0-245	1642	6.7	Serwanja *et al* 1969
Virginia	AA	-	MM-HU	0-245	1617	6.6	Serwanja *et al* 1969
Oklahoma	AA H Sh AAxH & Hx	36	(CST (HM-HU	0-210 0-210	1229 953	5.9 4.5	Totusek *et al* 1973
New Zealand	AA	10	CST	0-180	978	5.4	Walker & Pos 1963
New Zealand	HxAA	10	CST	0-180	1048	5.8	Walker & Pos 1963
New Zealand	AAxJ	5	CST	0-180	1415	7.9	Walker & Pos 1963
New Zealand	AAxFr	10	CST	0-180	1048	5.8	Walker & Pos 1963
Pennsylvania	AAxHol	24	CST	19-203	-	7.4[2]	Wilson *et al* 1971
Texas	SG	26	(O-MM & O-CST) -HU	0-205	1384	6.8	Wistrand & Riggs 1966

KEY TO ABBREVIATIONS USED IN TABLE R.3

Aberdeen Angus	AA
Africander	Af
African zebu	Az
Beef Shorthorn	BSh
Blanco Orejinegro	BlO
Boran	Bor
Brahman	Bra
Brown Swiss	BrSw
Charolais	Ch
Dairy Shorthorn	DSh
Friesian	Fr
Galloway	Gal
Hereford	H
Holstein	Hol
Jersey	J
Santa Gertrudis	SG
Shorthorn	Sh
Samburu	Sam

CST - calf-suckling technique
MM - machine milking
O - oxytocin technique
HU - half-udder technique
HM - hand-milked

[1]approximate

[2]mean yield of cows on different planes of nutrition

[3]report of experiment conducted between 1931 and 1935

[4]report of experiment conducted between 1915 and 1919

[5]range of values recorded

[6]fat corrected milk

[7]mean yield of cows at different stocking rates

TABLE R.4: Composition and estimated gross energy value of the milk produced by beef cows

Breed	Composition (g/kg) Butter fat	Solids-not-fat	Total Solids	[1]Gross energy MJ/kg	Authors
Hereford	38.0	87.0	125.0	3.02	Abadia & Brinks 1972
A. Angus	40.6	90.8	131.4	3.20	Cole & Johansson 1933
Hereford X D. Shorthorn[2]	41.1	88.4	129.5	3.17	Economides *et al* 1973
Hereford	39.0	90.0	130.0	3.12	Gleddie & Berg 1968
Galloway	40.0	91.0	130.0	3.18	Gleddie & Berg 1968
A. Angus	40.0	91.0	131.0	3.18	Gleddie & Berg 1968
Charolais X A. Angus	37.0	92.0	129.0	3.08	Gleddie & Berg 1968
Hereford, A. Angus & Galloway	49.9	90.7	140.6	3.55	Jeffrey & Berg 1971
Hereford[2]	26.7	88.5	115.2	2.61	Kropp *et al* 1973
Hereford X Holstein[2]	30.8	86.7	117.5	2.74	Kropp *et al* 1973
B. Shorthorn X Galloway[2]	36.8	82.2	119.0	2.87	Lowman & Edwards 1974
A. Angus	26.8	86.4	113.1	2.57	Melton *et al* 1967
Charolais	28.7	88.5	117.3	2.69	Melton *et al* 1967
Hereford	28.2	89.4	117.6	2.69	Melton *et al* 1967
A. Angus	41.6	85.8	127.3	3.13	Schwulst *et al* 1966
A. Angus	35.3	87.7	123.0	2.93	Serwanja *et al* 1969
A. Angus, Hereford, Shorthorn	32.0	90.0	122.0	2.85	Totusek *et al* 1973
A. Angus X Holstein[2]	34.3	86.1	120.4	2.86	Wilson *et al* 1969
Holsteins[2,3]	35.8	86.7	122.5	2.93	Wilson *et al* 1971

[1]calculated using equation of Tyrrell and Reid (1965)
GE of milk in MJ/kg = 0.0386 B. fat + 0.02056 Solids-not-fat - 0.236

[2]mean value of cows on different planes of nutrition

[3]cows maintained under beef cattle management

fat and solids-not-fat, although variable, are generally similar to those reported for dairy cows by Ling, Kon and Porter (1961). For Friesian dairy cows, Ling, Kon and Porter quote 34.9 g/kg and 85.9 g/kg as the average butter fat and solids-not-fat contents respectively.

For convenience and to facilitate comparison, the different units used for energy and protein in the various studies to be described have been converted into megajoules of metabolisable energy (MJME) and grammes of digestible crude protein (DCP) using the following conversion factors:

1 MJME = 0.239 McalME (Technical Bulletin No. 33 1975)
1 MJME = 0.0559 kg starch equivalent (ARC 1965)
1 MJME = 0.0668 kg total digestible nutrient (ARC 1965)
ME = digestible energy x 0.82 (ARC 1965)
DCP = available protein + 13.4 x daily dry matter intake (ARC 1965)

2.1 NUTRITION DURING THE REARING PERIOD AND FIRST PREGNANCY

The information available on the effect of different planes of nutrition during the rearing period and first pregnancy on the subsequent performance of beef cows appears to be very limited and lacking in detail.

Prolonged over-feeding during the rearing period and first pregnancy has been claimed to result in abnormal udder development and excessive fatness (Pope *et al* 1963; Baker, Ball, Kilkenny and Walsh 1972), and has been reported to reduce the first lactation milk yield of both dairy (Hansson 1956; Swanson 1960) and beef heifers (Arnett and Totusek 1963). However, the levels of energy and protein intake, above which milk yield may be reduced, have not been adequately defined for beef heifers under British conditions.

While there is general agreement in the literature that a low level of nutrition during the rearing period delays puberty in beef heifers (Wiltbank, Cook, Davis and Warwick 1957; Clanton, Zimmerman and Albin 1964; Wiltbank, Bond and Warwick 1965), the effect on subsequent milk yield in successive lactations is not clear.

Howes, Hentges Warnick and Cunha (1958) reported a significant reduction in first lactation milk yield when Hereford and Brahman heifers were fed 50 per cent of their NRC recommended protein requirements compared to controls fed 100 per cent of requirements. Neither the extent of the reduction in milk yield nor the period during which the two levels of protein were fed were specified.

Clanton, Zimmerman and Matsushima (1961) were unable to detect significant differences in milk yield when they fed beef heifers one of four specified planes of nutrition during their first pregnancy, but they reported considerable between-animal variation in milk yield.

Bond and Wiltbank (1970) found that both the energy and protein level received by Aberdeen Angus heifers from approximately seven months of age to approximately 180 days after their first calving, significantly ($P < 0.05$) influenced their first and second lactation milk yield. The design of this experiment was such that it was not possible to differentiate between the effects of plane of nutrition before and after calving. Furthermore, the precise levels of energy and protein intake were not defined.

2.2 NUTRITION DURING LATE PREGNANCY AND LACTATION

Few workers have studied the effect of plane of nutrition during the last eight to 12 weeks of pregnancy on the lactation performance of beef cows.

In two experiments conducted in Eire, Drennan (1974) found that two levels of energy intake in late pregnancy (93 *versus* 56 and 66 *versus* 47 MJME per head daily) had no significant effect on the milk yield of beef cows in their subsequent lactation. In both experiments, however, the live-weight changes of the cows before and after calving were significantly ($P < 0.01$) affected by energy intake in late pregnancy.

Schake, Riggs, McGinty and Marion (1966) fed mature Hereford cows either 100 per cent (control), 130 per cent (high) or 70 per cent (low) of their non-pregnant maintenance requirement for three to four months before calving. The maintenance level they assumed was not specified. At calving, the 130 per cent and 70 per cent levels were interchanged.

There was a suggestion that pre-calving level of nutrition affected daily milk yield in the first two months of lactation but that by the third month, post-calving level of nutrition was of greater importance with respect to milk yield. The averages of five daily milk yield estimates made at monthly intervals during lactation were 3.72, 3.86 and 3.65 kg on the control, 70-130 and 130-70 planes, respectively. These levels of milk production are lower than most of the estimates of daily milk yield in Table R.3 but suggest that the distribution of feed between pregnancy and lactation had little affect on milk yield in this experiment. However, the estimates of daily milk yield were very variable with coefficients of variation of between 30 and 50 per cent.

In a study of the effect of plane of nutrition during lactation, Wilson *et al* (1969) offered 24 group-fed Aberdeen Angus x Holstein cows either 132.5 MJME (high) or 98 MJME (low) per head daily from 76 to 200 days *post partum*, corresponding to 115 and 85 per cent of NRC (1963) recommended requirements. Daily milk yields were measured at two-week intervals by the oxytocin technique.

The daily milk yields of the cows were significantly ($P < 0.01$) affected by energy level and were 10.9 and 7.9 kg for the high and low levels respectively. This was equivalent to a response of 0.85 kg of milk a day for every additional daily intake of 10 MJME. Energy level did not significantly influence the butter fat content, protein content, or the gross energy value of the milk. However, the high energy level resulted in a significantly ($P < 0.01$) greater solids-not-fat content.

Energy level also significantly ($P < 0.01$) affected the live-weight changes of the cows. Cows on the high energy level maintained their initial live-weight, while cows on the low energy level mobilised, on average, 12 per cent of their initial live-weight during the 124-day period.

Economides *et al* (1973) individually fed six machine-milked Hereford x Dairy Shorthorn heifers 96 MJME (high) or 53 MJME (low) per head daily for 72 days, beginning approximately eight weeks *post partum*. The milk production of another four heifers was measured by a calf-suckling technique, but because there was evidence of an effect of method of milking on milk yield, only the responses obtained in the two machine-milked groups will be referred to here.

The numbers of cows involved were insufficient to warrant statistical analysis but there was a marked reduction in daily milk yield on the low level of energy intake compared to the high. The solids-not-fat content of the milk produced by the high group was significantly ($P < 0.01$) greater than that of the low group with mean values of 90.7 and 86.1 g/kg for the high and low groups respectively. The corresponding mean butter fat contents were 40.4 and 41.8 g/kg but the difference was not significant.

B.G. Lowman and R.A. Edwards (personal communication) machine-milked mature Blue-Grey cows from calving to 150 days *post partum*. The daily intakes of the cows were approximately 49 (low), 68 (medium) or 96 MJME (high) per head.

Lowman and Edwards observed a significant ($P < 0.01$) linear trend for milk yield to increase as level of energy intake increased and the 150-day cumulative milk yields were 715, 820 and 843 kg on the low, medium and high levels respectively. However, this was equivalent to a response (high *versus* low) of only 0.18 kg of milk per day for every additional intake of 10 MJME per day.

Energy intake did not significantly affect milk composition but there were highly significant ($P < 0.001$) linear trends for the live-weight losses of the cow to increase as plane of nutrition decreased.

To summarise, there is insufficient experimental evidence available on which to assess the effects of different planes of nutrition during late pregnancy on the lactation performance of beef cows. With respect to plane of nutrition during lactation, it appears that raising the plane of nutrition increases the milk yield of beef cows and influences their live-weight changes. There is also evidence which indicates that the solids-not-fat content of the milk produced by beef cows is increased by higher planes of nutrition during lactation.

Wilson *et al* and Lowman and Edwards observed very different responses in terms of milk yield to an additional daily intake of 10 MJME. However, the range of energy intakes over which the responses were observed, the methods used to measure milk production and the breeds of cow involved in the two studies also differed.

2.3 ENERGY AND PROTEIN ALLOWANCES CURRENTLY RECOMMENDED FOR BEEF COWS

The daily allowances of energy and protein currently recommended for beef cows at different stages of their production cycle are shown in Table R.5

TABLE R.5: Recommended daily allowances of energy and protein for a 500 kg beef cow

	DM (kg)	DCP (g)	ME (MJ)
Pregnancy			
NRC (1970) Stage of pregnancy not defined	7.6	210	57
ARC (1965) 8th month	7.5[1]	310[2]	61
9th month	7.5[1]	445[2]	80
Baker *et al* (1972) last 4 to 8 weeks	-	500-590	70- 97
Stewart *et al* (1972)[3] up to 6 weeks before calving	-	270	50
last 6 weeks	-	385	60
Lactation			
NRC (1972) first 3 to 4 months	10.5	570	90
ARC (1965) for 5 kg milk a day[4]	7.5[1]	455	74
10 kg milk a day[4]	10.0[1]	720	104
Baker *et al* (1972) first 12 weeks	-	680-770	80-105
12 weeks onwards[5]	-	660	80- 86
Stewart *et al* (1972)[3] first 3 weeks	-	385	60
3 to 12 weeks	-	610	80
12 weeks onwards	-	385	60

[1]not specified; assumed DM intake of M/D value 9.2;

[2]minimum DCP requirement of a pregnant cow carrying calf of potential birth-weight 40 kg;

[3]refers to 450 kg cow;

[4]not specified; assumed levels of milk production;

[5]Baker *et al* suggest that lower levels of energy and protein can be supplied provided the cow is in reasonable body condition.

Direct comparison of the various allowances recommended by the ARC (1965), NRC (1970), Baker *et al* (1972) and Stewart *et al* (1972) is difficult because the allowances in many instances do not relate to precisely the same stage of the production cycle. Furthermore, the allowances of Stewart *et al* (1972) refer to a 450 kg beef cow.

Only the NRC (1970) have quoted an average daily dry matter (DM) allowance but it was necessary to assume a daily DM intake to enable calculation of the ARC (1965) protein allowances which were quoted in terms of available protein and converted to DCP using an assumed DM intake. There is considerable variation in the recommended DCP allowances for beef cows in late pregnancy. The recommendations of the ARC (1965) and Stewart *et al* (1972) are in reasonable agreement but the recommendation of the NRC (1970) is markedly lower and that of Baker *et al* (1972) markedly higher. There is slightly better agreement with respect to the energy allowances for late pregnancy.

In lactation, the ARC (1965) do not specify the levels of daily milk yield which may be expected from beef cows and it was necessary to assume the two levels quoted in Table R.5.

There is reasonable agreement with respect to the daily DCP allowances in lactation. Stewart *et al* (1972) recommend a lower energy and protein allowance for the first three weeks after calving because they maintain that a high level of milk production is undesirable at this time when the appetite of the suckled calf for milk is limited.

The allowances of both energy and protein recommended by Baker *et al* (1972) from 12 weeks *post partum* onwards are relatively high, but they make the point that lower levels are acceptable provided the cow has adequate body reserves.

3. THE EFFECT OF NON-NUTRITIONAL FACTORS ON THE LACTATION PERFORMANCE OF BEEF COWS

Introduction

There are a number of non-nutritional factors which can influence the milk production of beef cows. The evidence relating to the effect of method of estimating milk production and factors associated with milk removal have been discussed in an earlier section. It was concluded that the methods used to estimate milk yield and collect milk samples can have a marked effect on the estimates of milk yield and composition obtained.

Breed of cow

The relative yield and composition of milk produced by different breeds and crosses of beef cow can only be assessed accurately when the breeds and crosses have been compared under the same conditions, using the same methods of estimating yield and obtaining milk samples.

There is general agreement in the literature that in North America, Aberdeen Angus cows have a higher milk yield than Hereford cows (Dunn *et al* 1965; Klett, Mason and Riggs 1965; Melton *et al* 1967; Gleddie and Berg 1968; Jeffrey, Berg and Hardin 1971a) and only Dickey, Koger, Franke and Burns (1970) have failed to detect a difference in milk yield between the two breeds (see Table R.3). In Texas, Melton *et al* (1967) found that Charolais cows had a higher milk yield than either Aberdeen Angus or Hereford cows (see Table R.3).

Studies have also shown that crossbred beef cows, particularly when they are the product of a cross between a dairy breed and a beef breed, have higher milk yields than pure beef breeds (Walker and Pos 1963; Pearson *et al* 1968; Todd, Riggs and Smith 1968; Deutscher and Whiteman 1971; McGinty and Frerichs 1971).

Sumption *et al* (1970) have categorised 15 breeds of cattle available to North American beef producers in terms of their milk yield, and Mason (1971) has summarised much of the available data relating to the lactation performance of the 'larger' European breeds of cattle. There is no published information on the relative milk yields of the different breeds and crosses of beef cow maintained under British conditions.

The differences between various breeds of dairy cow in terms of milk composition are well known, although it is also recognised that there is considerable variation between cows of the same breed (Rook 1961; Hall and Bucket 1969; Foley *et al* 1972; McDonald, Edwards and Greenhalgh 1973). Differences in milk composition between the different breeds and crosses of beef cow are less clearly defined.

In Texas, Melton *et al* (1967) reported significant ($P < 0.01$) differences between Charolais, Aberdeen Angus and Hereford cows in the solids-not-fat contents of their milk, but no significant differences between the breeds in the butter fat and total solids contents (see Table R.4). Kropp *et al* (1973) found that Hereford x Holsteins produced milk of a significantly ($P < 0.01$) higher butter fat content than did the Hereford, but that the Hereford's milk had a significantly ($P < 0.05$) higher solids-not-fat content. Gleddie and Berg (1968), however, were unable to detect significant differences between the solids contents of the milk produced by Aberdeen Angus, Galloway, Aberdeen Angus x Galloway, Hereford and Charolais x Aberdeen Angus cows, although the number of cows representing each breed and cross was small.

Size of cow

There is no simple definition of the size of a particular cow (Holmes 1973; Robertson 1973) and live-weight is the most commonly used measure, although linear measurements may be desirable when comparing cows of the same breed (Holmes 1973).

A number of studies have shown positive phenotypic correlations between the live-weight of dairy cows shortly after calving and their total milk yield in the subsequent lactation (e.g. Gaines, Davis and Morgan 1947; Bailey and Broster 1954; Erb 1962; Clark and Touchberry 1962; Reid *et al* 1964). It is difficult, however, to distinguish between the effects of genetic and environmental factors on this relationship because environmental factors may influence live-weight and milk production, simultaneously. Johannson (1964) in a review of the available evidence concluded that size of animal and milk yield were not correlated to any appreciable extent. Similarly, Taylor (1973) considered that while there was evidence of a small positive genetic association between the live-weight and milk yield of dairy cows, the effect was quantitatively small.

The relationship in beef cows has received much less attention. Jeffrey, Berg and Hardin (1971a) found a significant ($P < 0.01$) relationship between live-weight *post partum* and subsequent milk yield in one year of a two-year study of factors affecting the milk production of beef cows. When the effect of age of cow was eliminated, every 10 kg increase in live-weight *post partum* was associated with an increase in daily milk yield of 0.1 kg.

Todd, Riggs and Smith (1968) found no relationship between the size of beef cows and their milk yield or composition, and Christian, Hauser and Chapman (1965) and Wilson *et al* (1969) reported small, non-significant, negative correlations between body size, estimated from measurements of heart girth, height at the withers, etc, and milk yield.

In the absence of critical data on the relationship between live-weight and milk yield in beef cows, the conclusion reached from studies with dairy cows must be accepted.

Age

It is well established that the lactation milk yield of a dairy cow increases as the cow becomes older (e.g. Foley *et al* 1972; McDonald, Edwards and Greenhalgh 1973), and that the maximum is reached when the cow is approximately eight years of age (Foley *et al* 1972). This may be attributable partly to age *per se* and partly to the increase in live-weight usually associated with an increase in age (Clark and Touchberry 1962).

The evidence suggests that beef cows attain their maximum lactation yield at about six years of age (Gifford 1953; Heyns 1960; Dawson, Cook and Knapp 1960) corresponding to their fourth lactation (Gifford 1953; Jeffery, Berg and Hardin 1971a), although Rutledge, Robison, Ahlschwede and Legates (1971) reported that the maximum lactation yield of beef cows occurred at between eight and nine years of age.

Melton *et al* (1967) have demonstrated the magnitude of the effect of age on the milk production of Charolais, Aberdeen Angus and Hereford cows. The milk yields of cows two, three and four, and five or more years of age were 553, 667 and 809 kg respectively for a 175-day lactation period. The differences in milk yield were significant ($P < 0.01$).

There is little information in the literature on the rate of decline in lactation yield after the maximum is reached.

The butter fat and solids-not-fat content of the milk produced by dairy cows decrease as the cow becomes older and this is ascribed partly to the greater level of sub-clinical mastitis present in older cows (Rook 1961).

Melton *et al* (1967) did not detect a significant effect of age on the composition of milk produced by three breeds of beef cow. Similarly, Gleddie and Berg (1968) found no significant difference between the milk composition of two-year old and mature Herefords.

Suckling cows have a lower incidence of udder infections than do machine-milked cows (Walsh 1974) and thus, the effect of age on the composition of the milk produced by beef cows which normally suckle their calves may be less pronounced than in dairy cows which are machine-milked.

<u>Stage of lactation</u>

The lactation curve of a dairy cow is characterised by a rapid rise in daily milk yield during the first few weeks after calving, followed by a slow decline over the remainder of the lactation period (Wood 1976). Maximum daily milk yield, i.e. peak yield, occurs approximately six weeks after parturition (McDonald, Edwards and Greenhalgh 1973; Wood 1976).

There is very little detailed information in the literature on the shape of the lactation curve of beef cows and few workers have recorded milk production throughout the whole lactation period. It has been shown that the shape of the lactation curve of a beef cow can be influenced by the level of nutrition at different stages of lactation (Bond *et al* 1964; Furr and Nelson 1964; Wilson *et al* 1969; Deutscher and Whiteman 1971;

Kropp *et al* 1973), and also by the method used to estimate daily milk yield (Totusek *et al* 1973).

Studies have shown that the general shape of the lactation curve of a beef cow is similar to that of a dairy cow although it appears to be flatter with a less pronounced 'peak' (Cole and Johansson 1933; Gifford 1953; Dawson, Cook and Knapp 1960; Walker and Pos 1963; Totusek *et al* 1973). Peak milk yield has been reported to occur during either the first (Gifford 1953) or second (Cole and Johansson 1933; Dawson, Cook and Knapp 1960; Totusek *et al* 1973) month of lactation. Walker and Pos (1963), working with Aberdeen Angus x Friesian and Aberdeen Angus x Jersey cows, and Plum and Harris (1971) with Holstein cows managed as beef cows, reported that peak yield occurred later in lactation at between nine and 12 weeks after calving. This was probably because in these two studies the appetite of the suckled calves for milk was less than the potential milk output of their dams prior to the attainment of peak yield.

The trends in milk composition associated with the stage of lactation of dairy cows are well characterised. The butter fat and solids-not-fat content are at a maximum in early lactation, fall, rapidly at first and more steadily later, to a minimum which occurs at about six weeks for solids-not-fat and about ten weeks for butter fat (Rook 1961).

Only Gleddie and Berg (1968) appear to have considered the effect of stage of lactation on the composition of milk produced by beef cows. They estimated milk composition once per month during the first five months of lactation but were unable to detect a significant effect of month of lactation on milk composition.

Disease

It is known that many diseases, particularly mastitis and hypocalcaemia, reduce the yield (Foley *et al* 1972) and can alter the composition of the milk produced by dairy cows (Waite, White and Robertson 1956; Rook 1961; Wheelock and Dodd 1969). In beef cows, any disease is also liable to affect milk production with the magnitude of the effect dependent on the nature of the particular disease and its severity.

There is no reference in the literature to the possible effect of ill-health in a suckled calf on the milk production of its dam.

Birth-weight of calf

Evidence was cited in a previous section which indicated that some beef cows are genetically capable of producing more milk in early lactation than the suckled calf can consume, provided nutritional and environmental conditions are satisfactory. The appetite of a calf for milk is closely related to its weight (Roy 1970) and thus, the birth-weight of a suckled calf may influence the level of milk production of its dam with higher birth-weights associated with higher milk yields.

A number of workers have reported significant positive correlations between calf birth-weight and milk production (Drewry, Brown and Honea 1959; Heyns 1960; Wistrand and Riggs 1966; Drennan 1971; Rutledge *et al* 1971). Other workers have failed to detect a significant relationship between calf birth-weight and milk yield (Brumby, Walker and Gallagher 1963; Christian, Hauser and Chapman 1965; Gleddie and Berg 1968) and Jeffery, Berg and Hardin (1971a) considered that birth-weight was not an important factor influencing the milk production of beef cows.

Christian, Hauser and Chapman (1965) argued that by permitting fewer sucklings per day in the calf-suckling technique than occur under natural conditions, the potential daily milk intake of the calf is reduced. They infer that a positive correlation between birth-weight and milk yield does not exist in a natural suckling régime, but may exist when a restricted suckling régime is adopted as in the calf-suckling technique.

While the imposition of a restricted suckling régime may reduce the milk intake of a suckled calf, there is evidence which indicates that the milk production of beef cows in early lactation can markedly exceed the maximum milk intake of the calf (Research Investigations and Field Trials 1970-71, 1972-73; Plum and Harris 1971). Thus, calf birth-weight is likely to affect milk production under these circumstances. Furthermore, because birth-weight is influenced by breed (Preston and Willis 1974) it can be concluded that the milk production of beef cows may also be influenced by the breed of calf suckled.

Sex of calf

There is disagreement in the literature as to whether or not the milk production of beef cows is influenced by the sex of a suckled calf. Knapp and Black (1941), Cartwright and Carpenter (1961), Melton *et al* (1967) and Dickey, Koger, Franke and Burns (1970) reported that beef cows suckled by male calves had higher milk yields than contemporaries suckling female calves. Christian, Hauser and Chapman (1965), Gleddie and Berg (1968) and Wilson *et al* (1969) observed no effect of sex of calf on the milk production of their dams and Rutledge *et al* (1971) found that beef cows suckled by female calves produced more milk than those suckled by male calves. Jeffery, Berg and Hardin (1971a) found that the dams of male calves produced more milk than the dams of female calves in one year of a two-year study, and less in the second.

Numerous studies, summarised by Preston and Willis (1974), have shown that male calves are heavier at birth than are female calves and, because it was concluded in the previous section that the birth-weight of a suckled calf can influence the milk production of its dam under certain circumstances, it appears that the sex of calf suckled should also influence milk production. If the potential milk output of a beef cow is less than the potential milk intake of its calf, birth-weight and sex would be expected to have little or no effect; if, however, the potential milk output of a beef cow is greater than the appetite of the suckled calf for milk, male calves, because they are heavier at birth, would be expected to have a greater appetite for milk. Therefore, they may allow their dams to produce higher levels of milk production in early lactation than the dams of female calves.

An alternative explanation for the effect of sex of calf on milk production, proposed by Jeffery, Berg and Hardin (1971a), is that male calves are more aggressive than female calves, and thereby stimulate higher levels of milk production in their dams. The data of Melton *et al* (1967) tend to support this proposition. Melton *et al* found that Aberdeen Angus cows suckled by entire male calves had higher milk yields than contemporaries with female calves, despite the fact that in this particular study the male calves were only 0.1 kg heavier at birth than female calves.

Unfortunately, not all workers have specified whether or not male calves were entire or castrated, and castrates may have less aggressive suckling habits than entire male calves.

4. THE EFFECT OF NUTRITION ON THE REPRODUCTIVE PERFORMANCE OF BEEF COWS

INTRODUCTION

The reproductive performance of beef cows is a major factor affecting the biological and economic efficiency of suckled calf production.

The criteria commonly used to assess the reproductive performance of a beef herd are:

a) calving percentage, i.e. the percentage of cows given the opportunity to breed which produce a calf;

b) calving interval, i.e. the interval in days between the average date of calving of the herd in two successive years;

c) spread of calving, i.e. the interval in days between the first cow calving and the last cow calving in the herd.

Spread of calving has only recently received attention but has been shown by the MLC (1975) to be associated with the economic performance of the beef herd.

Table R.6 shows the average reproductive performance of beef cows in a sample of beef herds in the United Kingdom

TABLE R.6: Average reproductive performance of a sample of beef herds in the UK in 1973-74 (*after* MLC 1975)

Type of herd	Number of herds	Average no. of cows in herd	Calving percentage	Calving interval (days)	Spread of calving[1] (days)
Hill	103	60	93.2	375	114
Upland	102	51	94.3	375	111
Lowland	226	61	94.5	369	102

[1]spread of 90 per cent of calvings

Table R.6 shows that only six to seven per cent of beef cows given the opportunity to breed failed to produce a calf but that the average calving interval of each type of herd was in excess of 365 days. If an average calving interval of more than 365 days occurs in successive years, the average date of calving becomes progressively later with consequences for both the management and the profitability of the suckler herd.

Table R.6 also shows that the average spread of calving was markedly greater than the 70 days which Baker *et al* (1972) considered should be the maximum spread of calving aimed for in a beef herd. It is evident that the high calving percentages currently being attained in beef herds are achieved by tolerating a wider spread of calving than is desirable.

While a number of non-nutritional factors are known to influence the reproductive performance of beef cows, including disease, age, and bull to cow ratio during the breeding period, there are published data which indicate that nutrition plays an important role.

4.1 NUTRITION DURING THE REARING PERIOD

A number of studies have shown that increasing the plane of nutrition received by beef heifers during the rearing period reduces their age at puberty (Joubert 1954; Clanton, Zimmerman and Albin 1964; Wiltbank *et al* 1966; Wiltbank, Kasson and Ingalls 1969).

Wiltbank *et al* (1966) examined the effect of plane of nutrition on the average age and live-weight of beef heifers at their first ovulatory oestrus (puberty). Two nutritional treatments were imposed on the heifers from 200 to 396 days of age, resulting in average daily live-weight gains of either 0.4 kg (high plane) or 0.2 kg (low plane) per head during the 196-day period. The results of this study (see Table R.7) show that the lower plane of nutrition delayed puberty and decreased the live-weight of the heifers at that time.

TABLE R.7: Effect of plane of nutrition on the age and live-weight of beef heifers at first oestrus (*after* Wiltbank *et al* 1966)

	Plane of nutrition	
	High	Low
Number of heifers	171	182
Age at first oestrus (days)	332	395
Live-weight at first oestrus (kg)	264	240

Clanton, Zimmerman and Albin (1964) investigated the effect of two levels of energy and two levels of protein (in a factorial arrangement) on the average age at puberty of beef heifers individually fed for a 140-day period. The low protein (LP) and low energy (LE) levels corresponded to 60 per cent and 82 per cent of NRC recommendations, respectively; the high protein (HP) and energy (HE) corresponded to 100 per cent of NRC recommendations for a daily gain of 0.45 kg.

The average ages of the heifers at puberty were 384, 469, 459 and 471 days on the HP-HE, HP-LE, LP-HE and LP-LE levels respectively, and 93 per cent of the heifers on the HP-HE level had manifested a complete oestrous cycle by 15 months of age compared to only 36 per cent of heifers on the other three levels. These data indicate that restricting either the energy or protein intake of beef heifers, below NRC recommended levels, delays puberty.

It has been demonstrated by Bond, Wiltbank and Cook (1958) that when beef heifers displaying normal oestrous cycles are fed very low levels of energy and protein, ovarian activity ultimately ceases and the heifers become anoestrus. The effect observed was not irreversible, however, and when the levels of energy and protein offered to the heifers were increased, normal oestrous activity recommenced. Thus, the evidence indicates that plane of nutrition during the rearing period influences the age at which puberty is reached, and the continuance of regular oestrous cycles in beef heifers.

These conclusions have been reached from investigations undertaken almost exclusively in North America and Africa (see Review by Joubert 1963) and there is a lack of critical data obtained under UK conditions. In the UK more emphasis is placed on calving beef heifers at two rather than three years of age, and, in general, higher rates of daily live-weight gain are obtained than those quoted in the North American studies described.

Furthermore, an interaction has been observed between breed and level of nutrition in relation to both the age and live-weight of beef heifers at puberty (Wiltbank, Kassan and Ingalls 1969) and information is lacking on the effect of nutrition on the attainment of puberty in the breeds and crosses used as beef females in the UK.

4.2 THE EFFECT OF NUTRITION ON THE REPRODUCTIVE PERFORMANCE OF MATURE BEEF COWS

There are a number of difficulties associated with any appraisal of the experimental evidence relating to the effect of nutrition on the reproductive performance of beef cows.

Beef cows are generally expected to conceive for a subsequent production cycle during lactation. The energy and protein intake of a beef cow, in relation to its requirement for maintenance and milk production, will determine whether or not the cow is in positive or negative energy and protein balance and whether or not the cow is gaining or losing live-weight. Hence, the level of milk output of a beef cow prior to and during the mating period may influence its reproductive performance on any given level of energy and protein intake.

Most of the experimental evidence on the relationship between the nutrition of beef cows and their reproductive performance has been accumulated from studies undertaken in North America and Africa. The levels of milk production of beef cows in North America and Africa may differ in magnitude from those of beef cows in the UK and, hence, the conclusions reached as to adequate levels of nutrition for satisfactory reproductive performance in these areas may be inappropriate for beef cows in the UK.

A further problem arises because the level of body reserves of a beef cow at the beginning of an experimental period may influence its response in reproductive terms to different levels of energy and protein intake. While in some studies, levels of body reserves have been assessed by body score measurements (Wiltbank *et al* 1962; Wiltbank *et al* 1964), in the absence of a standardised method of describing the body condition of beef cows the interpretation of body score measurements is difficult.

The significance of body condition and whether or not body condition is improving, stable, or decreasing during the mating period has been the subject of research in sheep production (e.g. Coop 1966; Gunn, Doney and Russel 1969), but has received little attention in beef cows. The general conclusion reached from work with sheep is that when body condition is good, whether or not body condition is increasing, decreasing, or stable, it has little effect on fertility. When ewes are in poor body condition at mating, however, fertility is higher when body condition is improving. The significance of body condition and body condition changes at mating on the reproductive performance of beef cows is an area which requires critical examination.

The experimental evidence relating to the effect of under-nutrition on the reproductive performance of beef cows has been comprehensively reviewed by Lamond (1970). Lamond concluded that for an individual beef cow there is a threshold body-weight below which low fertility can be expected. He further concluded that beef cows can lose up to 15 per cent of their body-weight during mid and late pregnancy without any detriment to their productivity and that when beef cows have a high plane of nutrition after calving, and they are not mated within at least 60 days of calving, fertility should be normal even if a low plane of nutrition was experienced before calving.

Lamond also discussed in qualitative terms the significance for fertility, of changes in body condition and live-weight at the time of mating in relation to current plane of nutrition.

EXPERIMENTAL SECTION

INTRODUCTION

The two experiments to be described represent the first and second year of a three-year investigation of the response of autumn-calving beef cows to three planes of nutrition during lactation.

In Experiment 1, the response of beef heifers to three planes of nutrition during lactation and the effect of two methods of measuring the milk production were examined. Experiment 2 examined the response of beef cows to three planes of nutrition during lactation using only one method of measuring milk production.

The materials and methods used in the two experiments were similar and are therefore described jointly. Certain aspects of the procedures adopted in the experiments are discussed in Appendix 3.

The conclusions reached from the two experiments are summarised in a final section which includes suggestions for areas of future research and practical management and feeding recommendations for beef cows.

1. MATERIALS AND METHODS

LOCATION AND DURATION OF EXPERIMENTS

EXPERIMENTAL DESIGN

ANIMALS

Cows

Calves

Replacements: *a) cows*
b) calves

TREATMENTS

Methods of milking: *a) the machine-milking technique*
b) the calf-suckling technique

Plane of nutrition

FACILITIES

MANAGEMENT OF ANIMALS

Management prior to Experiment 1

Management at calving

Management during experimental periods: *a) cows*
b) calves

Management between Experiments 1 and 2

Management from turnout to weaning in Experiment 2

RECORDING OF FEED INTAKES, LIVE-WEIGHTS AND CONDITION SCORES

Feed intakes: *a) cows*
b) calves

Live-weights and condition scores: *a) cows*
b) calves

SAMPLING AND ANALYTICAL TECHNIQUES

Milk

Feeds: *a) silage*
b) concentrates and hay

STATISTICAL PROCEDURES

Milk yields

Live-weights and condition scores

Hay intakes of calves

Analysis

LOCATION AND DURATION OF EXPERIMENTS

Both experiments took place at Boghall, one of the farms of The Edinburgh School of Agriculture, situated seven miles from Edinburgh. Boghall Farm is 200 m above sea level at latitude 55°52'N and longitude 3°13'W.

Experimental treatments were imposed on lactating beef cows from parturition in the autumn until late April the following spring. Table M.1 shows the average date of calving, the range in date of calving and the length of each experiment.

TABLE M.1: Average date of calving, range in date of calving and length of experimental periods

	Experiment 1	Experiment 2
Average date of calving	22.10.73	9.10.74
Range in date of calving (days)	66	106
Date experiment terminated	15.4.74	17.4.75
Mean (±SD) length of experimental period (days)	175 ± 17.6	190 ± 29.2

As a result of a range in date of calving at the beginning of each experiment, the length of time individual cows were subject to experimental treatment varied and results are presented for the first 150 days of lactation only. Of the 71 lactations recorded, five were less than 150 days in length.

EXPERIMENTAL DESIGN

In Experiment 1, 36 cows were randomly assigned to one of six treatments arranged in a two times three factorial design giving six replicates per treatment. The factors considered were method of milking (machine-milking and a calf-suckling technique) and plane of nutrition during lactation (high, medium and low).

In Experiment 2, the 36 cows were assigned, on the basis of treatment in Experiment 1, to one of three planes of nutrition during lactation (high, medium and low), giving 12 replicates per treatment. Only one method of measuring milk yield (a calf-suckling technique) was used in Experiment 2.

The two experiments formed part of a three-year investigation of serial factorial design. Twelve of the 36 cows were selected at random to remain on the same plane of nutrition in both experiments, ie four cows on each plane of nutrition, two of which were machine-milked and two calf-suckled in Experiment 1. The remaining eight cows on each plane of nutrition in Experiment 1 were randomly assigned, within method of milking, to one of the two other planes of nutrition in Experiment 2.

ANIMALS

Cows

Thirty-six Hereford x British Friesian cows in their first lactation (ie heifers) were used in Experiment 1, and 36 in their second lactation in Experiment 2. The same cows were involved in both experiments with three exceptions, detailed in the section on replacements.

At the beginning of each experiment the cows were weighed twice, and condition scored according to the method described by Lowman, Scott and Somerville (1973), approximately 12 hr *post partum*. In Experiment 1, the mean (±SD) live-weight of the cows *post partum* was 433 ± 38.7 kg and their mean condition score 2.7 ± 0.56. In Experiment 2, the mean live-weight of the cows *post partum* was 500 ± 56.1 kg and their mean condition score 2.6 ± 0.29.

Calves

The calves used in the calf-suckling technique were sired by an Aberdeen Angus bull in Experiment 1 and a Charolais bull in Experiment 2. All calves had the same sire in each experiment.

Replacements

a) Cows

One cow aborted at the beginning of Experiment 1 and was not replaced. Two cows which participated in Experiment 1 failed to conceive and were unavailable for Experiment 2. This necessitated the introduction of three replacement cows in Experiment 2. The three Hereford x British Friesian females introduced had failed to conceive as heifers and, although they were the same age as the other cows involved in Experiment 2, they were of different parity and had calves sired by a different Charolais bull. One of these cows was allocated to each treatment in Experiment 2.

b) Calves

In Experiment 1, the calf of a heifer assigned to the calf-suckling technique died at birth. A 24 hr old calf from a heifer assigned to machine-milking was available and was fostered-on within 6 hr of calving. A similar problem was encountered in Experiment 2 when a three-day old calf (from a Hereford x British Friesian cow and sired by the same bull as other calves involved in Experiment 2) was fostered-on.

In Experiment 2, one calf died at seven days of age. No Charolais cross calf was available, and a one-week old Hereford x British Friesian calf was purchased from a local dairy farm and was fostered-on.

All three cows readily accepted their fostered-on calf and it was assumed that their lactation performance was not affected. The growth and feed intake data of the fostered-on Hereford x British Friesian calf in Experiment 2 were excluded from the analysis.

TREATMENTS

Methods of milking

a) The machine-milking technique

In Experiment 1, the 18 cows assigned to machine-milking had their calves removed approximately 12 hr *post partum*. Subsequently, the cows were machine-milked twice daily, at 07.00 hr and 15.00 hr using Alfa Laval bucket units (Alfa Laval Co Ltd, Cwmbran, Monmouthshire). The milk produced by each cow was weighed to the nearest 100 g on a suspended balance and the yield recorded at every milking.

Twice-daily milking was reduced to once per day if a cow yielded less than 0.25 kg at three consecutive milkings. Milking continued once daily at 07.00 hr unless the yield was less than 0.25 kg at three consecutive milkings at which point milking was discontinued.

The milking procedure was similar to that used for dairy cows and included washing the udder, examining the fore-milk for mastitis and, following milk removal, teat dipping with an iodine-based compound. Hand-stripping of residual milk was not practised, and machine-stripping of specific quarters proved necessary in only a small proportion of cows.

b) The calf-suckling technique

The calf-suckling technique involved the weighing of a calf before and after suckling to determine, by weight difference, its milk intake and hence the milk production of the dam.

From 12 hr *post partum* onwards, calves were kept tied behind their dams (see Diagram 1 on page 98) and were only released to allow suckling. At each suckling, young calves were not removed from their dams until teat-sucking had ceased. In older calves, rapid changing from teat to teat was assumed to signify the end of suckling. The number of times per day cows were allowed to suckle their calves at different stages of lactation is shown in Table M.2.

TABLE M.2: Suckling frequency per day and times of suckling

Suckling frequency per 24 hours	Days *post partum* Experiment 1	Days *post partum* Experiment 2	Times of suckling (hr) Experiments 1 and 2			
4	1 to 7	1 to 7	07.00,	11.30,	16.00,	22.00
3	8 - 42	8 - 56	07.00,	-	16.00,	22.00
2	43 - 150	57 - 150	07.00,	-	16.00,	-
1	151+	151+	07.00,	-	-	-

In Experiment 2, the frequencies of suckling were modified and cows were allowed to suckle their calves three times per day up to 56 days *post partum*. The calves were observed during suckling and if a calf was seen to defecate or urinate, all data relating to the milk intake of the calf for the particular day were disregarded.

The recording of milk yield by the calf-suckling technique commenced approximately 24 hr *post partum*. From one to seven days *post partum*, milk yields were determined daily by weighing calves before and after each of the four sucklings per day. From eight days *post partum* onwards, milk yields were determined on two consecutive days each week. In addition, when the suckling frequency was reduced, milk yield determinations were made on the two days before, on the two days after, and on the day that the suckling frequency was reduced. The calves were weighed to the nearest 250 g on one of two Avery platform balances (Avery Scales, Birmingham, Warwickshire) which were regularly serviced and tested for accuracy. The daily milk yield of the cows was calculated by summing the calf weight increments recorded at every suckling on that day.

Planes of nutrition

The cows were individually offered one of three levels of nutrition during lactation. The levels were designed to provide either 175 per cent of the estimated energy requirement of a cow for maintenance (high), 125 per cent (medium) or 90 per cent (low). These levels of feeding were imposed on the cows from 24 hr *post partum* until the experiments were terminated in late April. The estimated maintenance requirement of each cow (0.5 MJME/kg$^{0.75}$ per day) was based on the mean of two live-weight measurements made approximately 12 hr *post partum*.

The rations offered to the cows consisted of grass silage and a concentrate supplement combined at a fixed ratio on a dry matter (DM) basis to give a ration energy concentration (M/D) of approximately 10.3 MJME/kgDM. The fresh weight of silage and concentrates offered to the cows remained constant throughout the experimental period.

Immediately prior to each experiment the silage to be used was sampled in the silo. Twenty-four core samples were taken at random and chemically analysed to provide an estimate of the DM, metabolisable energy (ME) and digestible crude protein (DCP) of the silage. The DM and ME values were used to calculate the ratio of silage to concentrate supplement required to achieve an M/D of 10.3, and the quantities of silage and concentrates necessary to provide either 175, 125 or 90 per cent of the estimated maintenance requirement of the cows of different live-weights *post partum*.

In Experiment 1, it was necessary to offer silage and a concentrate supplement combined at a ratio of 4.5 : 1 on a DM basis to achieve the required M/D value (10.3). In Experiment 2, because the silage available was estimated to be of higher energy value, the required ratio of silage to concentrate supplement was 7.3 : 1.

The average chemical composition and estimated nutritive values of the silages offered in the experiments determined from samples collected daily, are shown in Table M.3.

TABLE M.3: Average chemical composition and estimated nutritive values of the silages

	Experiment 1	Experiment 2
Dry matter (g/kg)	230.9	262.1
pH	4.1	4.0
MAD-fibre (g/kgDM)	406.1	321.5
Crude protein (g/kgDM)	113.7	133.0
Ash (g/kgDM)	80.7	82.7
[1]Metabolisable energy (MJ/kgDM)	8.7	10.1
[1]Digestible crude protein (g/kgDM)	63.2	80.0

[1]see text for equations used to calculate ME and DCP

The DM, ME and DCP content of the silage was higher in Experiment 2 than in Experiment 1. Details of the method and frequency of sampling, analytical techniques and equations used to calculate the nutritive values of the silages are described in a subsequent section.

In each experiment, three different concentrate supplements were formulated, and one was offered on each plane of nutrition. The required composition of the supplements (Table M.4) was dependent on the estimated nutritive value of the silage determined prior to the experiments. Molasses was incorporated in the supplements to facilitate cubing.

TABLE M.4: Composition of the concentrate supplements offered at each of the three levels of nutrition

Constituents (kg)	Experiment 1 High	Experiment 1 Medium	Experiment 1 Low	Experiment 2 High	Experiment 2 Medium	Experiment 2 Low
Barley	918	725	351	907	545	-
Urea	12	16	22	-	-	-
Soya bean meal	-	182	540	-	295	766
Molasses	50	50	50	50	50	50
[1]Minerals and vitamins	20	27	37	43	110	184

[1]"Hiphos C516": Isaac Spencer & Co (Aberdeen) Ltd
(declared composition: Ca - 20%; P - 15%; NaCl - 7.5%; Mg - 10%; Cu - 600 ppm; Co - 10 ppm; Mn - 4400 ppm; Zn - 600 ppm; Fe - 10 ppm; Vit A 108,840 iu/kg and Vit D_3 10,880 iu/kg)

The concentrate supplements offered on each plane of nutrition differed in DCP content in an attempt to ensure that the minimum daily DCP intake was 640 g per head, sufficient to meet the estimated daily requirement of a 500 kg cow for maintenance and the production of 7 kg of milk. (The equation used to estimate DCP requirement in g per day was $22.94 + 2.538W^{0.75} + 50Y$, where W is the live-weight of the cow in kg and Y is milk yield in kg; R.A. Edwards, personal communication).

The chemical composition and estimated nutritive values of the supplements, determined from samples collected every 28 days, are shown in Table M.5.

TABLE M.5: Chemical composition and estimated nutritive values of the concentrate supplements offered at each of the three levels of nutrition

	Experiment 1			Experiment 2		
	High	Medium	Low	High	Medium	Low
Dry matter (g/kg)	849	853	852	871	859	860
Crude protein (g/kgDM)	177	238	334	109	213	368
Crude fibre (g/kgDM)	68	64	68	47	49	60
Ether extract (g/kgDM)	14	12	12	13	9	10
Nitrogen-free-extractives (g/kgDM)	695	630	519	768	606	384
Ash (g/kgDM)	46	55	66	64	123	179
[1]Metabolisable energy (MJ/kgDM)	13.0	12.6	12.1	13.1	11.5	10.6
[1]Digestible crude protein (g/kgDM)	134	188	284	83	173	331

[1]see text for equations used to calculate DCP and ME

The higher energy value of the silage available for Experiment 2 meant that a lower level of concentrate supplementation was required to achieve a ration M/D of 10.3. Hence, a higher DCP content was required in the supplements used in Experiment 2 in order to ensure a minimum daily DCP intake of 640 g per cow. The mineral and vitamin inclusion rate in the concentrate supplements was also varied (see Table M.4) to ensure that the mineral and vitamin intake of all cows was in excess of their ARC (1965) recommended requirements.

The quantities of silage, concentrates and dry matter offered to the cows are shown in Table M.6. It should be noted that the values appearing in Table M.6 refer to the quantities of feed offered to the cows and not necessarily to the quantities consumed. The intakes of the cows are described in the results section.

TABLE M.6: Quantities of silage, concentrates and dry matter offered to the cows

	Experiment 1			Experiment 2		
	High	Medium	Low	High	Medium	Low
Silage (kg/day)	24.9	18.6	13.6	34.2	25.0	18.0
Concentrates (kg/day)	2.36	1.69	1.24	1.31	1.03	0.81
Dry matter (kg/day)	7.67	5.63	4.14	9.80	7.17	5.26
M/D (MJME/kgDM)	9.8	9.7	9.5	10.4	10.2	10.2

Table M.6 shows that in Experiment 1 the required M/D value (10.3) was not achieved. This was because the ME value of the silage determined from the core samples removed prior to the start of the experiment was less than the ME value of the silage offered to the cows, determined from daily samples.

The slight variation in the M/D value of the rations offered on each plane of nutrition resulted from the different levels of minerals and vitamins incorporated in the concentrate supplements.

FACILITIES

The cows and calves were housed in one, single-span, portal-frame building (21 x 24 m) in both experiments.

The cows were tied by the neck in a byre system and bedded on sawdust. Each cow had an individual feed-container and self-fill waterbowl. The design of the standings, and the arrangement to allow individual feeding of the cows without spillage, are shown in Diagrams 1 and 2.

Calves used in the calf-suckling technique were tethered by rope halters in open-fronted pens, behind their dams. Each pen held two calves with a central, shared hay-rack, self-fill water-bowls and individual bucket-holders for supplementary concentrate feeding. The design of the calf pens and their position relative to the cows are shown in Diagrams 1 and 2.

MANAGEMENT OF ANIMALS

Management prior to Experiment 1

The cows involved in the experiments were purchased in a group of 42 bulling heifers in October 1972. Their origin, previous history and exact age were unknown.

On their arrival on the farms of The Edinburgh School of Agriculture the heifers were housed in a single court and offered a silage/barley diet. An Aberdeen Angus bull was introduced on 10th December and removed on 16th February. Pregnancy diagnosis, prior to turnout, revealed that six of the heifers were not pregnant, and these were removed from the group.

The remaining 36 heifers were turned out to grass in late April and grazed temporary grass at a stocking density of five per hectare. Approximately two weeks before calving, the heifers were transferred to a field adjacent to the experimental building.

Management at calving

The cows calved in a 6 hectare field adjacent to the experimental building, unless a difficult calving was encountered in which case the cow was brought inside. The cow and calf were then transferred into the

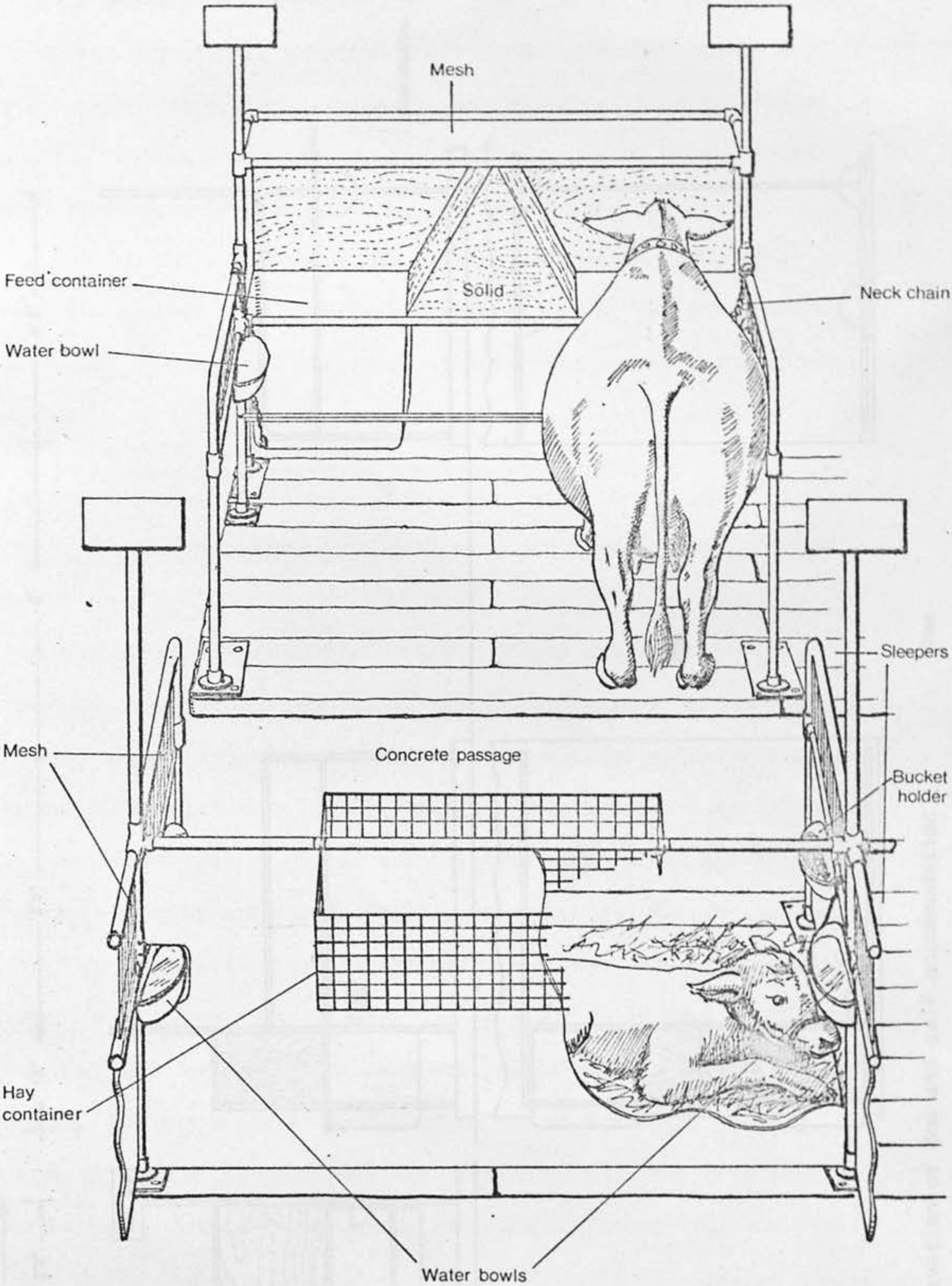


DIAGRAM 1: Design of cow and calf accommodation

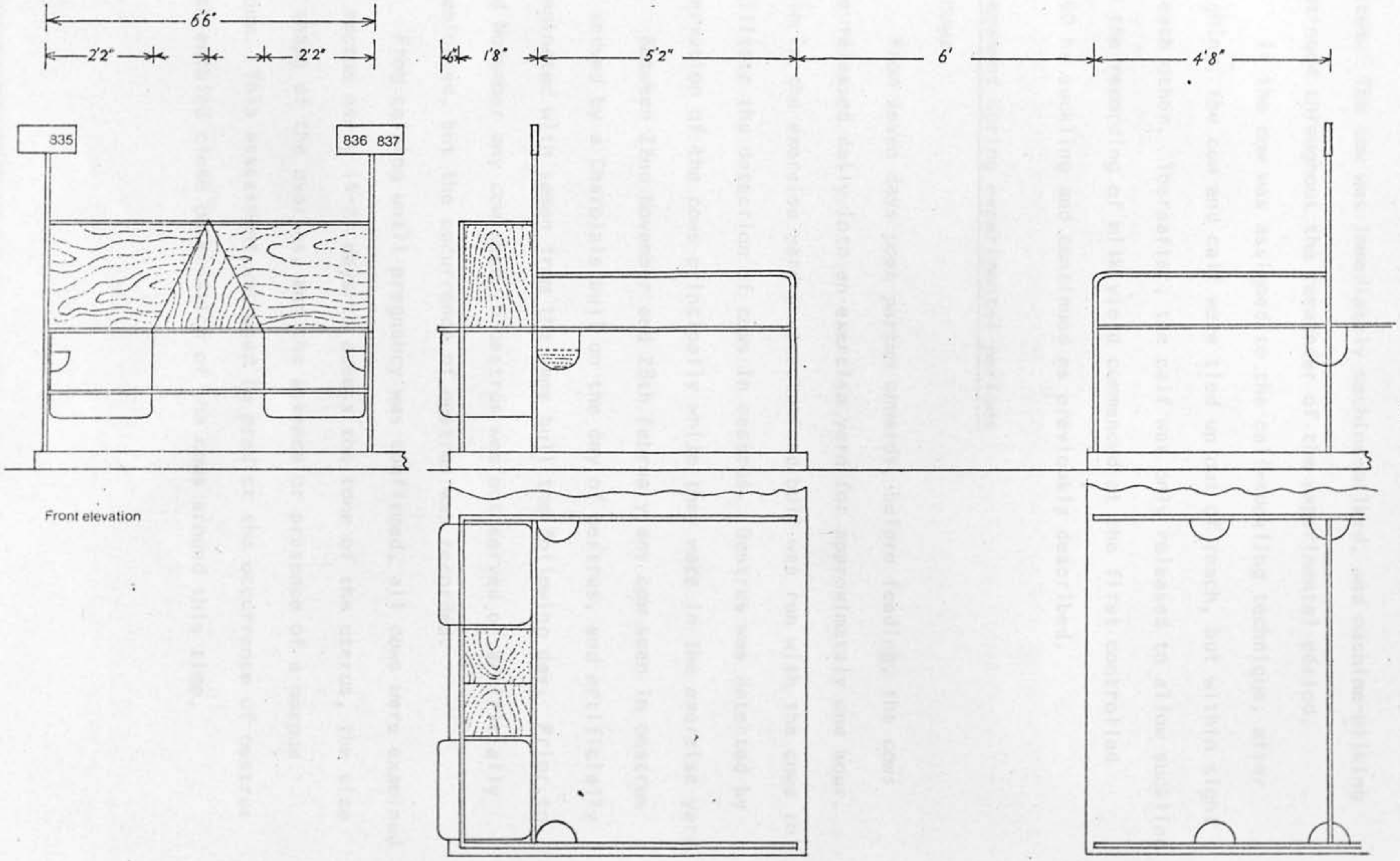


DIAGRAM 2: Plan and elevation of cow and calf accommodation

experimental building approximately 12 hr *post partum* and weighed. If the cow was assigned to machine-milking, the calf was removed and placed in a separate building where it was reared on an early-weaning system. The cow was immediately machine-milked, and machine-milking continued throughout the remainder of the experimental period.

If the cow was assigned to the calf-suckling technique, after weighing, the cow and calf were tied up out of reach, but within sight of each other. Thereafter, the calf was only released to allow suckling and the recording of milk yield commenced at the first controlled 07.00 hr suckling and continued as previously described.

Management during experimental periods

a) Cows

From seven days *post partum* onwards, before feeding, the cows were released daily into an exercise yard for approximately one hour. While in the exercise yard a vasectomised bull was run with the cows to facilitate the detection of cows in oestrus. Oestrus was detected by observation of the cows principally while they were in the exercise yard.

Between 22nd November and 28th February any cow seen in oestrus was served by a Charolais bull on the day of oestrus, and artificially inseminated with semen from the same bull the following day. Prior to 22nd November any cow seen in oestrus was not served or artificially inseminated, but the occurrence of oestrus was recorded.

From calving until pregnancy was confirmed, all cows were examined *per rectum* every 14-21 days to assess the tone of the uterus, the size and shape of the ovaries, and the absence or presence of a *corpus luteum*. This assessment was used to predict the occurrence of oestrus which enabled close observation of the cows around this time.

The examinations also permitted the identification and rectification of certain ovarian malfunctions. For example, if ovarian cysts were found, these were manually ruptured whenever possible. The cows were examined *per rectum* for pregnancy 42 days after mating. All examinations *per rectum* were performed by an experienced veterinarian.

b) Calves

The calves were bedded on straw until approximately eight weeks of age and thereafter on sawdust. In both experiments, all male calves remained entire.

From seven days of age, the calves were offered supplementary concentrates up to a maximum of 2 kg per head daily. Until the calves were approximately 12 weeks old the concentrate supplement was offered in the form of a proprietary brand of rearing pellet - Quicklettes (BOCM Silcock, Basingstoke, Hampshire). The approximate ME and DCP values of Quicklettes were 12.7 MJ/kgDM and 180 g/kgDM respectively. From 12 weeks of age until the end of the experimental periods, the concentrate supplement offered to the calves was a barley/groundnut mixture. The composition of this mixture and its estimated ME and DCP values are shown in Table M.7.

TABLE M.7: Composition and nutritive value of the concentrate supplement offered to calves from 84 days of age

Rolled barley (kg)	825	1000 kg
Groundnut cake (kg)	125	
Molassine meal (kg)	25	
[1]High-phosphorus mix (kg)	25	
Metabolisable energy (MJ/kgDM)	12.7	
Digestible crude protein (g/kgDM)	133	

[1]see footnote of Table M.4 for composition

The calves were offered hay *ad libitum* from seven days of age until the end of the experimental periods. In Experiment 1, the ME and DCP values of the hay were 9.3 MJ/kgDM and 80 g/kgDM respectively, and in Experiment 2, 9.3 MJ/kgDM and 45 g/kgDM respectively.

Management of cows between Experiments 1 and 2

At the end of Experiment 1, the machine-milked cows were dried-off and the calf-suckling cows had their calves weaned and were also dried-off. After one week in courts, the cows were turned out to hill grazings where they remained until one week prior to calving.

At the end of Experiment 1, the average age of the calves involved in the calf-suckling technique was 170 days. These calves took no further part in the experiment.

Management of cows and calves from turnout to weaning in Experiment 2

At the end of Experiment 2, the cows and calves were divided into two groups on the basis of sex of calf. From turnout, each group grazed permanent pasture at a stocking density of 2.8 cows and calves per hectare until weaning on 21st July 1975. The average age of the calves was 190 and 285 days at turnout and weaning respectively. The calves had access to supplementary concentrates (2 kg per head daily) for one month after turnout. The cows and calves were weighed twice at weaning.

RECORDING OF FEED INTAKES, LIVE-WEIGHTS AND CONDITION SCORES

Feed intakes

a) Cows

An individual cow's silage and concentrate allowance was offered once daily between 09.00 and 11.00 hr. Any silage not consumed the previous day was weighed prior to feeding and discarded. Individual feed allowances and feed refusals were weighed to the nearest 50 g on a bench scale.

b) Calves

The concentrate allowance offered to the calves was weighed to the nearest 50 g on a bench scale every day. If a calf had failed to consume any of the previous day's allowance, this was weighed and discarded.

The design of the calf pens was such that it was only possible to record the hay intakes of pairs of calves. The hay intake of each pair of calves was recorded one week per month by weighing the quantities of hay offered and refused to the nearest 50 g on a suspended balance.

Live-weights and condition scores

a) Cows

During the experimental periods the cows were weighed weekly, and condition scored every 14 days according to the method described by Lowman, Scott and Somerville (1973). The cows were weighed and condition scored more frequently immediately after calving and at the end of each experimental period.

Every attempt was made to weigh the cows at a standard time of day (08.00 to 10.00 hr) on each occasion. All live-weights were recorded after milking or suckling and before the cows were fed. The cows were weighed to the nearest 2 kg in a standard cattle-weighing crate. Two experienced operators condition scored the cows to the nearest quarter of a score throughout the experiments. Both operators condition scored an individual cow simultaneously and awarded a score by agreement.

b) Calves

Calf live-weight changes were calculated from the mean of two pre-suckling weights recorded at 07.00 hr on two consecutive days each week. The condition scores of the calves were recorded, but will not be reported.

SAMPLING AND ANALYTICAL TECHNIQUES

Milk

In Experiment 1, the milk produced by the machine-milked cows was regularly sampled to determine its composition. The first six milkings were sampled separately to determine the composition of colostral milk and thereafter, aliquot samples were taken from the morning and afternoon milkings on three consecutive days each week.

The sampling procedure was as follows: after the milking unit was removed, the milk produced by each cow was transferred into a bucket and weighed. The milk was then decanted into a plastic cylinder to ensure thorough mixing. Samples were withdrawn by dipping a glass rod of diameter 8 mm to the bottom of the cylinder and transferring the milk, suspended by gravity, into a glass bottle containing formalin as a preservative (0.05 ml per 150 ml milk). A sample of approximately 15 ml was taken at each of the six milkings sampled per week and bulked.

Two 5 ml sub-samples were analysed for butter fat content (BS 696 Pt II, 969) and total solids (BS 1741, 1963). The solids-not-fat fraction was calculated by difference and the gross energy value was derived from the butter fat (BF) and solids-not-fat (SNF) content using the equation of Tyrrell and Reid (1965):

$$GE = 0.0386\ BF + 0.0256\ SNF - 0.236$$

(GE in MJ/kg fresh milk and BF and SNF in g/kg fresh milk)

Feeds

a) Silage

The 36 cows, plus 16 involved in a concurrent experiment, required approximately 1200 kg of silage per day. This quantity was removed from the silo each day. Six 50 g grab samples were taken at intervals, while the silage was being apportioned among the cows, and bulked. The silage was sampled daily.

After thorough mixing, two 750 g sub-samples were dried in a forced-draught oven at 100^{o}C to determine oven DM (ODM). Oven-drying silage has been shown to drive off some of the volatile DM (Wilson, Tilley and Steemers 1964) and thus ODM determinations underestimate the true DM of silage. Therefore, twice per week the true DM of the silage was determined by toluene distillation *after* Dewar and McDonald (1961). A relationship was established between the ODM and toluene DM of each silage and all ODM values were converted to true DM.

The following analyses were performed on an oven-dried, milled sample of silage:

Modified-acid-detergent fibre (MAD-F)	*after*	Clancy and Wilson (1966)
Crude protein	*after*	Watson and Nash (1960)
Ash	*after*	The Fertiliser and Feeding Stuffs Regulations (1973)

The following equations were used to calculate the ME and DCP values of the silages:

$$ME = 17.4 - 0.02\ MAD\text{-}F \quad \text{if } ODM \leqslant 250\ g/kg$$
$$ME = 16.4 - 0.0188\ MAD\text{-}F \quad \text{if } ODM > 250\ g/kg$$

(developed by Department of Advisory Nutrition,
The Edinburgh School of Agriculture)

$$DCP = 0.09115\ CP - 3.67 \quad \text{(Watson and Nash 1960)}$$

In the above equations, ME is expressed in MJ/kg/ODM and MAD-F, DCP and CP in g/kg ODM. The ME and DCP values in the ODM of the silage were then adjusted to a true DM basis.

No chemical determinations were made on any silage which was offered to the cows but not consumed. In previous experiments involving similar levels of nutrition and similar diets, unconsumed silage was collected each day and subject to the same laboratory analysis as the silage offered. Statistical analysis indicated, however, that there was no significant difference ($P > 0.05$) between the composition of the silage offered and the composition of silage offered but not consumed (B.G. Lowman, personal communication). For this reason it was considered unnecessary to analyse, separately, unconsumed silage. As a precautionary measure, any poorly conserved silage was not offered to the cows.

b) Concentrates and hay

The concentrate supplements offered to the cows and calves and the hays offered to the calves were sampled every 28 days. Analytical techniques and the equations used to derive the ME and DCP values of concentrates and hay are described in Appendix 4.

STATISTICAL PROCEDURES

Milk yields

In the calf-suckling cows, because observations of daily milk yield were made on only two days each week, cumulative milk yields were not directly available. The milk production of the machine-milked cows was recorded at every milking except on a limited number of occasions when by mischance, yield was not recorded. This resulted in missing observations and prevented the direct calculation of cumulative milk yields.

In order to estimate cumulative milk yields an equation developed by Wood (1969) was fitted to the observations of daily milk yield for each cow. The equation was fitted to all yield observations made while the cow was subject to experimental treatment. The form of equation used was:

$$Y = an^{b} e^{-cn}$$

where Y = milk yield (kg/day)

n = days *post partum*

e = base of natural logarithms

and a), b), c) = coefficients defining lactation curve

In addition to providing an estimate of cumulative milk yield, the use of this equation enabled:

a) milk yield to be estimated at a specific stage of lactation (eg peak milk yield) on the basis of successive yield measurements;

b) the lactation curve of each cow to be described mathematically which permitted the pattern of milk production on different treatments to be compared statistically;

c) the extrapolation of the lactation curves of five cows to 150 days. These cows had failed to complete 150 days on experimental treatment. The procedure was validated by predicting the 150-day cumulative milk yields of a sample of 10 cows (which had lactation records of more than 150 days) on the basis of their 120, 130, 140 and 150-day records (see Appendix 4).

Live-weights and condition scores

Cubic regression equations were used to describe the change in live-weight and the change in condition score of each cow during the experimental periods. The form of equation used was:

$$Y = a + bx + cx^2 + dx^3$$

where Y = live-weight (kg) or condition score

x = days *post partum*

and a), b), c), d) = coefficients

The use of these equations allowed the estimation of live-weight and condition score at any stage of lactation based on successive measurements of these parameters but did not permit extrapolation. Certain data relating to the live-weight and condition score changes of the five cows subject to experimental treatment for less than 150 days were excluded from the analysis.

Hay intakes of calves

The design of the calf pens was such that it was only possible to record the hay intakes of pairs of calves. A pair of calves did not constitute an experimental unit because, although every attempt was made to pair calves of similar age, differences in age did exist. Furthermore, during the course of Experiment 2 it proved necessary to pair bull and heifer calves separately and this involved a rearrangement of certain pairs. Each pair of calves, however, was suckled by dams on the same plane of nutrition. Thus, it was possible to estimate the hay intake of each group of calves suckled by dams on the same plane of nutrition.

The hay intake of each pair was recorded one week per month. In order to estimate the hay intake of each treatment group to 150 days of age, it was assumed that each calf of a pair consumed half the total quantity of hay during the week when the intake of the pair was measured, irrespective of their relative ages. This provided an estimate of the hay intake of each calf every fourth week. For each of the three treatment groups of calves, the average hay intake at each week of age was calculated by averaging the intake of those calves whose intakes were known at that particular age.

<u>Analysis</u>

In both experiments, data relating to the feed intake, lactation performance, live-weight and condition score changes of the cows were analysed by a standard analysis of variance procedure.

In Experiment 1, the lactation performance and live-weight changes of the cows were adjusted to a standard live-weight *post partum*, and condition score changes to a standard condition score *post partum*, by covariance analysis. An example of the analysis of variance table is shown in Appendix 4.

In the analyses of data relating to the lactation performance, live-weight and condition score changes of the cows in Experiment 2, the residual effects of treatment in Experiment 1 were examined. None proved statistically significant but the main residual effects of previous experimental treatments and their first order interactions were included in the analyses. Covariance analysis was used to adjust the lactation performance of the cows to a standard calf birth-weight, live-weight changes to a standard live-weight *post partum*, and condition score changes to a standard condition score *post partum*. In the analysis of certain parameters, up to five covariates were tested independently and pairs of covariates simultaneously before deciding on the basis of the resultant reduction in variance, which covariates it was valid to retain in the final analysis. An example of the analysis of variance table is shown in Appendix 4. Any missing values were estimated using a standard missing-plot technique.

In both experiments, the effect of plane of nutrition was apportioned into the linear and non-linear components (Steel and Torrie 1960). The procedure used applied to equally spaced treatments because the energy intake of the cows on the medium plane of nutrition was considered intermediate. Evidence of a significant effect was determined by an F-test. Treatment means were compared by Student's t-test.

Covariance analysis was used to adjust calf weight changes to a standard sex and calf weaning weights to a standard age and sex.

Other statistical analysis included the determination of multiple, simple and partial correlation coefficients and regressions (Fisher 1958).

Where possible, results are presented in tabular or graphical form. In the tables, unless otherwise specified, the significance levels refer to the significance of the linear effect of plane of nutrition. With data appearing in graphical form, the standard errors of selected values are presented. These were omitted when they detracted from the clarity of the figure.

Levels of statistical significance are indicated as follows:

$P > 0.05$ = NS

$P < 0.05$ = *

$P < 0.01$ = **

$P < 0.001$ = ***

2. RESULTS OF EXPERIMENT 1

Health

a) Cows

The general health of the cows during the experimental period was good. Regular visual examination of the milk produced by the machine-milked cows revealed only three cases of clinical mastitis. Two cows responded to treatment with intramammary injections of penicillin, but the third eventually ceased to produce milk in the infected quarter although the cow's general health and appetite were unaffected. No cases of clinical mastitis were identified in the calf-suckling cows.

During the course of the experiment a number of cows became infected with 'foul in the foot' (an *Actinomyces necrophorus* infection). These cows responded rapidly to a three-day course of treatment with intramuscular injections of terramycin and, subsequently, the regular use of a footbath containing a five per cent formalin solution minimised the problem.

b) Calves

Most of the calves had mild scour on at least one occasion during the experiment. No Salmonella-group organisms were isolated from faecal swabs taken at monthly intervals and the scour was ascribed to either a localised *E. coli* intestinal infection or a digestive upset. Treatment varied according to the severity of the scour but was based on a course of Vetoryl[1] or Stromez[2] which was followed on four occasions by antibiotic

---

[1] Arnolds Veterinary Products Ltd, Reading, Berkshire

[2] Imperial Chemical Industries Ltd, Macclesfield, Cheshire

therapy, administered by a veterinarian, when the calf did not respond to the initial treatment. The scour was associated with a temporary reduction in the appetite of the calves for milk but at no time during the experiment was a calf's milk intake deliberately restricted. A record was kept of all ill-health in the cows and calves and examination of these records indicated that the incidence of scour in the calves was not related to the plane of nutrition of the dam.

In addition to scour, three calves suffered from virus pneumonia and two from navel-ill.

No data were excluded from the analyses because of ill-health in either a cow or calf.

Feed intakes

The mean daily intakes of silage, concentrates, dry matter, metabolisable energy and digestible crude protein are presented in Table E.1. Although the fresh weight of silage and concentrates offered to each heifer remained constant throughout the experimental period, day-to-day variation in the composition of the silage resulted in day-to-day variation in the intake of DM, ME and DCP. The variation in the composition of the silage offered and examples of the resultant variation in the daily intakes of the heifers are shown in graphical form in Appendix 4 (Figures 2, 3 and 4).

At no time during the experiment did any cow fail to consume the concentrate allowance provided, and the average quantity of silage dry matter offered but not consumed by the heifers was only 0.80, 0.16 and 0.22 per cent on the high, medium and low planes of nutrition respectively. This was equivalent to 0.60, 0.12 and 0.17 per cent of the total daily DM (i.e. silage DM plus concentrate DM) offered to the cows on the high,

TABLE E.1: Mean daily intakes of silage, concentrates, dry matter (DM), metabolisable energy (ME) and digestible crude protein (DCP) in Experiment 1

Mean daily intakes	Plane of nutrition			Residual SD	Significant linear effect
	High	Medium	Low		
Fresh silage (kg)	24.7	18.5	13.6	1.64	***
Fresh concentrates (kg)	2.36	1.69	1.24	0.199	***
DM (kg)	7.62	5.65	4.14	0.206	***
ME (MJ)	74.6	54.5	39.3	4.91	***
DCP (g)	640	548	502	46.8	***

TABLE E.2: Mean daily intakes of metabolisable energy (ME) and digestible crude protein (DCP) in Experiment 1, expressed as a percentage of maintenance requirement (M) and in productive terms

	Plane of nutrition		
	High	Medium	Low
[1]Daily ME intake as percentage of M	162	115	80
[2]Daily ME intake in terms of M + kg milk	M + 5.7	M + 1.4	M - 1.9
[3]Daily DCP intake as percentage of M	249	208	185
[4]Daily DCP intake in terms of M + kg milk	M + 7.7	M + 5.7	M + 4.6

[1]ME required for maintenance: $0.5\ MJ/W^{0.75}$ where W = *post partum* live-weight

[2]assumed that the production of 1 kg milk requires 5 MJME

[3]DCP required for maintenance = $22.94 + 2.538W^{0.75}$

[4]assumed that the production of 1 kg milk requires 50 g DCP

medium and low planes of nutrition respectively. On the high plane of nutrition, the range was from 2.3 to 0.25 per cent of silage DM which represented a range of 1.75 to 0.21 per cent of the total DM offered.

In Table E.2 the mean daily intakes of the heifers are expressed as a percentage of estimated maintenance requirement and in relation to the estimated levels of milk production which they could support with zero live-weight change. These values relate to the estimated energy and protein requirements for maintenance and production, based on the live-weight of the heifers 12 hr *post partum*. Tables E.1 and E.2 show that the required intakes of protein and energy were not achieved. The required energy intake was not achieved because the energy value of the silage, estimated from the core-samples taken prior to the experiment, was higher than the energy value estimated from daily samples taken from the silage at feeding. The energy value and protein content of the silage estimated from daily samples were used to calculate the daily intakes of the heifers.

Method of milking

Data relating to the lactation performance, live-weight and condition score changes of the heifers were evaluated by variance analysis. The interactions between method of milking and plane of nutrition were tested for significance, but no significant effect was obtained. For this reason, only the treatment means for each method of milking are presented here. Unadjusted means of selected parameters, and means adjusted by covariance analysis, for each of the six treatments are shown in Appendix 4 (Table 5).

The lactation performance of the heifers for each method of milking, adjusted to a standard live-weight *post partum*, is presented in Table E.3.

TABLE E.3: Effect of method of milking on the lactation performance of beef heifers

	Method of milking		SE of difference and significance	
	Machine-milking	Calf-suckling		
[1]150-day cumulative milk yield (kg)	965	993	66.7	NS
[1]Peak milk yield (kg)	7.6	7.7	0.49	NS
[1]Days *post partum* peak milk yield recorded	26	31	5.8	NS
Coefficients a)	10.8	10.0	1.60	NS
Coefficients b)	0.203	0.174	0.0660	NS
Coefficients c)	0.008	0.006	0.0025	NS

[1]adjusted to a standard live-weight *post partum* by covariance analysis

The 150-day cumulative milk yields and the shapes of the lactation curves (defined by the unadjusted mean a, b and c coefficients used to describe the lactation curves) were not significantly affected by method of milking.

The initial live-weight of the heifers measured 12 hr *post partum* had a significant ($P < 0.01$) effect on 150-day cumulative milk yield and peak yield (i.e. maximum daily milk yield), but the effect of live-weight *post partum* on the stage of lactation at which peak milk yield occurred and the shape of the lactation curve defined by the a, b and c coefficients was not significant.

Every kg increase in live-weight *post partum* was associated with an increase of 3.3 kg and 0.02 kg in 150-day cumulative milk yield and peak milk yield respectively. The regressions of the lactation parameters on live-weight *post partum*, together with the standard error (SE) and significance of each coefficient are presented in Appendix 4 (Table 6). It should be noted that the allocation of food, within each plane of nutrition, was based on an individual heifer's metabolic live-weight *post partum*. Thus, the significant regressions of the lactation parameters on live-weight *post partum* may partly represent the removal of residual nutritional variation within each plane of nutrition.

Condition score *post partum* also had a significant ($P < 0.05$) effect on the 150-day cumulative milk yields of the heifers and a one unit increase in condition score was associated with an increase (±SE) in 150-day cumulative milk yield of 153 ± 69.1 kg. Condition score and live-weight *post partum* were correlated ($r = +0.67$; $P < 0.001$). When they were included in the variance analysis of 150-day milk yield, simultaneously, there was only a very slight reduction in the residual variance, relative to the residual variance when live-weight was included independently. This did not approach significance; therefore, condition score *post partum* was not included as a covariate in the final analysis of the lactation parameters.

The mean a, b and c coefficients, unadjusted for live-weight *post partum*, were used to construct lactation curves for each method of milking. These are presented in Figure E.1 and show that the shape of the lactation curve was similar for both methods of milking. Daily milk production increased to a maximum of approximately 7.5 kg at four weeks *post partum*, and then declined steadily to approximately 5.25 kg at 150 days *post partum*.

All the heifers continued to lactate until the end of the experimental period with the exception of one machine-milked heifer on the low plane of nutrition which dried-off (i.e. ceased to produce more than 0.25 kg of milk a day on three consecutive days), 84 days *post partum*. This heifer produced very little milk at any stage of lactation and had a maximum daily milk yield of only 2.6 kg, six days *post partum*.

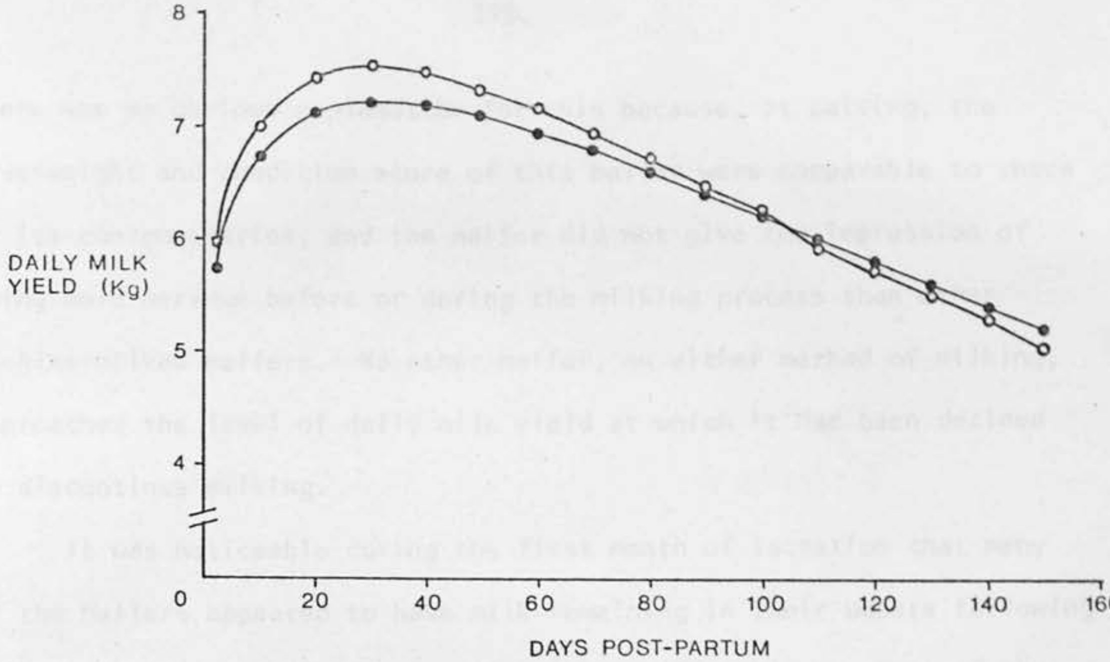


Fig. E1 Effect of stage of lactation and method of milking on the unadjusted mean daily milk yield of beef heifers.
o—o Calf-suckling ●—● Machine-milking

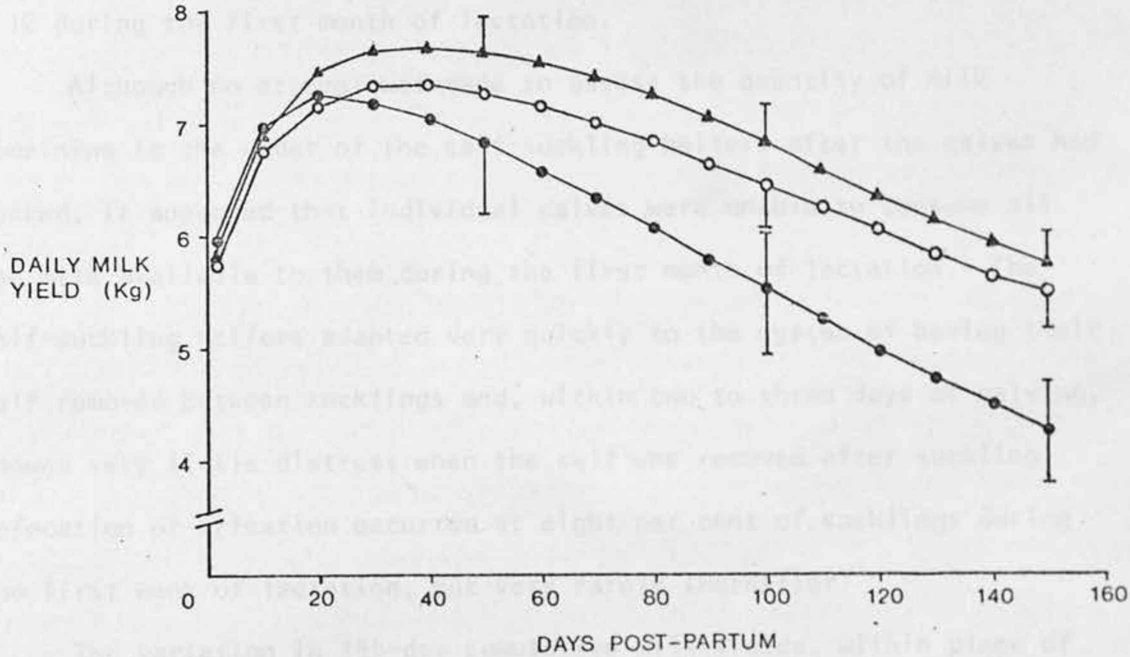


Fig. E2 Effect of stage of lactation and plane of nutrition on the unadjusted mean (±SE) daily milk yield of beef heifers
o—o High; ▲—▲ Medium; ●—● Low plane of nutrition

There was no obvious explanation for this because, at calving, the live-weight and condition score of this heifer were comparable to those of its contemporaries, and the heifer did not give the impression of being more nervous before or during the milking process than other machine-milked heifers. No other heifer, on either method of milking, approached the level of daily milk yield at which it had been decided to discontinue milking.

It was noticeable during the first month of lactation that many of the heifers appeared to have milk remaining in their udders following milk removal by either machine-milking or calf-suckling. Most of the machine-milked heifers were very nervous at the first few milkings after calving, but they became progressively less so during the first month of lactation. Thus, inhibition of the milk-ejection reflex by stress may have been the reason for the apparent incomplete removal of milk during the first month of lactation.

Although no attempt was made to assess the quantity of milk remaining in the udder of the calf-suckling heifers after the calves had sucked, it appeared that individual calves were unable to consume all the milk available to them during the first month of lactation. The calf-suckling heifers adapted very quickly to the system of having their calf removed between sucklings and, within two to three days of calving, showed very little distress when the calf was removed after suckling. Defecation or urination occurred at eight per cent of sucklings during the first week of lactation, but very rarely thereafter.

The variation in 150-day cumulative milk yields, within plane of nutrition, was significantly ($P < 0.05$) greater in the machine-milked than the calf-suckling heifers. Variance analysis of the effect of plane of nutrition for each of the two methods of milking, independently, revealed coefficients of variation of 150-day milk yield of 27.2 and 11.2 per cent for machine-milking and calf-suckling respectively. When the data of the machine-milked heifer, which dried-off prematurely, were excluded from the analysis, the coefficient of variation for machine-milking was reduced to 19.1 per cent, but was still significantly ($P < 0.05$) greater than that of the calf-suckling technique.

Plane of nutrition

a) Milk yield

The effect of plane of nutrition on the lactation performance of the heifers is presented in Table E.4. The levels of significance in this and subsequent tables refer to the significance of the linear effect of plane of nutrition. The 150-day yields of heifers on the high and medium planes of nutrition differed ($P < 0.05$) from that on the low plane, but there was no difference between the milk yields of the heifers on the high and medium planes of nutrition. This indicated a non-linear response to additional inputs of feed in terms of 150-day cumulative milk yield.

The effect of plane of nutrition on peak milk yield and the a, b and c coefficients, used to describe the lactation curves, was not significant. The mean a, b and c coefficients, unadjusted for live-weight *post partum*, were used to construct lactation curves for each plane of nutrition and these are presented in Figure E.2. The standard errors of daily milk yield at selected stages of lactation, calculated on a within treatment basis, are also shown.

TABLE E.4: Effect of plane of nutrition on the lactation performance of beef heifers

	Plane of nutrition			Residual SD	Significant linear effect
	High	Medium	Low		
[1]150-day cumulative milk yield (kg)	1049	1043	844	207.2	*
[1]Peak milk yield (kg)	8.0	8.0	7.1	1.53	NS
[1]Days *post partum* peak milk yield recorded	35	33	19	17.9	*
Coefficients a)	10.4	10.3	10.6	4.68	NS
Coefficients b)	0.173	0.210	0.181	0.1981	NS
Coefficients c)	0.005	0.005	0.010	0.007	NS

[1]adjusted to a standard live-weight *post partum* by covariance analysis

When the effect of plane of nutrition on the 150-day cumulative milk yields of the heifers was examined, within each of the two methods of milking, independently, two dissimilar trends emerged (see Appendix 4, Table 7). The 150-day cumulative milk yields of the calf-suckling heifers, adjusted to a standard live-weight *post partum*, were 1090, 968 and 902 kg and those of the machine-milked heifers, 1013, 1125 and 776 kg on the high, medium and low planes of nutrition respectively. In the calf-suckling heifers, there was a significant ($P < 0.05$) linear trend for milk yield to increase as plane of nutrition increased, whereas in the machine-milked heifers there was evidence of a non-linear effect but this was not significant. In view of this inconsistency and the greater variability of the milk yields obtained by machine-milking, it was decided to examine further the response of the calf-suckling heifers, independently.

The response of the calf-suckling heifers to different levels of energy intake, in terms of 150-day cumulative milk yield, was determined by multiple regression analysis. The multiple regression equation of 150-day cumulative milk yield (Y) on energy intake (x_1) and live-weight *post partum* (x_2) was:

$$Y = -39 + 4.6x_1 + 1.8x_2 \qquad (R = 0.62;\ P < 0.05)$$

Where Y is in kg	b_1 and b_2 = partial regression coefficients
x_1 is in MJME/day	SE of $b_1 = \pm 1.76$*
x_2 is in kg	SE of $b_2 = \pm 0.84$ (NS)

The addition of the independent variates in quadratic form did not significantly reduce the residual sums of squares. Thus, over a range of from 34 to 84 MJME per day, the response of the calf-suckling heifers to an additional daily intake of 10 MJME in terms of 150-day cumulative milk yield was 46 kg, i.e. 0.31 kg of milk a day.

b) Milk composition

The composition and gross energy value of the milk produced by the 18 machine-milked heifers are presented in Table E.5. The gross energy values were derived from the butter fat (BF) and solids-not-fat (SNF) contents of the milks, using the equation of Tyrrell and Reid (1965). There was a highly significant ($P < 0.001$) linear trend for SNF content to increase as plane of nutrition increased. This was associated with a non-significant trend for BF content to decrease as plane of nutrition increased, however, and the total solids content and gross energy value were not significantly affected by plane of nutrition.

The effect of stage of lactation on the composition of the milk produced by the machine-milked heifers on the three planes of nutrition is shown in Figures E.3, E.4 and E.5.

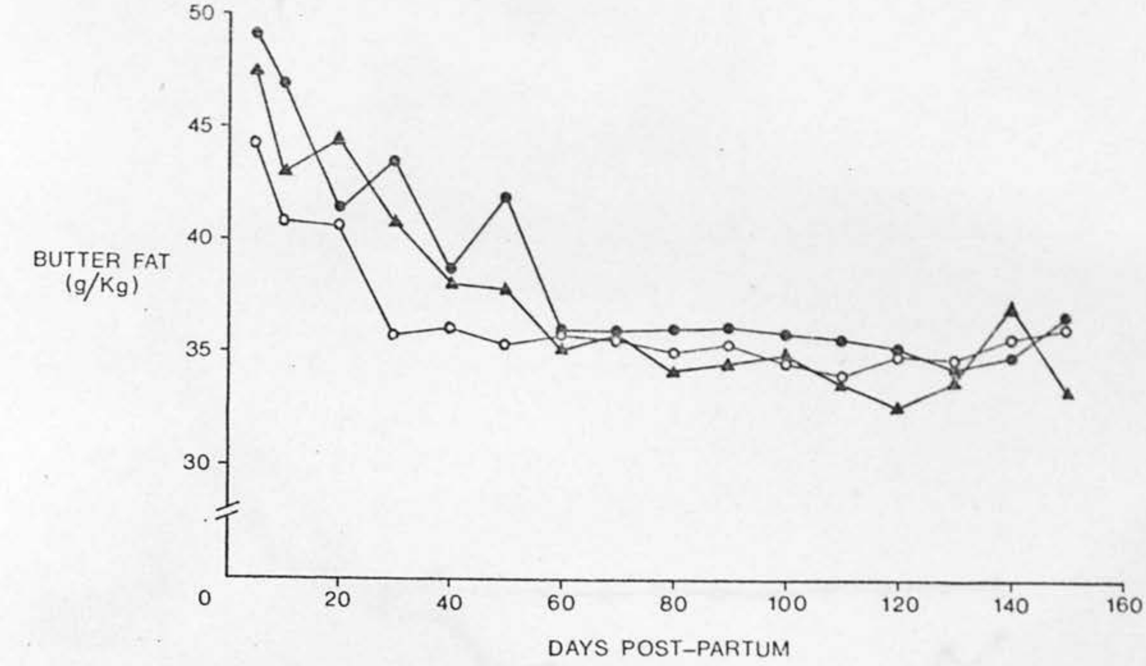
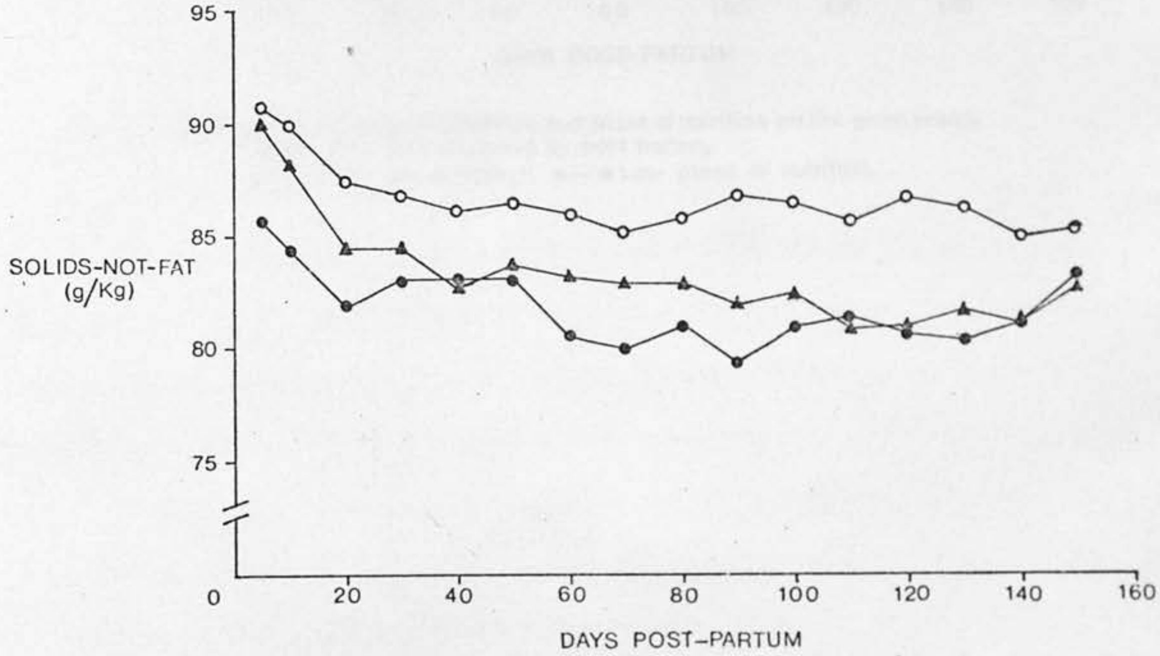


Fig E3 Effect of stage of lactation and plane of nutrition on the butter fat content of beef heifers' milk.
o—o High, ▲—▲ Medium; ●—● Low plane of nutrition



Fig, E4 Effect of stage of lactation and plane of nutrition on the solids-not-fat content of beef heifers' milk.
o—o High; ▲—▲ Medium; ●—● Low plane of nutrition.

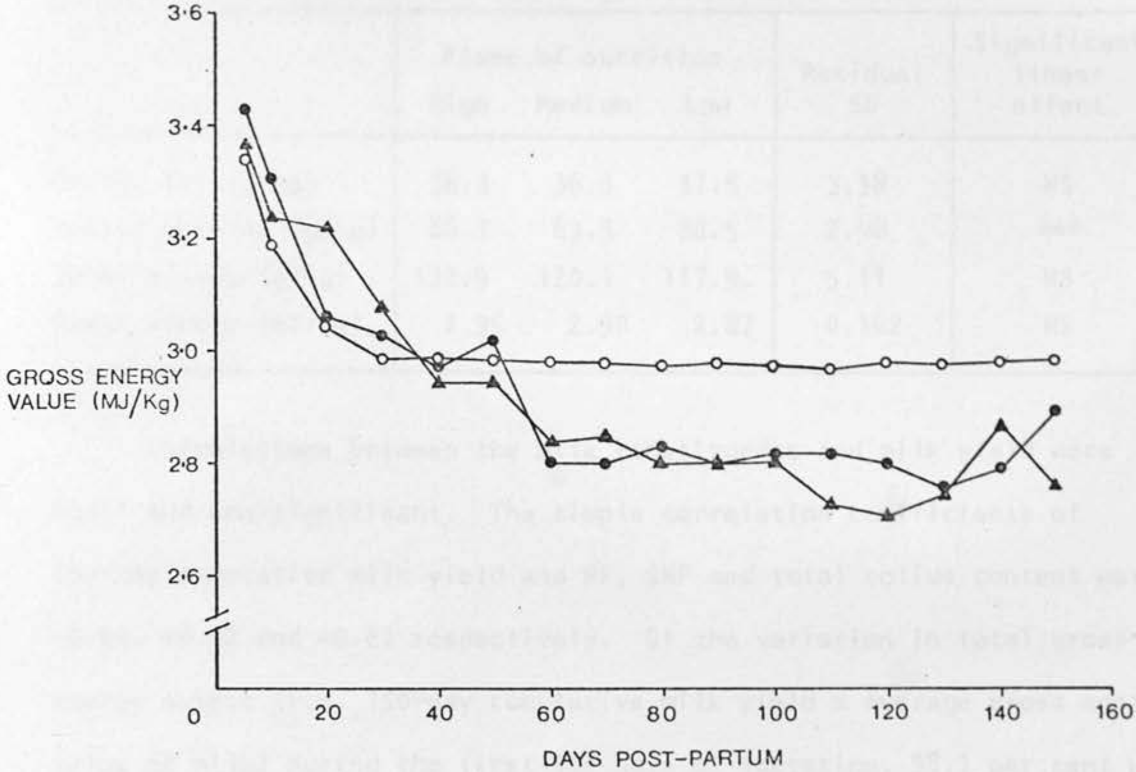


Fig. E5 Effect of stage of lactation and plane of nutrition on the gross energy value of the milk produced by beef heifers.
o—o High ▲—▲ Medium ●—● Low plane of nutrition.

TABLE E.5: Effect of plane of nutrition during lactation on the composition and gross energy value of the milk produced by beef heifers

	Plane of nutrition			Residual SD	Significant linear effect
	High	Medium	Low		
Butter fat (g/kg)	36.3	36.9	37.5	3.38	NS
Solids-not-fat (g/kg)	86.7	83.3	80.5	2.48	***
Total solids (g/kg)	122.9	120.1	117.9	5.11	NS
Gross energy (MJ/kg)	2.95	2.90	2.87	0.162	NS

Correlations between the milk constituents and milk yield were small and non-significant. The simple correlation coefficients of 150-day cumulative milk yield and BF, SNF and total solids content were +0.01, +0.02 and +0.02 respectively. Of the variation in total gross energy output (i.e. 150-day cumulative milk yield x average gross energy value of milk) during the first 150 days of lactation, 98.1 per cent was accounted for by differences in milk yield, and less than 2 per cent by differences in gross energy value.

The composition of the milk obtained at the first six milkings *post partum* (i.e. colostral milk), and the average composition of normal milk during the first, second and third 50 days of lactation are presented in Appendix 4 (Tables 8 and 9 respectively). The SNF content, total solids content and gross energy value of the colostral milk were higher ($P < 0.001$) than those of normal milk, but the difference between the BF contents of the two milks was not significant.

c) Live-weight and condition score changes

The live-weight and condition score losses incurred by the heifers, estimated from the cubic regression equations fitted to the live-weight and condition score data of each cow, are presented in Table E.6.

TABLE E.6: Effect of plane of nutrition during lactation on the live-weight and condition score changes of beef heifers

	Plane of nutrition High	Medium	Low	Residual SD	Significant linear effect
Live-weight changes					
Live-weight *post partum* (kg)	416	433	450	38.9	*
[1]Maximum live-weight loss (kg)	59	87	111	30.6	***
[1]Days *post partum* minimum live-weight recorded	127	139	131	28.7	NS
[1]Live-weight loss to 150 days *post partum* (kg)	53	85	106	33.5	***
Condition score changes					
Score *post partum*	2.65	2.60	2.82	0.590	NS
[2]Maximum score loss	1.10	1.31	1.51	0.244	***
[2]Days *post partum* minimum score recorded	79	109	118	42.9	*
[2]Score loss to 150 days *post partum*	0.87	1.23	1.33	0.256	***

[1]adjusted to standard live-weight *post partum* by covariance analysis
[2]adjusted to standard condition score *post partum* by covariance analysis

The significant ($P < 0.05$) linear trend for live-weight *post partum* to increase as plane of nutrition decreased occurred by chance, despite complete randomisation of heifers to treatments. The maximum live-weight loss of a heifer was calculated by subtracting the minimum estimated live-weight from the estimated live-weight *post partum*. Maximum condition score losses were calculated in a similar manner.

Table E.6 shows that plane of nutrition affected the magnitude of the live-weight and condition score losses incurred by the heifers but that, irrespective of plane of nutrition, the heifers mobilised live-weight and condition during the early part of the 150-day lactation period and regained a small amount of weight and condition towards the end of the period. Substantial live-weight and condition score losses were incurred by heifers on the low plane of nutrition which were 24 per cent lighter at 150 days *post partum* than at calving.

The live-weight losses incurred in early lactation may partly reflect changes in gut-fill. Between 12 hr and 10 days *post partum*, the live-weight losses of the heifers were 8, 13 and 18 kg ($P < 0.001$) on the high, medium and low planes of nutrition respectively, a proportion of which was probably attributable to a reduction in gut-fill. From 10 to 150 days *post partum*, however, when changes in gut-fill would be expected to have little effect on the live-weight losses of the heifers there was still a highly significant ($P < 0.001$) linear trend for live-weight losses to increase as plane of nutrition decreased. The live-weight losses of the heifers between 10 and 150 days *post partum* were 44, 73 and 90 kg on the high, medium and low planes of nutrition respectively.

The effect of stage of lactation and plane of nutrition on the daily live-weight changes of the heifers and their condition score changes are shown in Figures E.6 and E.7 respectively. Figure E.6 shows that on each of the three planes of nutrition the rate of live-weight loss declined as lactation progressed.

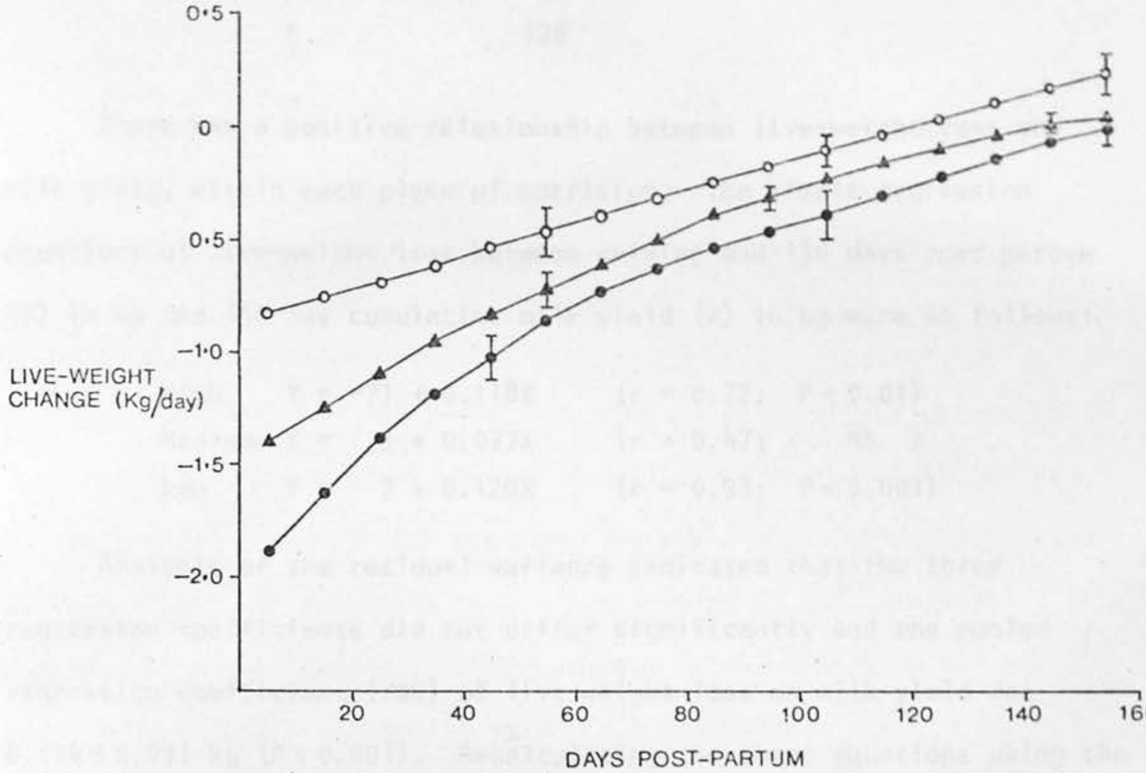


Fig. E6 Effect of stage of lactation and plane of nutrition on the unadjusted mean (±SE) live-weight changes of beef heifers.
o—o High ▲—▲ Medium ●—● Low plane of nutrition

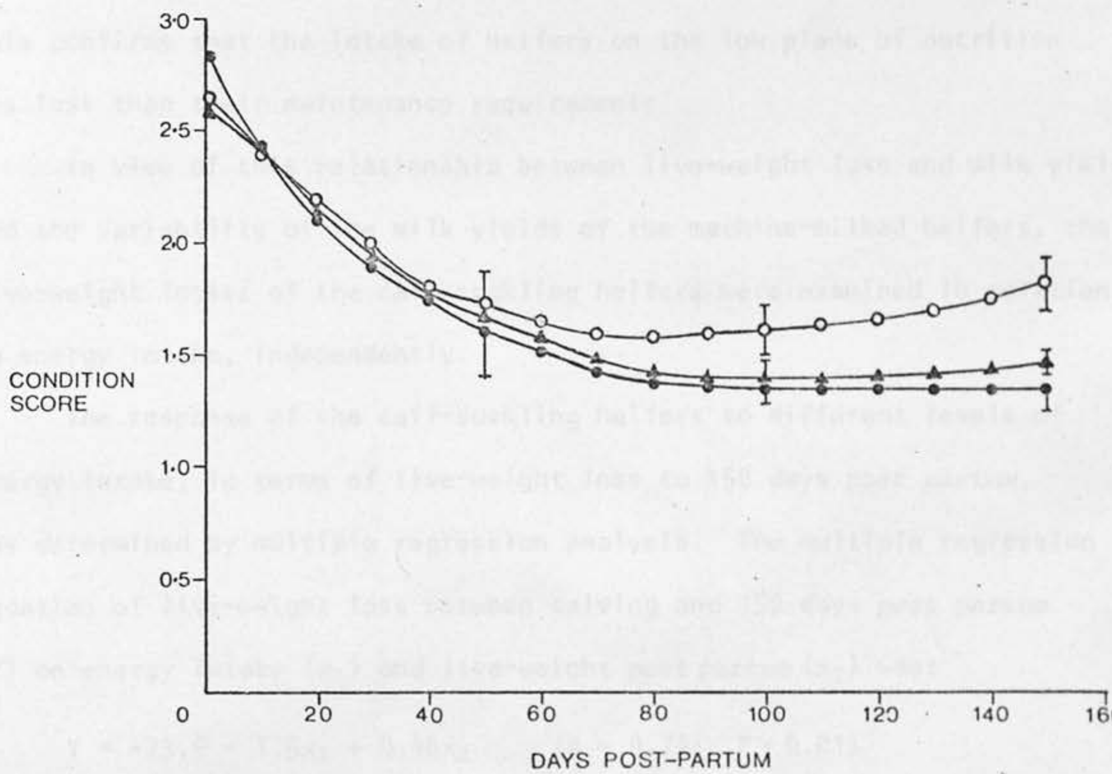


Fig E7 Effect of stage of lactation and plane of nutrition the unadjusted mean (± SE) condition score of beef heifers
o—o High ▲—▲ Medium ●—● Low plane of nutrition

There was a positive relationship between live-weight loss and milk yield, within each plane of nutrition. The simple regression equations of live-weight loss between calving and 150 days *post partum* (Y) in kg and 150-day cumulative milk yield (X) in kg were as follows:

High	$Y = -71 + 0.118X$	$(r = 0.72;\ P < 0.01)$
Medium	$Y = 3 + 0.077X$	$(r = 0.47;$ NS $)$
Low	$Y = 7 + 0.120X$	$(r = 0.93;\ P < 0.001)$

Analysis of the residual variance indicated that the three regression coefficients did not differ significantly and the pooled regression coefficient (±SE) of live-weight loss on milk yield was 0.114 ± 0.291 kg ($P < 0.001$). Recalculating the three equations using the pooled regression coefficient gave values for the intercepts of -67, -38 and 12 kg for the high, medium and low planes of nutrition respectively. This confirms that the intake of heifers on the low plane of nutrition was less than their maintenance requirements.

In view of this relationship between live-weight loss and milk yield, and the variability of the milk yields of the machine-milked heifers, the live-weight losses of the calf-suckling heifers were examined in relation to energy intake, independently.

The response of the calf-suckling heifers to different levels of energy intake, in terms of live-weight loss to 150 days *post partum*, was determined by multiple regression analysis. The multiple regression equation of live-weight loss between calving and 150 days *post partum* (Y) on energy intake (x_1) and live-weight *post partum* (x_2) was:

$$Y = -23.5 - 1.5x_1 + 0.46x_2 \qquad (R = 0.74;\ P < 0.01)$$

Where Y is in kg	b_1 and b_2 = partial regression coefficients
x_1 is in MJME/day	SE of $b_1 = \pm 0.376$**
x_2 is in kg	SE of $b_2 = \pm 0.179$*

Thus, over a range of from 34 to 84 MJME, every additional 10 MJME consumed per day reduced the live-weight loss of the heifers between calving and 150 days *post partum* by 15 kg.

d) Reproductive performance

One calf-suckling heifer on the high plane of nutrition and one machine-milked heifer on the low plane of nutrition failed to conceive. The remainder of the heifers conceived during a 98-day breeding period. Further details of the reproductive performance of these heifers, combined with the reproductive performance of the cows involved in Experiment 2, are presented in Appendix 4 (Table10).

e) Calf performance

The milk and supplementary feed intakes of the calves involved in the calf-suckling technique are presented in Table E.7. The milk intakes of the calves to 150 days of age were equivalent to the unadjusted 150-day cumulative milk yields of their dams.

TABLE E.7: Milk and supplementary feed intakes of calves suckling beef heifers on one of three planes of nutrition during lactation

	Plane of nutrition of dam			Residual SD	Significant linear effect
	High	Medium	Low		
Total milk intake to 150 days of age (kg)	1063	978	920	145.0	NS
Total concentrate intake to 150 days (kg/head)	151	148	162	22.0	NS
Age at which maximum concentrate intake (2 kg/head) attained (days)	103	102	96	12.2	NS
[1]Total hay intake to 150 days of age (kg/head)	94	110	102	-	-

[1]estimated on a group basis

The age at which a calf was assumed to have attained its maximum concentrate intake of 2 kg a day was when it consumed this quantity on the previous three consecutive days. However, after having satisfied this criterion, individual calves subsequently failed to consume 2 kg of concentrates every day.

There was no evidence that plane of nutrition of the dam had any effect on the supplementary feed intakes of the calves.

The live-weight changes of the calves are presented in Table E.8. The birth-weights of the calves are included for reference, but were recorded prior to the imposition of experimental treatments. The mean live-weights of the calves at 150 days of age were not affected by plane of nutrition of the dam.

TABLE E.8: Effect of plane of nutrition of the dam during lactation on the growth rates of suckled calves

	Plane of nutrition of dam			Residual SD	Significant linear effect
	High	Medium	Low		
[1]Birth-weight (kg)	32.1	32.2	34.1	3.32	NS
[1]Daily weight gain to 150 days of age (kg)	0.95	0.94	0.92	0.116	NS
[1]150-day weight (kg)	175	174	172	18.0	NS

[1]adjusted for sex by covariance analysis

The live-weight gain of the calves between birth and 150 days of age was positively correlated ($P < 0.01$) to their milk intake over the period. When the effect of sex of calf was eliminated, a 1 kg increase in the daily milk intake of the calves between birth and 150 days of age was associated with an increase (±SE) of 10.5 ± 2.99 kg ($P < 0.01$) in their live-weight gain.

f) Subsequent performance of heifers

The effect of the plane of nutrition received by the heifers during their first lactation was examined in relation to certain aspects of their subsequent performance (Table E.9).

TABLE E.9: Effect of plane of nutrition during the first lactation on the subsequent performance of beef cows

	Plane of nutrition			Residual	Significant linear
	High	Medium	Low	SD	effect
Gestation length (days)	284	286	287	7.5	NS
[1]Calf birth-weight at beginning of second lactation (kg)	41.4	38.7	41.9	6.45	NS
[2]Live-weight increase of cow between first and second calving (kg)	64	44	58	31.0	NS
[2]Live-weight of cow at calving at beginning of second lactation (kg)	493	490	490	30.9	NS
[3]150-day cumulative milk yield in second lactation (kg)	1271	1298	1286	123.7	NS

[1]adjusted to a standard sex by covariance analysis

[2]adjusted to a standard live-weight post first parturition by covariance analysis

[3]adjusted to a standard calf birth-weight by covariance analysis

There was no evidence of any residual effect of plane of nutrition during the first lactation on the subsequent performance of the heifers.

3. DISCUSSION OF EXPERIMENT 1

Method of milking

a) Lactation performance

In this investigation, although the mean 150-day cumulative milk yields determined by machine-milking and the calf-suckling technique were not significantly different, milk yields determined by machine-milking were significantly ($P < 0.05$) more variable than those determined by the calf-suckling technique.

The lower coefficient of variation of milk yield estimated by the calf-suckling technique is consistent with the results of a similar comparison reported in Appendix 2, and with the data of Totusek *et al* (1973) who found that the coefficient of variation of the daily milk yield of beef cows measured by a calf-suckling technique was 10 percentage units lower than that of milk yield measured by hand milking. The coefficient of variation of the milk yield of the machine-milked heifers in the present study was of the same magnitude as the 25 per cent reported for dairy cows by Lucas (1960), but higher than the 20 per cent reported by Broster, Broster and Smith (1969) for unrelated dairy heifers maintained under uniform conditions. The coefficient of variation of the milk yield of the calf-suckling heifers in this study was lower than that reported for dairy cows.

In the present investigation, the use of the calf-suckling technique reduced the variability of the estimates of milk yield which indicates that the machine-milked heifers had, in general, higher maximum and lower minimum levels of milk production. The higher maximum milk yields obtained by machine-milking imply that the potential milk yield of some calf-suckling heifers was not expressed, presumably because their calves were unable to consume all the milk available to them in early lactation. Fewer sucklings per day were permitted in the calf-suckling technique than have been reported to occur under natural conditions by Drewry, Brown and Honea (1959), Walker (1962) and Ewbank (1969), and this may have been partly responsible for the lower maximum milk yields obtained by the calf-suckling technique. Nevertheless, in normal systems of single-suckled calf production, the appetite of the calf will set an upper limit to the milk production of the dam and this limitation is removed when milk production is measured by machine-milking. Consequently, the use of machine-milking to measure the milk production of beef cows may provide information which is not directly applicable to the systems of suckled calf production which currently obtain in the United Kingdom.

The low milk yields recorded in certain machine-milked heifers probably resulted from the failure of the pre-milking stimulus to elicit a satisfactory milk-ejection reflex and in this context, stress before and during milking may have been a contributory factor. In one extreme case a machine-milked heifer dried-off 84 days *post partum* and other studies have shown that when beef cows are machine-milked there is a tendency for individual cows to dry-off early in lactation (Cole and Johansson 1933; Abadia and Brinks 1972; B.G. Lowman and R.A. Edwards, personal communication). In the study reported in Appendix 2, four out of six machine-milked beef cows dried-off within 100 days of calving whereas eight calf-suckling cows, maintained in otherwise identical conditions, were still lactating 150 days *post partum*. These cows had low levels of body reserves at calving and this may have further increased the variability of the milk yields obtained by machine-milking.

Although it may be possible to minimise the inhibition of milk-ejection by adapting beef cows to a machine-milking routine in a pre-experimental period, this is seldom convenient, particularly if it is required to impose experimental treatments before or immediately after calving. Thus, the evidence suggests that the response of beef cows to the stimuli associated with machine-milking is variable and consequently this method is less reliable and less precise than the calf-suckling technique for measuring the milk production of beef cows.

The relative precision of the two methods has a marked effect on the number of cows, and therefore, the resources of feed, accommodation and labour required to detect statistically significant treatment differences in milk yield under experimental conditions. The coefficients of variation of cumulative milk yield obtained in the present investigation (26.2 and 11.2 per cent for machine-milking and the calf-suckling techniques respectively) were such that 60 cows per treatment would be required to detect a significant ($P < 0.05$) treatment difference in milk yield of 10 per cent when machine-milking is used as the method of measurement, compared to only 10 per treatment if the calf-suckling technique were used.

b) Collection of milk samples in the calf-suckling technique

Unfortunately, measuring milk production by the calf-suckling technique is more laborious and time-consuming than machine-milking and does not facilitate the collection of representative milk samples for the determination of chemical composition. While no attempt was made to collect milk samples in the present investigation, a method has recently been devised by workers at the North of Scotland College of Agriculture (Economides 1972). The procedure involves machine-milking two diagonally opposite quarters of the udder, while the calf is allowed to suck the other two. The calf is weighed before and after suckling to determine its milk intake and the same amount of milk is removed by machine-milking. However, this method can be criticised because the restriction of the calf to only two quarters of the udder may result in the removal of more milk from each of these two quarters than would normally be the case when the calf has access to all four. An alternative procedure, which would overcome this problem, would be to machine-milk two diagonally opposite quarters each time the calf is allowed to suckle during a 24 hr period, removing half the amount of milk consumed by the calf at the corresponding sucklings during the previous 24 hr period.

c) Defecation and urination in calf-suckling technique

A disadvantage of the calf-suckling technique, referred to by Yates, Macfarlane and Ellis (1971), is that if a calf defecates or urinates between the pre- and post-suckling weighings, this results in an underestimate of milk production. In the present investigation, observation of the calves while they were suckling indicated that defecation or urination is only likely to present a problem during the first week of lactation. This is contrary to the findings of Schake *et al* (1966) who reported that the frequency of urination and defecation by calves involved in the calf-suckling technique increased as lactation advanced. Nevertheless, this potential source of inaccuracy can be obviated by observing the calves at suckling and disregarding milk intake data when a calf is seen to defecate or urinate between weighings. It is advisable, however, to record milk production every day during the first week of lactation to allow for the possible loss of data and also to accustom calves, early in life, to the procedure used in the calf-suckling technique.

d) Health of cows and calves

The health problems encountered with the calves involved in the calf-suckling technique in the present investigation highlight a potential disadvantage of this method of measuring the milk production of beef cows. Young calves are susceptible to disease and any ill-health in calves which are being used in the calf-suckling technique is likely to be associated with a lower than normal milk intake and an underestimate of the milk production of the cow. It can be argued that in normal systems of suckled calf production, calves will have periods of anorexia, and that this should be taken into account when estimating the milk production of beef cows. However, the calf-suckling technique usually involves restraining calves in close proximity to each other and this may increase their susceptibility to diseases, particularly those of a highly infectious nature. Therefore, it is suggested that particular attention be paid to ensuring that calves involved in the calf-suckling technique are healthy when yield estimates are made. In this particular experiment, the scour which affected many of the calves was mild, transient and readily cured by antibiotic therapy. Thus, while the milk yields of some calf-suckling heifers may have been underestimated because of a temporary reduction in the appetite of their calves, the effect was probably small in relation to their total lactation yield.

In experiments designed to examine the effect of different levels of nutrition on the milk production of dairy cows, Waite (1961) has pointed out that udder disease or injury may easily invalidate the results, particularly those for milk composition. In the present investigation, no cases of clinical mastitis were identified in the calf-suckling heifers compared to three in the machine-milked group. In this connection, it may be noted that Walsh (1974) also recorded a higher incidence of clinical mastitis in machine-milked dairy cows than in contemporaries suckled by calves. It may be concluded that mastitis is less likely to present a problem when the calf-suckling technique is used.

e) Suckling régime adopted in calf-suckling technique

Although the procedure adopted in the calf-suckling technique proved to be satisfactory, one minor modification was considered necessary for future experiments. Three times a day suckling was reduced to twice a day at 42 days *post partum* and the unadjusted peak milk yield of the calf-suckling heifers on the high plane of nutrition occurred 35 days *post partum*. To ensure that the attainment of peak yield is not influenced by a reduction in suckling frequency, three times a day suckling will be continued until 56 days *post partum* in future experiments.

f) Application of calf-suckling technique

In the present investigation, the calf-suckling technique was used to measure the milk production of beef cows at a time of year when it was convenient to house the cows and calves and apply the technique. It is more difficult to use the calf-suckling technique when cows and calves are maintained under grazing conditions because the segregation of beef cows from their calves may disrupt their normal grazing and behavioural patterns. Under grazing conditions, the oxytocin technique described in Section 1.3 may prove more convenient but there is a need for research to evaluate the accuracy and reliability of this method of measuring the milk production of beef cows.

Method of defining nutritional treatments and relationship between live-weight and conditions score and milk yield

The maintenance of an animal is related to metabolic size, and it is now generally accepted that body-weight raised to the power 0.75 (Kleiber 1965) gives the best estimate of the metabolic body size of a mature ruminant (Baker, Large and Spedding 1973). In the present investigation, in an attempt to standardise the amount of energy received by the heifers of different live-weights, the amount allocated to each heifer within each plane of nutrition was based on the individual's metabolic live-weight *post partum*. The energy allowance for maintenance per unit of metabolic live-weight (0.5 MJME per day) was similar to the 0.49 MJME currently recommended in Technical Bulletin Number 33 (1975).

As described in the Materials and Methods Section, the nutritional treatments were defined as multiples of estimated energy requirement for maintenance. This method of defining nutritional treatments, originally proposed by Blaxter and Graham (1955), was to some extent arbitrary because, within treatments, the energy available above or below maintenance was correlated with live-weight *post partum*, i.e. on the high and medium treatments, the heavier heifers had more energy available for milk production or live-weight change than the lighter, and on the low treatment, the lighter heifers were less deficient in energy, in absolute terms, than heavier heifers. Thus, the effects of live-weight *post partum* on the lactation performance and live-weight changes of the heifers were confounded by the method used to allocate levels of energy intake. Nevertheless, the magnitude of the effect of live-weight *post partum* on milk production and live-weight changes was much greater than could be attributed wholly to the association between live-weight and energy intake. Although the level of feeding allocated to each heifer was made without reference to their condition score, because condition score and live-weight were positively correlated, the relationship observed between condition score and milk yield is also confounded by the method used to define nutritional treatments.

The inclusion of live-weight *post partum* as a covariate in the analyses of variance of the lactation and live-weight change parameters, and as an independent variate in the multiple regression analyses described in the results section, was statistically valid because heifers were allocated to treatments without any reference to their live-weight *post partum*. The above observations do suggest, however, that it is necessary to consider carefully the way in which nutritional treatments are defined and the particular method adopted in the present investigation does not appear satisfactory.

It is of interest to consider further the relationships established between the live-weight and condition score of the heifers *post partum* and their subsequent milk yield. The confounding effect of the method used to define the nutritional treatments should not be over-emphasised. The additional energy available above maintenance for a heifer of 500 kg *post partum* compared to a heifer of 400 kg was only 5.0 and 2.0 MJME per day on the high and medium treatments respectively, and the reduction in energy provided below maintenance 0.8 MJME on the low treatment. The magnitude of the increase in milk yield as live-weight *post partum* increased was greater than could be wholly attributable to these differences in energy intake.

Every 10 kg increase in live-weight *post partum* was associated with an increase in daily milk yield of 0.22 kg which is greater than the response of 0.1 kg recorded by Jeffery, Berg and Hardin (1971a) who eliminated the effect of age of cow in the relationship. In the present investigation, the ages of the heifers at calving were not known and could not be taken into account. Furthermore, the existence of a relationship between condition score at calving and subsequent milk yield implicates level of body reserves as another contributory factor because live-weight and condition score *post partum* were positively correlated. Thus, the relationship recorded between live-weight *post partum* and subsequent milk yield may be a reflection of differences in age, body reserves, body size and energy supply above maintenance.

The increase in milk yield associated with an increase in condition score at calving demonstrates an advantage of having heifers in good body condition at first calving. A one unit increase in body condition was associated with an increase in milk yield of 1 kg a day. The relationship established between energy intake during lactation and the milk yield of the calf-suckling heifers suggests that to achieve an improvement in daily milk yield of 1 kg by better feeding in lactation, an additional 32.3 MJME per day would have to be supplied. However, the condition score of the heifers at calving may have been positively correlated with their age and thus differences in age may have influenced the relationship between condition score and milk yield.

Diets offered and energy and protein balance

In the series of experiments of which the present investigation formed part, the intention was that the diets offered on each treatment should supply a minimum of 640 g of DCP per day, sufficient to meet the estimated daily requirements of a 500 kg cow producing 7 kg of milk. In the present study, although the daily DCP intakes on the medium and low treatments failed to reach 640 g, this was partly offset by the lower average live-weight of the heifers during the 150-day lactation period.

An approximate DCP balance was calculated (see Table D.1) which showed that the DCP allowance on each treatment was sufficient, or nearly sufficient, to satisfy the requirements of the heifers estimated from the equation

$$\text{DCP requirement in grammes} = 22.94 + 2.538W^{0\cdot75} + 50Y$$

where W = live-weight in kg and Y = milk yield in kg
(R.A. Edwards, personal communication)

The above equation gives a higher estimate of DCP requirements than those recommended by the ARC (1965) which were calculated to be 516, 504 and 440 g per day for the heifers on the high, medium and low treatments respectively.

On the basis of these two estimates of requirements it appears that an adequate but not excessive amount of protein was provided on each of the three treatments. Furthermore, neither the concentration of crude protein in the dry matter nor the protein to energy ratios differed markedly. It may be concluded, therefore, that the nutritional responses observed were attributable to differences in energy intake and that protein was unlikely to be limiting performance.

TABLE D.1: Estimated daily energy and protein balance

		Plane of nutrition	
	High	Medium	Low
Average live-weight (kg)	380	373	379
Average metabolic live-weight (kg)	86.1	84.9	85.9
Average daily milk yield (kg)	6.63	6.95	6.00
ME requirement (MJ): Maintenance[1]	43.0)	42.4)	42.9)
ME requirement (MJ): Milk production[2]	33.2) 76.2	34.8) 77.2	30.0) 72.9
ME intake (MJ)	74.5	54.5	39.3
Intake minus requirement (MJ)	-1.7	-22.7	-33.6
DCP requirement (g): Maintenance[3]	241.5)	238.4)	241.0)
DCP requirement (g): Milk production[4]	331.5) 573	347.5) 586	300.0) 541
DCP intake (g)	640	548	502
Intake minus requirement (g)	+67	-38	-39

[1]10.5 MJME/$W^{0.75}$; [2]5.0 MJME/kg; [3]22.94 + 2.538g/$W^{0.75}$; [4]50 g/kg
where W = live-weight (kg)

In this experiment protein allowances were expressed in terms of DCP. A new system of calculating protein allowances is currently being developed, however, which recognises and takes account of the different degradabilities of different sources of protein (M. Lewis, personal communication). It has been established that the protein contained in silage is more readily degraded in the rumen than the protein contained in soya bean meal (Beever, Thomson and Harrison 1974; Hume and Purser 1975). It should be noted that in the present investigation as the plane of nutrition of the cows increased, a higher proportion of their protein intake was in a readily degradable form. Hence, although the high plane cows had a higher DCP intake relative to their estimated requirements than did the low plane cows, this may have been partly offset by a lower efficiency of protein ultisation.

Table D.1 shows that on the high plane of nutrition the average estimated energy requirement of the heifers was only just below their average estimated requirements for maintenance and milk production. It is, therefore, surprising that at 150 days *post partum* these heifers were 53 kg lighter and their condition score 0.87 units less than at calving. While a reduction in gut-fill may account for a proportion of the live-weight loss recorded, gut-fill changes should not have influenced the reduction in condition score. This suggests that either the energy intake of the high plane heifers was overestimated or that their requirements were underestimated.

Table D.1 also shows that heifers on the low plane of nutrition had, on average, a daily energy deficit of approximately 34 MJME. It has been estimated that 1 kg of live-weight loss supplies the equivalent of 28 MJ dietry ME (Technical Bulletin Number 33, 1975) which suggests that to meet their average daily energy deficit, the heifers should have mobilised over 1 kg of live-weight a day. On average, the low plane heifers mobilised only 0.7 kg a day, indicating that either their energy intake was underestimated or their requirement over-estimated, i.e. the converse of the situation on the high plane. No obvious explanation for this apparent contradiction can be offered.

Feed intakes

This investigation has demonstrated some of the problems associated with the use of silage in experimental diets. Although a large number of core samples were collected before the experiment commenced, the average composition of these samples did not prove accurately representative of the average composition determined from samples collected daily while the silage was being apportioned among the heifers. Furthermore, the composition of the silage varied from day to day throughout the course of the experiment and this resulted in day to day variation in the intakes of the heifers.

During the winter, many beef cows are offered diets which include silage *ad libitum* and there is a lack of information on the quantity of dry matter consumed in the form of silage. Although this experiment was not designed to examine the maximum voluntary dry matter intake of the heifers, it is interesting to note that there was little evidence to suggest that a daily dry matter intake of 7.6 kg (74 per cent of which was consumed in the form of silage) approached the maximum intake of the heifers.

Milk yields and calf performance

The nature of the response of the machine-milked heifers to an increase in energy intake in terms of milk yield differed from the response observed in the calf-suckling group. The non-linear response of the machine-milked heifers was not statistically significant and probably occurred because, by chance, the heifers responsive to the stimuli associated with machine-milking were unequally distributed among the three planes of nutrition. In view of this and the remarks made earlier in relation to machine-milking, it is considered that the response obtained in the calf-suckling heifers was more reliable, and also more representative of the response which would be observed in normal systems of suckled calf production, than the pooled response of the machine-milked and calf-suckled groups.

The response of the calf suckling heifers to an additional daily energy intake of 10 MJME was 0.31 kg of milk per day. This was lower than the response of 0.55 kg per 10 MJME reported by Wilson *et al* (1969), but greater than the 0.18 kg per 10 MJME recorded by B.G. Lowman and R.A. Edwards (personal communication). Each of these responses was observed in investigations which involved different methods of estimating milk production and different breeds or crosses of beef cow. Nevertheless, the magnitude of the difference between the response reported by Wilson *et al*, and that recorded in the present investigation is surprising, particularly because Wilson *et al* recorded the response at higher levels of energy intake.

In beef cows, the benefit of higher milk yields will only be realised if the growth rates of their calves are improved or if the calves consume less supplementary feed. In the present investigation, the existence of a significant ($P < 0.05$) positive correlation between the milk intake and live-weight change of the calves involved in the calf-suckling technique demonstrates the importance of milk intake as a determinant of the pre-weaning growth rates of suckled calves, even when solid food is made available to the calves from birth onwards. This is in agreement with the findings of other studies reported in the literature (see Table R.2 in Section 1.5 of Review of Literature) and in the present investigation, an increase in milk intake of 1 kg per day between birth and 150 days improved the live-weight gain of the calves by 23 g per day.

Although calf growth rate and milk intake were positively correlated, the increase in the milk yield of the calf-suckling heifers in response to higher levels of nutrition during lactation was insufficient to have any appreciable effect on the growth rates of their calves. Thus, while the milk yields of beef cows influence the growth rates of their calves, milk yield appears relatively unresponsive to higher planes of nutrition during lactation.

Unfortunately, the facilities available for the present study did not permit the hay intakes of the calves to be measured accurately. Nevertheless, there was no indication that the planes of nutrition imposed on the calf-suckling heifers influenced the solid food intake of their calves between birth and 150 days. Thus, the results of the present investigation suggest that improving the plane of nutrition received by beef heifers during their first lactation has little effect on the growth rates of their calves. It must be emphasised, however, that the heifers were in good body condition at calving and that their calves had access to supplementary solid food from birth onwards.

Milk composition

Interest in the chemical composition of milk produced by a beef cow stems from its nutritional importance in the diet of the suckled calf. In the present study, milk composition data were only available from the machine-milked group. However, in the absence of a significant effect of method of milking on milk yield, it would not be expected that, on average, the composition of the milk produced by the machine-milked group would differ markedly from that of the calf-suckling group.

The mean BF and SNF contents were of the same general magnitude as those reported in the literature for beef cows (see Table R.4, page 60) and the effect of stage of lactation on the two traits followed similar trends to those reported for dairy cows by Burt (1957), Rook (1961) and Balch (1972). As the plane of nutrition received by the machine-milked heifers decreased, there was a highly significant ($P < 0.001$) depression in SNF content and a non-significant trend for BF content to increase. This is in agreement with the conclusions reached by Burt (1957), Rook (1961) and Balch (1972) in reviews of the experimental evidence relating to the effect of nutrition on the composition of milk produced by dairy cows, and also with the results obtained by Wilson *et al* (1969) and Economides *et al* (1973) with beef cows. In their reviews, Burt (1957), Rook (1961) and Balch (1972) concluded that the fall in SNF content is largely attributable to a reduction in protein content, although a small decrease in lactose content can also occur. Thus, a reduction in the energy intake of a beef cow during lactation will probably cause a reduction in the protein concentration of the milk consumed by the suckled calf.

In the present investigation, the fall in the SNF content as plane of nutrition decreased was partly offset by an increase in BF content and consequently, the gross energy value of the milk was not significantly affected by plane of nutrition. Furthermore, less than two per cent of the variation in the total gross energy output of the machine-milked heifers in the first 150 days of lactation was attributable to differences in the gross energy value of the milk. It is concluded that a reduction in the plane of nutrition received by a beef cow during lactation will reduce the protein concentration of the milk consumed by a suckled calf but will have little effect on the energy concentration. It would be of interest to confirm, however, that in beef cows the reduction in SNF content as plane of nutrition decreases is mainly attributable to a reduction in protein content.

Live-weight losses and fertility

This experiment has demonstrated the capacity of energy deficient beef cross dairy heifers, particularly those suckling calves, to maintain milk production by depleting body reserves. A reduction in energy intake during lactation of 47 per cent reduced the milk yield of the calf-suckling heifers by only 17 per cent.

The machine-milked and calf-suckled heifers on the low plane of nutrition, and to a lesser extent those on the medium plane, drew heavily upon body reserves to maintain milk production. Low levels of nutrition resulting in substantial live-weight losses during the mating period have been implicated as a cause of poor reproductive performance in both dairy (King 1968; Kail, Amir and Bleiberg 1968) and beef cows (Witt, Warnick, Koger and Cunha 1958; Wiltbank *et al* 1962 and 1964; Bellows 1967; Dunn, Ingalls, Zimmerman and Wiltbank 1969). In the present investigation, although the heifers on the medium and low planes of nutrition mobilised live-weight and body condition during the mating period, this had no detrimental effect on their fertility and only one of these heifers failed to conceive during a 100-day mating period. It appears that the energy intake of the heifers on all planes of nutrition, in relation to their requirements for maintenance and milk production, was adequate for satisfactory reproductive performance. However, before definitive conclusions can be reached as to the adequacy of a diet for satisfactory reproductive performance, more data are required than were available from the present investigation.

Subsequent performance of heifers

Suckled calf production is a continuous process and the effect of different levels of nutrition imposed in one phase of the production cycle must be considered in relation to the subsequent performance of the beef cow. In the present study, the nutritional levels imposed on the heifers had no effect on their live-weight 12 hr after calving at the beginning of their second lactation, or on their subsequent lactation performance. It should be borne in mind, however, that the heifers were dried-off approximately 175 days *post partum* which is earlier than is usual in commercial practice. Therefore, during the grazing season, the heifers had an opportunity to replenish body reserves and regain weight lost in their first lactation, without an additional nutritional requirement for milk production.

Conclusions

It appears that when beef heifers are in good body condition at calving and have a protein intake sufficient to meet their estimated requirements, energy allowances in lactation need be little more than the maintenance level for satisfactory reproductive performance. Furthermore, although milk yields will be depressed by low levels of energy intake during lactation, calf growth rates appear not to be markedly affected when supplementary solid food is made available to the calves from birth onwards. Before these findings can be translated into commercial practice, however, their validity under group feeding conditions requires critical examination.

4. RESULTS OF EXPERIMENT 2

Health

a) Cows

Apart from mild mastitic infections and 'foul in the foot' (an *Actinomyces necrophorus* infection), both of which were readily cured by antibiotic therapy, no health problems were encountered in the cows.

b) Calves

One calf died as a result of an acute colibacillosis infection when seven days old and was replaced by a purchased calf.

Every calf had mild scour on at least one occasion during the experimental period. In general, the milk intake of calves less than two months old was reduced, temporarily, with the extent of the reduction in intake dependent on the severity of the scour. In older calves, however, there was no obvious affect on milk intake.

Approximately 75 per cent of the calves had mild scour intermittently from 12 to 16 weeks of age. These calves responded to a three-day course of Vetoryl[1] or Stromez[1] but, two or three days after completing the course of treatment, the calves started to scour again and their intake of concentrates decreased.

Examination of faecal swabs collected from affected calves indicated that the scour was not the symptom of a bacterial infection and the scour appeared to be associated with the change in the composition of the concentrate supplement offered to the calves. For this reason, the quantity of concentrate supplement offered to an affected calf was reduced to approximately 50 per cent of its intake prior to the appearance

---

[1]see footnote on page 112

of scour, and was gradually increased as the calf recovered. All the affected calves recovered but mild scouring continued to occur spasmodically and the daily concentrate intake of the calves remained erratic during the four-week period following the change in the composition of the concentrate supplement offered.

Although the concentrate intake of individual calves was reduced, at no time during the experimental period was the milk intake of a calf deliberately restricted.

Examination of records kept of any ill-health in the calves revealed that the incidence and severity of the scour, associated with the change in the composition of the concentrate supplement offered, was greater among calves suckling dams on the medium plane of nutrition than in calves suckling dams on the high or low planes of nutrition.

Other health problems encountered in the calves included navel-ill, virus pneumonia and foul in the foot but the incidence of these infections was low and the affected calves responded rapidly to treatment.

No data were excluded from the analyses because of ill-health in either a cow or calf.

<u>Feed intakes</u>

The mean daily intakes of silage, concentrates, DM, ME and DCP are presented in Table E.10. Although the fresh weight of silage and concentrates offered to an individual cow remained constant throughout the experimental period, day-to-day variation in the composition of the silage offered resulted in day-to-day variation in the cow's intake of DM, ME and DCP. The variation in the composition of the silage offered and examples of the resultant variation in the daily intakes of the cows are shown in graphical form in Appendix 4 (Figures 2, 3 and 4).

TABLE E.10: Mean daily intakes of silage, concentrates, dry matter (DM), metabolisable energy (ME) and digestible crude protein (DCP) on the three treatments in Experiment 2

Mean daily intakes	Plane of nutrition High	Medium	Low	Residual SD	Significant linear effect
Fresh silage (kg)	33.1	24.8	18.0	2.52	***
Fresh concentrates (kg)	1.31	1.03	0.81	0.091	***
DM (kg)	9.51	7.12	5.26	0.769	***
ME (MJ)	99.1	72.7	53.4	8.31	***
DCP (g)	785	665	608	65.1	***

TABLE E.11: Mean daily intakes of metabolisable energy (ME) and digestible crude protein (DCP), in Experiment 2, expressed as a percentage of maintenance requirement (M) and in productive terms[1]

	Plane of nutrition High	Medium	Low
Daily ME intake as percentage of M	188	137	101
Daily ME intake in terms of M + kg milk	M + 9.3	M + 4.0	M + 0.1
Daily DCP intake as percentage of M	271	228	209
Daily DCP intake in terms of M + kg milk	M + 9.9	M + 7.5	M + 6.3

[1]see footnote of Table E.2

At no time during the experimental period did any cow fail to consume the concentrate allowance provided,and the average quantity of silage DM offered but not consumed by the cows was 3.40, 0.72 and 0.11 per cent on the high, medium and low planes of nutrition respectively. This was equivalent to 3.22, 0.66 and 0.09 per cent of the total daily DM (i.e. silage DM plus concentrates DM) offered to the cows on the high, medium and low planes of nutrition respectively. On the high plane of nutrition, the silage DM offered but not consumed ranged from 0.09 to 6.52 per cent which represented a range of 0.08 to 6.42 per cent of the total DM offered.

In Table E.11 the mean daily intakes of the cows are expressed as a percentage of their estimated maintenance requirement and in relation to the estimated levels of milk production which they could support with zero live-weight change. These values relate to the estimated energy and protein requirements for maintenance and production, based on the live-weight of the cows 12 hr *post partum*.

Tables E.10 and E.11 show that the desired intakes of protein and energy were not achieved. A higher energy intake was achieved than had been intended because the DM and ME value of the silage, estimated from the core samples taken prior to the experiment, were lower than the DM and ME value estimated from daily samples taken from the silage at feeding. The DM, ME and DCP content of the silage estimated from daily samples were used to calculate the daily intakes of the cows.

It had been intended that the daily DCP intakes of the cows should be in excess of 640 g per head. Although the mean daily intakes on the high and medium planes of nutrition were in excess of this level, the mean daily intakes of cows on the low plane of nutrition just failed to reach the desired level.

Lactation performance

Table E.12 shows the lactation performance of the cows, adjusted to a standard calf birth-weight by covariance analysis, and the unadjusted mean a, b and c coefficients used to describe the lactation curves. Five covariates were tested independently in the variance analysis of the effect of plane of nutrition on the lactation performance of the cows; live-weight of the cow *post partum*, condition score *post partum*, 150-day cumulative milk yield in Experiment 1, and birth-weight and sex of calf. Of these, only birth-weight of the calf significantly ($P < 0.05$) reduced the residual variance and was included in the final analysis.

TABLE E.12: Effects of plane of nutrition on the lactation performance of beef cows

	Plane of nutrition			Residual SD	Significant linear effect
	High	Medium	Low		
[1]150-day cumulative milk yield (kg)	1385	1274	1197	123.7	**
[1]Peak milk yield (kg)	10.1	9.9	9.1	1.24	NS
[1]Days *post partum* peak milk yield recorded	45	32	29	21.4	NS
Coefficients a)	12.5	14.8	13.9	4.66	NS
Coefficients b)	0.213	0.142	0.109	0.1282	NS
Coefficients c)	0.003	0.005	0.004	0.0023	NS

[1]Adjusted to a standard calf birth-weight by covariance analysis

Calf birth-weight had a significant ($P < 0.01$) effect on 150-day cumulative milk yield and peak milk yield, and every 1 kg increase in calf birth-weight was associated with an increase in 150-day yield milk of 15 kg. The regressions of the lactation parameters on calf birth-weight together with the standard error and significance of each coefficient are shown in Appendix 4 (Table 11).

When calf birth-weight was tested as a covariate in the variance analyses of the a, b and c coefficients, the residual variance was not significantly reduced. Thus, the a, b and c values presented were not adjusted to a standard calf birth-weight.

The unadjusted mean a, b and c coefficients were used to construct lactation curves for each plane of nutrition. These are presented in Figure E.8 which shows that the shape of the lactation curve was similar on each of the three planes of nutrition.

Peak milk yield and 150-day cumulative milk yield were closely correlated (partial $r = +0.77$; $P < 0.001$). When energy intake was held constant, every 1 kg increase in peak milk yield was associated with an increase ($\pm$SE) in 150-day cumulative milk yield of 75 ± 11.2 kg ($P < 0.001$).

The response of the cows to different levels of energy intake in terms of 150-day cumulative milk yield was determined by multiple regression analysis. The multiple regression equation of 150-day milk yield (Y) on energy intake (x_1) and calf birth-weight (x_2) was:

$$Y = 431 + 3.8x_1 + 14.6x_2 \qquad (R = 0.76;\; P < 0.001)$$

Where Y is in kg	b_1 and b_2 = partial regression coefficients
x_1 is in MJME/day	SE of $b_1 = \pm 0.98^{***}$
x_2 is in kg	SE of $b_2 = \pm 3.57^{***}$

The addition of the independent variates in quadratic form did not significantly reduce the residual sums of squares. Thus, over a range of from 48 to 118 MJME per day, the response of the cows to an additional daily intake of 10 MJME, in terms of 150-day cumulative milk yield, was 38 kg, i.e. 0.25 kg of milk a day.

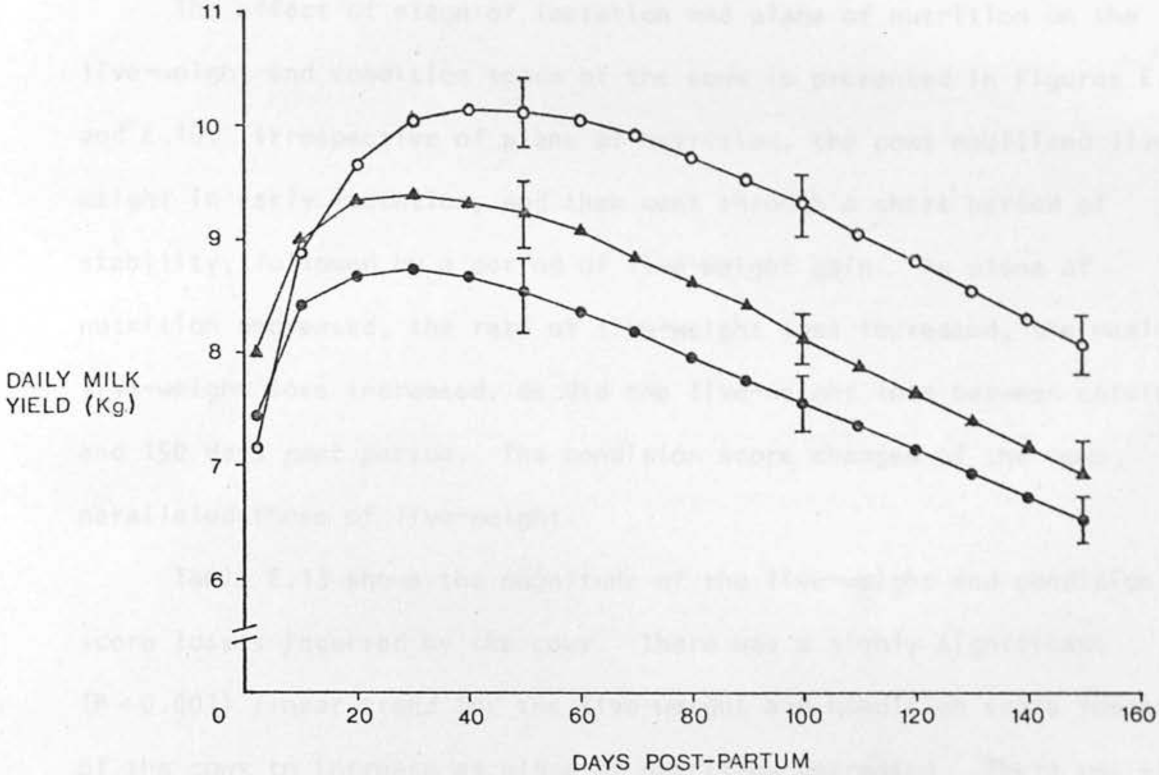


Fig. E8 Effect of stage of lactation and plane of nutrition on the unadjusted mean (± SE) daily milk yield of beef cows.
o—o High; ▲—▲ Medium; ●—● Low plane of nutrition.

Live-weight and condition score changes

The effect of stage of lactation and plane of nutrition on the live-weight and condition score of the cows is presented in Figures E.9 and E.10. Irrespective of plane of nutrition, the cows mobilised live-weight in early lactation, and then went through a short period of stability, followed by a period of live-weight gain. As plane of nutrition decreased, the rate of live-weight loss increased, the maximum live-weight loss increased, as did the live-weight loss between calving and 150 days *post partum*. The condition score changes of the cows paralleled those of live-weight.

Table E.13 shows the magnitude of the live-weight and condition score losses incurred by the cows. There was a highly significant ($P < 0.001$) linear trend for the live-weight and condition score losses of the cows to increase as plane of nutrition decreased. There was also a highly significant ($P < 0.001$) linear trend for the cows to reach their minimum live-weight and their minimum condition score later in lactation as plane of nutrition decreased.

Three cows on the low plane of nutrition failed to reach their minimum condition score by 150 days *post partum*. Two of these cows reached their minimum condition score while subject to experimental treatment but the third was still declining in condition score at the end of the experimental period.

Part of the live-weight losses incurred by the cows in early lactation may reflect changes in gut-fill, particularly on the low plane of nutrition. Between 12 hr and 10 days *post partum*, the live-weight losses of the cows were 15, 19 and 29 kg ($P < 0.001$) on the high, medium and low planes of nutrition respectively, a proportion of which was

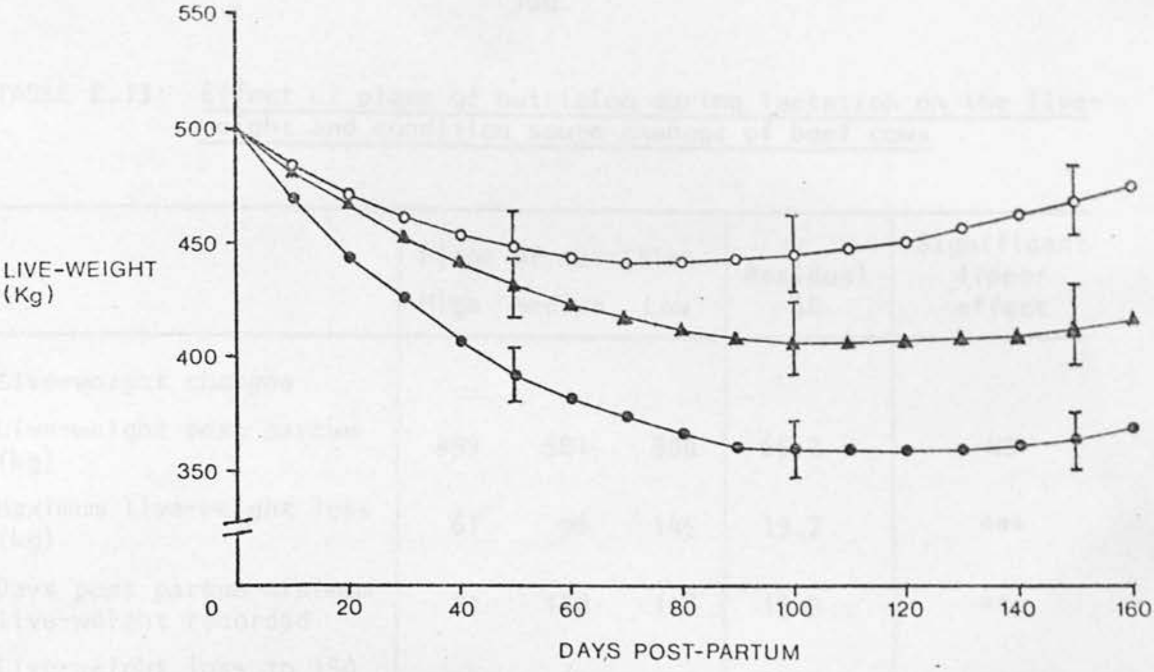


Fig. E9 Effect of stage of lactation and plane of nutrition on the unadjusted mean (±SE) live-weight of beef cows.
o—o High; ▲—▲ Medium; ●—● Low plane of nutrition.

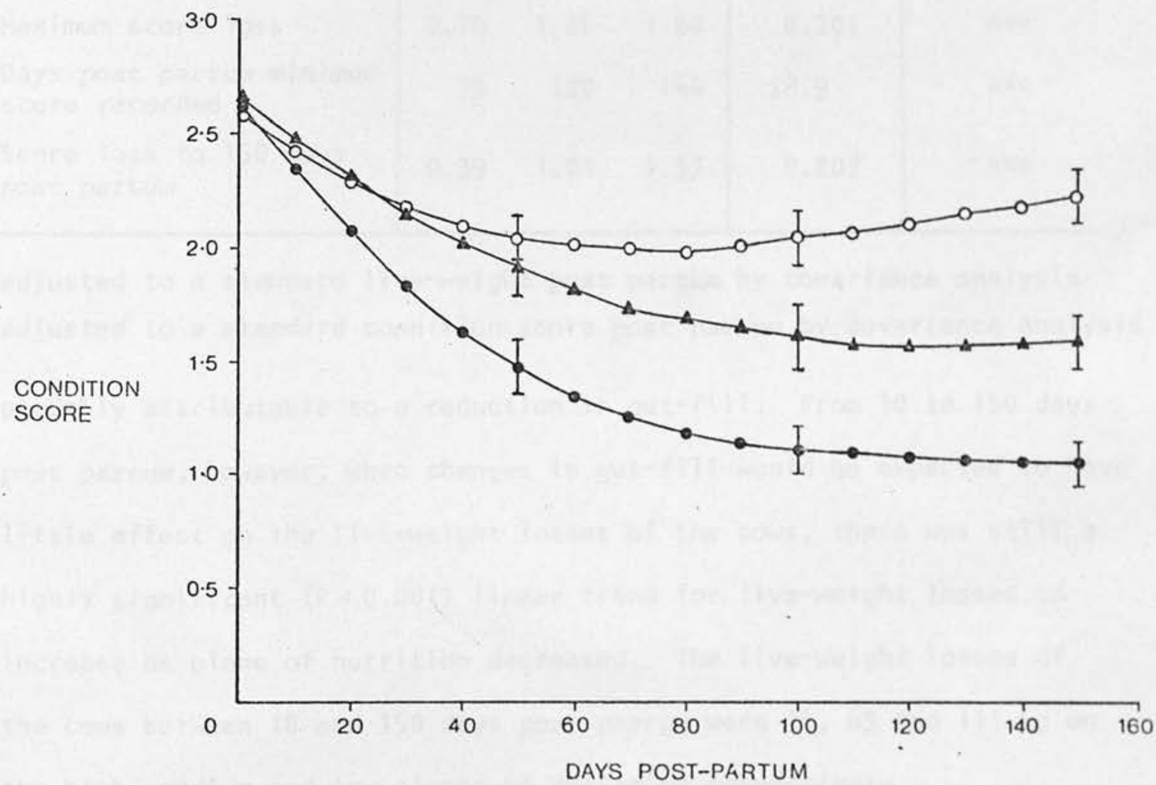


Fig.E10 Effect of stage of lactation and plane of nutrition on the mean (±SE) condition score of beef cows.
o—o High; ▲—▲ Medium; ●—● Low plane of nutrition.

TABLE E.13: Effect of plane of nutrition during lactation on the live-weight and condition score changes of beef cows

	Plane of nutrition			Residual SD	Significant linear effect
	High	Medium	Low		
Live-weight changes					
Live-weight *post partum* (kg)	499	501	500	65.2	NS
[1]Maximum live-weight loss (kg)	61	96	145	19.7	***
[1]Days *post partum* minimum live-weight recorded	81	108	118	19.9	***
[1]Live-weight loss to 150 days *post partum* (kg)	31	87	139	23.7	***
Condition score changes					
Score *post partum*	2.59	2.65	2.66	0.302	NS
[2]Maximum score loss	0.70	1.06	1.60	0.201	***
[2]Days *post partum* minimum score recorded	79	120	144	28.9	***
[2]Score loss to 150 days *post partum*	0.39	1.01	1.57	0.207	***

[1]adjusted to a standard live-weight *post partum* by covariance analysis
[2]adjusted to a standard condition score *post partum* by covariance analysis

probably attributable to a reduction in gut-fill. From 10 to 150 days *post partum*, however, when changes in gut-fill would be expected to have little effect on the live-weight losses of the cows, there was still a highly significant ($P < 0.001$) linear trend for live-weight losses to increase as plane of nutrition decreased. The live-weight losses of the cows between 10 and 150 days *post partum* were 16, 69 and 111 kg on the high, medium and low planes of nutrition respectively.

The response of the cows to different levels of energy intake, in terms of their live-weight loss from parturition to 150 days *post partum* was determined by multiple regression analysis. The multiple regression equation of live-weight loss to 150 days (Y) on energy intake (x_1) and live-weight *post partum* (x_2) was:

$$Y = 71.5 - 2.25x_1 + 0.36x_2 \quad (R = 0.92; \; P < 0.001)$$

Where Y is in kg	b_1 and b_2 = partial regression coefficients
x_1 is in MJME/day	SE of b_1 = ±0.172***
x_2 is in kg	SE of b_2 = ±0.063***

The addition of the independent variates in quadratic form did not significantly reduce the residual sums of squares. Thus, over a range of from 48 to 118 MJME, every additional 10 MJME consumed per day reduced the live-weight loss of the cows between calving and 150 days *post partum* by 22.5 kg.

There was a "positive" relationship between live-weight loss and milk yield, within each plane of nutrition. The simple regression equations of live-weight loss from calving to 150 days *post partum* (Y) in kg on the unadjusted 150-day cumulative milk yield (X) in kg were as follows:

High	$Y = -132 + 0.116X$	$(r = 0.70;$	$P < 0.05)$
Medium	$Y = 22 + 0.052X$	$(r = 0.40;$	NS)
Low	$Y = 75 + 0.053X$	$(r = 0.30;$	NS)

Analysis of the residual variance indicated that the three regression coefficients were not significantly different and the pooled regression coefficients (±SE) of live-weight loss on milk yield was 0.080 ± 0.0447 kg (NS).

Reproductive performance

One cow on the high plane of nutrition, one on the medium plane and three on the low plane failed to conceive during a 100-day breeding period.

The failure of one of the three cows on the low plane to conceive was attributed to the presence of ovarian adhesions and a cystic fallopian tube, diagnosed by rectal examination. No clinical, pathological explanation was found, however, for the failure of the other four cows to breed.

Further details of the reproductive performance of the cows are presented in Appendix 4 (Table 10).

Calf performance

There was a significant ($P < 0.001$) association between the milk intake and live-weight gain of the calves between birth and 150 days of age (partial $r = +0.79$). Live-weight gain increased (±SE) by 9.0 ± 2.04 kg ($P < 0.001$) for every 1 kg increase in daily milk intake over the 150-day period, when the effect of sex of calf was eliminated. The milk and supplementary feed intakes of the calves are presented in Table E.14. The milk intakes of the calves to 150 days were equivalent to the unadjusted 150-day cumulative milk yields of their dams. Plane of nutrition of the dam had no effect on the total concentrate intake of the calves to 150 days of age.

On average, the calves attained their maximum concentrate intake (i.e. they consumed 2 kg a day on three consecutive days) between 100 and 110 days of age. However, after having consumed 2 kg a day on three consecutive days, the daily concentrate intake of many calves frequently dropped below 2 kg, particularly calves suckled by dams on the medium plane of nutrition.

Figure E.11 shows the mean daily concentrate intakes of the calves. Plane of nutrition of the dam did not influence the development of concentrate intake in the calves, but Figure E.11 shows that at 13 weeks of age, just after the composition of the concentrate supplement offered to the calves was changed and many of the calves developed mild scour, there was a temporary reduction in the concentrate intake of the medium group of calves.

TABLE E.14: Milk and supplementary feed intakes of calves suckled by dams on one of three planes of nutrition during lactation

	Plane of nutrition of dam			Residual SD	Significant linear effect
	High	Medium	Low		
Total milk intake to 150 days of age (kg)	1401	1272	1182	148.5	*
Total concentrate intake to 150 days of age (kg/head)	135	130	132	23.8	NS
Age at which maximum daily concentrate intake (2 kg/head) attained (days)	102	110	110	15.5	NS
[1]Total hay intake to 150 days of age (kg/head)	108	121	122	-	-

[1]estimated on a group basis

There was no evidence of a relationship between the milk and concentrate intakes of the calves to 150 days of age ($r = -0.26$; NS).

The estimated hay intake of calves suckled by dams on the high plane of nutrition was less than the estimated hay intakes of the calves suckled by dams on the medium and low planes of nutrition. Although the hay consumption of the calves was not recorded precisely, Figure E.12 shows that the estimated mean daily intake of the high group of calves

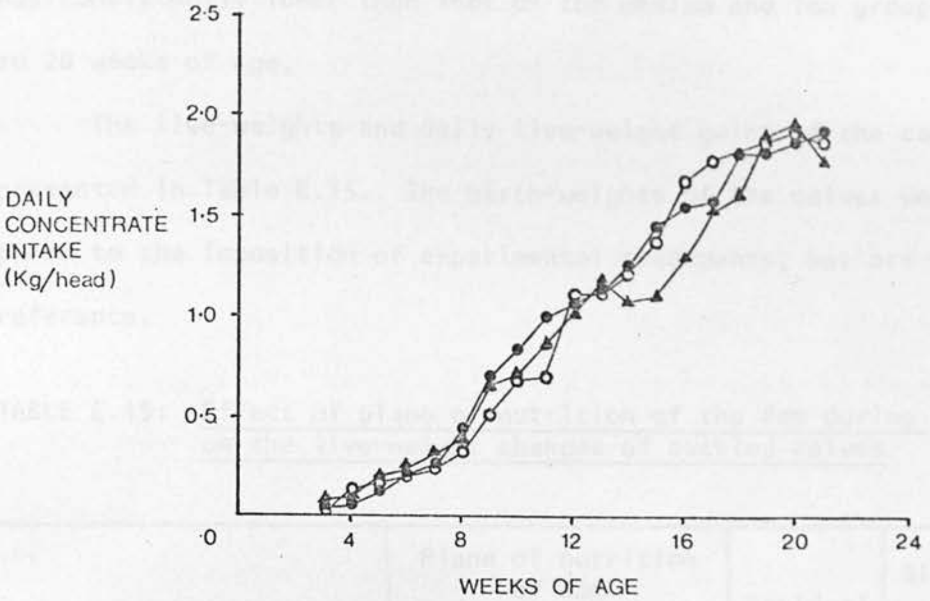


Fig.E11 Daily concentrate intake of calves suckled by dams on one of three planes of nutrition.
○—○ High; ▲—▲ Medium; ●—● Low plane of nutrition.

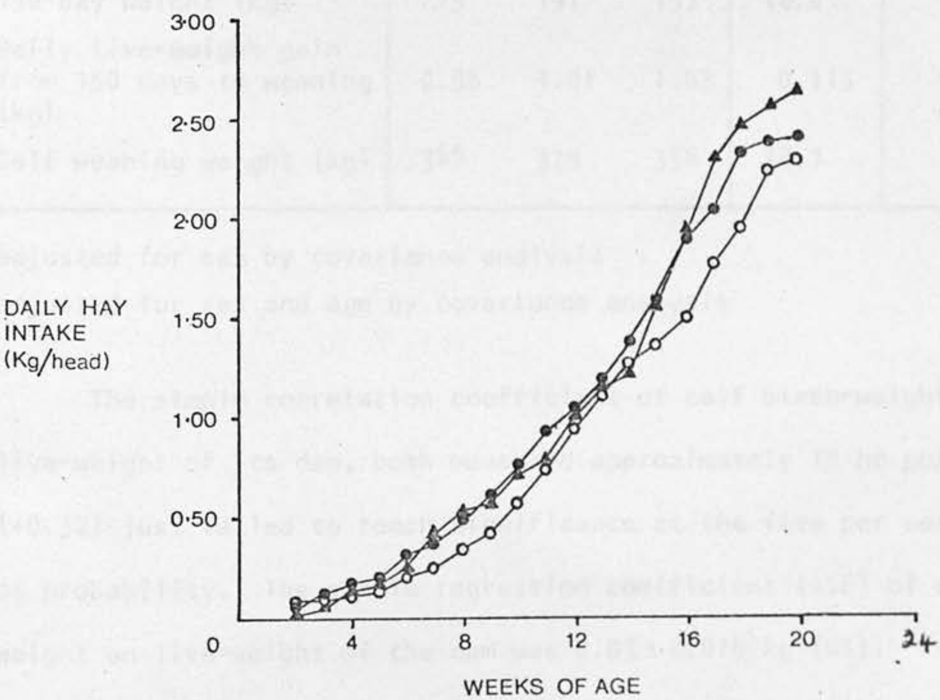


Fig.E12 Daily hay intake of calves suckled by dams on one of three planes of nutrition.
○—○ High; ▲—▲ Medium; ●—● Low plane of nutrition.

was consistently lower than that of the medium and low groups from four to 20 weeks of age.

The live-weights and daily live-weight gains of the calves are presented in Table E.15. The birth-weights of the calves were recorded prior to the imposition of experimental treatments, but are included for reference.

TABLE E.15: Effect of plane of nutrition of the dam during lactation on the live-weight changes of suckled calves

	Plane of nutrition of dam			Residual SD	Significant linear effect
	High	Medium	Low		
[1]Birth-weight (kg)	40.5	38.8	38.8	5.96	NS
[1]Daily live-weight gain to 150 days of age (kg)	1.16	1.01	1.06	0.098	*
[1]150-day weight (kg)	215	191	197	18.0	*
[1]Daily live-weight gain from 150 days to weaning (kg)	0.96	1.01	1.03	0.113	NS
[2]Calf weaning weight (kg)	347	329	338	28.7	NS

[1]adjusted for sex by covariance analysis
[2]adjusted for sex and age by covariance analysis

The simple correlation coefficient of calf birth-weight and the live-weight of its dam, both measured approximately 12 hr *post partum* (+0.32) just failed to reach significance at the five per cent level of probability. The simple regression coefficient (±SE) of calf birth-weight on live-weight of the dam was 0.03 ± 0.016 kg (NS).

Between birth and 150 days of age, the calves suckled by low plane dams had a significantly ($P < 0.05$) lower daily live-weight gain than calves suckled by high plane dams. The medium group of calves had the lowest daily live-weight gain between birth and 150 days, probably because the incidence and severity of scour was greater in this group of calves than in the high or low groups.

Between 150 days of age and weaning, the low group of calves had a higher average daily live-weight gain than the high group, although the difference was not significant. This offset the influence of the higher growth rates of the high group during the winter and by weaning there were no significant differences between the live-weights of the three groups of calves.

It appeared that a negative relationship may have existed between the daily live-weight gains of the calves from birth to 190 days (i.e. the average age of the calves at turnout to grass) and the daily live-weight gains of the calves from 190 days to weaning. However, the partial correlation between the two traits (holding sex of calf constant) was not significant ($r = -0.19$).

Subsequent performance of cows

Table E.16 shows the effect of the plane of nutrition received by the cows during the first six months of lactation on certain aspects of their subsequent performance.

No trend emerged with respect to gestation length, but the gestation length of cows on the low plane of nutrition was significantly ($P < 0.05$) shorter than that of cows on the medium plane.

There was a significant ($P < 0.05$) linear trend for the birth-weight of calves born at the beginning of the subsequent lactation to be depressed as plane of nutrition of the dam decreased. Gestation length and calf birth-weight were positively correlated ($r = 0.56$; $P < 0.01$) and if the gestation length of cows on the low plane of nutrition was shorter by chance, this may have exaggerated the trend for calf birth-weight to be depressed as the previous plane of nutrition of the dam decreased. Therefore, the effect of nutrition of the dam was examined in relation to calf birth-weight, adjusted to a standard gestation length (and sex of calf) by covariance analysis. The adjusted birth-weights of calves from dams on the high, medium and low planes of nutrition were 44.8, 41.4 and 41.3 kg respectively and the linear trend was significant ($P < 0.05$). This suggests that, irrespective of any effect on gestation length, the plane of nutrition of the dam influenced calf birth-weight.

TABLE E.16: Effect of plane of nutrition during lactation on the subsequent performance of beef cows

	Plane of nutrition			Residual SD	Significant linear effect
	High	Medium	Low		
Gestation length (days)	287	290	281	9.3	NS
[1]Calf birth-weight at beginning of subsequent lactation	45.2	43.2	39.0	5.99	*
[2]Live-weight of cows at beginning of subsequent lactation	532	508	506	19.7	**
[2]Live-weight increase of cow between previous calving and calving at beginning of subsequent lactation	27.9	3.3	1.6	19.32	**

[1]adjusted to a standard sex by covariance analysis
[2]adjusted to a standard live-weight *post partum* by covariance analysis

The plane of nutrition received by the cows during the first six months of lactation significantly ($P < 0.01$) influenced their live-weight at the beginning of the following lactation, and their live-weight change between the previous calving and calving at the beginning of the subsequent lactation.

5. DISCUSSION OF EXPERIMENT 2

Lactation performance

The levels of milk production recorded in the present investigation were considerably lower than those quoted for dairy cows (Milk Marketing Board 1976), but higher than most previously reported estimates of the milk yield of beef cows (see Table R.3). The latter observation tends to support the contention of Christian, Hauser and Chapman (1965), Wilson *et al* (1969), Deutscher and Whiteman (1971) and Kropp *et al* (1973) that beef cross dairy cows sustain higher levels of milk production than the pure beef breeds and their crosses which have been traditionally used as dams in suckled calf production.

This has implications for the feeding of beef cows during lactation because the feed requirements of lactating beef cows are positively related to their level of milk production. If, as the available evidence suggests, beef cross dairy cows have higher milk yields than pure beef breeds and crosses, their feed requirements during lactation will also be greater. Thus, the feeding standards which have proved satisfactory for traditional breeds and crosses of beef cows during lactation may be inappropriate for beef cross dairy cows with their higher levels of milk production.

The general shape of the lactation curves observed in the present investigation was similar to that reported for dairy cows by Foley *et al* (1972), Broster (1972a) and Wood (1976). Peak milk yield was recorded between four and seven weeks *post partum* which is comparable to the range of four to six weeks commonly quoted for dairy cows (e.g. Foley *et al* 1972).

In dairy cows it is well established that peak milk yield and total lactation milk yield are positvely correlated and that the failure to attain a high peak milk yield results in a reduction in total lactation milk yield (Broster 1972a). A significant ($P < 0.001$) relationship was observed between peak yield and total lactation yield in the present investigation which indicates that the total lactation milk yield of a beef cow is also greatly influenced by milk yield in early lactation. Although plane of nutrition did not have a statistically significant ($P < 0.05$) effect on peak milk yield, there was evidence of a reduction in peak milk yield on the low plane of nutrition.

This suggests that, if practical feeding recommendations are adopted for beef cows which involve high levels of feeding in early lactation (e.g. Baker *et al* 1972), then the cows should be capable of sustaining a relatively high level of milk production throughout the remainder of lactation. The practical feeding recommendations made by Stewart *et al* (1972), however, involve a relatively low level of feeding during the first three weeks of lactation in an endeavour to reduce the incidence of nutritional scour in the suckled calves. The relationships found between nutrition, peak milk yield and total milk yield suggest that this practice is inadvisable because it may tend to reduce the level of milk production sustained throughout the remainder of lactation.

The above proposition is partly based upon the assumption that if beef cows produce a low peak milk yield as a consequence of a low plane of nutrition in early lactation, their subsequent milk yield will also be adversely affected even were they subsequently offered a high plane of nutrition. The planes of nutrition imposed in the present investigation were held constant throughout the period of lactation studied, and the yield response of beef cows to a change in plane of nutrition at different stages of lactation has not yet been quantified.

The lactation curves observed in the present investigation corresponded to the milk intakes of the suckled calves. In this context they showed that at two days of age, the milk intake of the calves was between 7 and 8 kg a day. This level of milk consumption is similar to the 8 kg quoted by Roy (1970) as the maximum daily voluntary intake of a 40 kg pail-fed calf offered whole milk of dry matter 126 g per kg. Whether or not the maximum voluntary intake of the calves involved in the present investigation exceeded 8 kg a day is not clear because no attempt was made to determine the amount of milk available but not consumed by the calves.

<u>Effect of calf birth-weight on milk yield of dam</u>

This investigation has demonstrated that the milk yield of a beef cow is positively related to the birth-weight of its calf with heavier calves at birth associated with higher milk yields. This is in agreement with the findings of Drewry, Brown and Honea (1959), Heyns (1960), Wistrand and Riggs (1966), Drennan (1971) and Rutledge *et al* (1971), but at variance with those of Brumby, Walker and Gallagher (1963), Christian, Hauser and Chapman (1965) and Gleddie and Berg (1968).

In the present investigation, calf birth-weight and live-weight of the dam were not closely related. Furthermore, live-weight of the dam at calving did not have a significant effect on subsequent milk yield. It may be concluded, therefore, that live-weight of the dam at calving was not a common factor related both to birth-weight of the calf and subsequent milk yield.

One possibility which cannot be discounted is that during pregnancy the size of the foetus present in the uterus may influence the release of lactogenic hormones and that the higher milk yields recorded in dams with large calves arises through a hormonal influence. However, indirect evidence to disprove this theory stems from work with sheep where Davies (1958), Alexander and Davies (1959), and Peart (1967) have concluded that the milk yield of ewes is influenced by the number of lambs suckled and not by the number of lambs born.

It appears, therefore, that the influence calf birth-weight has on milk yield acts through an appetite effect with heavier calves at birth demanding and consuming more milk than lighter calves. The disagreement in the literature as to whether or not calf birth-weight influences milk yield, referred to earlier, probably arises because in certain situations either the inherent ability of the cow or its nutritional status is not consistent with a level of milk production in excess of the appetite of the suckled calf. In this situation, no effect of calf birth-weight on the milk yield of the dam would be expected. When, however, the inherent ability and nutritional status of a beef cow are such that its potential milk output exceeds the appetite of the calf, birth-weight may then influence the milk yield of the dam.

MLC (1973) have clearly shown that a relationship exists between the average birth-weight of suckled calves and their sire breed. Therefore, it is possible for a producer to influence the average birth-weight of suckled calves by the choice of sire breed, irrespective of the dam breed involved. Beef cows suckling calves sired by a breed of bull which produces heavy calves at birth may tend to produce higher milk yields and have correspondingly higher feed requirements during lactation than those suckling calves sired by a breed of bull which produces calves of lower birth-weight. Thus, the breed of bull used in a suckler herd can influence the milk yield of the cows, and, therefore, their feed requirements.

Relationship between condition score at calving and subsequent milk yield

Although a significant ($P < 0.05$) relationship was not detected between the condition score of the cows 12 hr *post partum* and their subsequent milk yield, it would be unwise to deduce from this that the body condition of beef cows at calving is not an important factor influencing their subsequent lactation performance. The range in the condition scores of the cows at calving was not wide (coefficient of variation - 11 per cent), mainly because the cows had been subject to a uniform environmental and nutritional régime for the previous five months. Furthermore, the condition scoring system adopted may not provide a sufficiently sensitive measure of body condition to enable a statistically significant relationship to be detected between body condition at calving and milk yield.

It is suggested that the body condition of a beef cow at calving may influence milk yield by affecting the cow's ability to mobilise body reserves to counter-balance inadequate nutrition during lactation. Spedding (1962) has proposed a similar hypothesis in relation to the body condition of ewes at lambing.

Relationship between milk yield in current lactation and milk yield in previous lactation

The absence of a significant ($P < 0.05$) relationship between the first and second lactation milk yields of these cows suggests that it may be inadvisable to select beef cows on the growth characteristics of the first calf. It also indicates that the use of a changeover design in experiments designed to examine the effect of different factors on milk yield may be less efficient than is generally supposed. There may be a higher correlation, however, between the lactation milk yields of beef cows in their second and subsequent lactations when the effect of age at calving is likely to be less pronounced.

Energy and protein balance

An approximate energy and protein balance is presented in Table D.2 which illustrates the extent of the estimated energy and protein deficit or surplus of the cows on each of the three planes of nutrition. The data appearing in Table D.2 are subject to a number of assumptions and errors owing to the absence of certain determinations. Nevertheless, they provide an indication of the magnitude of the energy deficit of the cows on the medium and low planes of nutrition and demonstrate the ability of energy deficient beef cross dairy suckler cows to sustain milk production at the expense of body reserves.

On average throughout the 150-day lactation period, the cows on the high plane of nutrition had an estimated daily ME intake very similar to their estimated daily requirement. They mobilised live-weight and body condition during the first two months of lactation, however, when their daily milk yield was relatively high; later in lactation when their daily milk yield was decreasing they regained a proportion of this live-weight and body condition loss.

The average energy deficits of the cows on the medium and low planes of nutrition were 19 per cent and 36 per cent respectively. These deficits were met by mobilising body reserves and cows on the low

TABLE D.2: Estimated daily energy and protein balance

		Plane of nutrition		
		High	Medium	Low
Average live-weight		459	432	394
Average metabolic live-weight (kg)		99.2	94.8	88.4
Average daily milk yield (kg)		9.34	8.48	7.88
ME requirement (MJ):	Maintenance[1]	49.6) 96.3	47.4) 89.8	44.2) 83.6
	Milk production[2]	46.7)	42.4)	39.4)
ME intake (MJ)		99.1	72.7	53.4
Intake minus requirement (MJ)		2.8	-17.1	-30.2
DCP requirement (g):	Maintenance[3]	274.7) 742	263.5) 688	247.3) 641
	Milk production[4]	467.0)	424.0)	394.0)
DCP intake (g)		785	665	608
Intake minus requirement (g)		43	-23	-33

[1] 0.5 MJME/$W^{0.75}$; [2] 5.0 MJME/kg; [3] 22.94 + 2.538 g/$W^{0.75}$; [4] 50 g/kg
where W = live-weight (kg)

plane of nutrition mobilised approximately 1.2 kg of live-weight a day in the first 120 days of lactation, thereby making available the equivalent of approximately 30 MJ dietry ME to sustain milk production (see Table D.2). No adjustment has been made for gut-fill changes, or for the additional energy required by the low plane cows to regain the 6 kg live-weight in the last 30 days of lactation, but 30 MJME is in reasonable agreement with the expected value of 33 MJME quoted in Technical Bulletin Number 33 (1975) as the dietry ME released by 1.2 kg of live-weight loss. Indeed, within the limits of accuracy of the estimates made of energy exchange in the present investigation, the relationship between the energy intake and energy requirement of the cows produced the expected response in terms of live-weight loss.

The ability of energy deficient lactating beef cows to mobilise body reserves for the synthesis and secretion of milk has been recognised, as has its significance for the economic efficiency of suckled calf production (Ball, Broadbent and Dodsworth 1971; Economides *et al* 1973). The physiological limits of this source of energy, however, have not been fully investigated. In the present investigation, the low plane cows mobilised an average of 1.2 kg a day, and thereby made available approximately 30 MJME a day. This represented 36 per cent of the average daily energy requirement of the low plane cows. Thus, a significant proportion of the energy required by a lactating beef cross dairy suckler cow can be met by mobilising body reserves without causing a marked reduction in milk yield. Furthermore, the linear nature of the relationship observed between milk yield and energy intake suggests that levels of energy intake resulting in rates of live-weight loss in excess of 1.2 kg a day may be possible without daily milk yield declining at a faster rate than was observed in the present investigation. By allowing beef cows to accumulate body reserves of fat cheaply on low-cost feeds and then utilising these reserves during lactation, if only expensive feeds are available, the economic efficiency of suckled calf production may be improved. This has particular relevance for autumn-calving suckler herds in the United Kingdom.

With reference to the protein intakes of the cows, Table D.2 shows that the estimated DCP intake of the high plane cows was slightly in excess of their estimated requirements, but that cows on the medium and low planes were marginally protein deficient. The DCP requirements of the cows calculated using ARC (1965) estimates were 677, 597 and 540 g a day on the high, medium and low planes of nutrition respectively. On the basis of these estimates, the cows were supplied with adequate protein on each of the three planes of nutrition.

Effect of nutrition on lactation performance

There was a significant ($P < 0.01$) linear trend for the 150-day cumulative milk yields of the cows to increase as plane of nutrition increased, confirming the trend observed in the calf-suckling heifers in Experiment 1.

The failure to detect a significant ($P < 0.05$) effect of nutrition on peak milk yield and the stage of lactation at which peak milk yield occurred was probably attributable to the considerable variation between cows in these traits. The stage of lactation at which peak milk yield was attained proved particularly variable with a coefficient of variation in excess of 60 per cent.

The a, b and c coefficients used to describe the lactation curves of the cows also proved variable within each level of nutrition.

There was little evidence to suggest that either the a or c coefficients were influenced by plane of nutrition but there was an indication of an effect of nutrition on the b coefficient which provides a measure of the pre-peak curvature of a lactation curve. As plane of nutrition increased, the b coefficient increased in value which suggests that better nutrition tends to delay the attainment of peak milk production. This trend just failed to reach significance at the 5 per cent level of probability.

Reference to the graphical presentation of the lactation curves (Figure E.8) showed that although their general shape was not markedly affected by plane of nutrition, their elevation, i.e. the level of daily milk yield, was clearly increased by better nutrition.

Figure E.8 also revealed that the lactation curves began to diverge within three weeks of calving. This suggests that the nutritional régime imposed on beef cows after calving will have an almost immediate effect on their level of daily milk yield.

Relationship between energy intake and milk yield

Within a range of 48 to 118 MJME every additional 10 MJME consumed per day increased the daily milk yield of the cows by 0.25 kg. This was a lower response than was observed in the calf-suckling heifers in Experiment 1, but the difference between the two was not significant ($P > 0.05$). The response observed in the present investigation was lower than the response reported for beef cows by Wilson *et al* (1969) but greater than was recorded by B.G. Lowman and R.A. Edwards (personal communication) in machine-milked Blue-Grey cows.

An additional energy intake of 10 MJME a day is capable of sustaining the production of an additional 2 kg of milk of average quality assuming no live-weight change occurs (Technical Bulletin, November 33, 1975). The response observed in the present investigation represented only 12.5 per cent of this potential response, demonstrating the ability of beef cows to buffer differences in energy intake by depleting or repleting body reserves. The yield response of the beef cows involved in the present investigation to an additional intake of 10 MJME a day was also only approximately half the response recorded in dairy cows (see Review of Broster 1972a). Thus, this experiment has shown that the level of milk production of beef cows, and their response to additional inputs of energy, are both lower than those of dairy cows.

Live-weight and condition score changes

In the present investigation, the live-weight and condition score changes of the cows were used as indices of their body-tissue changes. The deficiencies of live-weight change as an index of body-tissue change are well documented (Benedict and Ritzman 1927; Blaxter 1962; Bath *et al* 1965; Moe, Tyrrell and Flatt 1971; Hughes 1976). Nevertheless, when live-weight changes are monitored over a relatively long period of time, with cows given a constant weight of food at the same time of day on each occasion, then live-weight changes provide a useful indication of changes in body-tissue.

Plane of nutrition had a highly significant ($P < 0.001$) effect on the live-weight and condition score changes of the cows involved in this investigation. This indicated marked differences between the cows on the three planes of nutrition in the amount of body-tissue mobilised.

Body-tissue changes of themselves have no direct bearing on the performance of beef cows but indirectly can influence their reproductive performance (Lamond 1970) and their subsequent lactation performance if body reserves depleted in one lactation are not replenished, or partly replenished, before the following lactation period (Economides *et al* 1973).

Reproductive performance

MLC (1975) data have clearly shown the deleterious effect of low levels of fertility on the financial performance of beef herds in the United Kingdom. Unfortunately, the number of cows involved in this investigation was too small to enable definitive conclusions to be reached as to the adequacy of the three nutritional levels for satisfactory reproductive performance.

There was no marked effect of nutrition on fertility, and on the low plane of nutrition, nine of the 12 cows conceived during the 100-day mating period. All the cows were in good body condition at calving, however, and appeared to have substantial levels of body reserves of fat. Therefore, despite the considerable live-weight and condition score losses incurred by the cows on the low plane of nutrition, their live-weight at the time of mating may have been above the level suggested by Lamond (1970) to be compatible with good fertility.

It is suggested that the level of nutrition required by beef cows between calving and mating to ensure high conception rates is likely to depend partly upon their body reserves of fat at calving. The interaction between level of body reserves at calving, milk yield in early lactation and nutrition is an area which requires critical examination.

Although there was not a marked reduction in the fertility of the low plane cows, should the incidence of reproductive failure recorded on the low plane of nutrition prove to be repeatable, on the basis of MLC (1975) figures, it would almost certainly be uneconomic to adopt this level of nutrition in commercial practice.

Subsequent performance

In relation to dairy cows, both Blaxter (1956) and Broster (1972a) have emphasised the need to consider not only the immediate effects of different levels of nutrition but also their effect on the subsequent performance of the cows. With beef cows this is equally important.

At the time of writing only a limited amount of information was available on the possible residual effects of the nutritional régimes imposed in this investigation. This information related to the live-weight changes of the cows after the end of the period when the different nutritional régimes were imposed.

The cows on each of the three planes of nutrition had regained the live-weight lost during their second lactation by the beginning of the following lactation. Furthermore, the cows which had received the high plane of nutrition were 5.6 per cent heavier at the beginning of their third lactation than at the beginning of their second lactation, but the cows which received the medium and low planes were only 0.7 per cent and 0.3 per cent heavier respectively.

Beef cows have been observed to increase in live-weight up to approximately 10 years of age (MLC 1973), but the consequences of failing to do so have not been established. It is possible that if beef cows are unable to increase in live-weight over successive reproductive cycles as a result of inadequate nutrition, then this may eventually affect their performance.

A possibility in the context of this particular investigation is that the additional live-weight of the high plane cows at the beginning of their third lactation was a reflection of higher levels of body reserves and this could influence their subsequent milk production and fertility.

Effect of nutrition on gestation length and calf birth-weight

It was found that the average gestation length of Hereford cross British Friesian cows mated to a Charolais bull was 286 days. This is two to three days longer than the figures quoted for dairy cows (Milk Marketing Board 1966) but within the range reported by Preston and Willis (1974) for a number of different beef breeds maintained in a wide range of environments.

Anderson and Plum (1965) in a review of factors affecting gestation length in cattle pointed out that individual sires within a breed can markedly influence gestation length. Nevertheless, knowledge of the average gestation length of a particular breed or cross can be useful under practical conditions. Provided dates of effective mating are known, it enables expected dates of calving to be calculated more accurately. This can be advantageous, particularly in situations where there is a high incidence of dystokia because cows require to be regularly observed prior to parturition and this is facilitated by knowledge of their expected date of calving.

Although the evidence was inconclusive, it appeared that a low plane of nutrition in early pregnancy reduced gestation length. Tudor (1972) also noted a reduction in the gestation length of beef cows offered a sub-maintenance level of nutrition, but in Tudor's experiment the cows were subject to a sub-maintenance régime during the last 100 days of pregnancy rather than early pregnancy.

In the present study, in addition to a reduction in gestation length on the low plane of nutrition, a reduction in calf birth-weight was also recorded as the previous plane of nutrition of the dam decreased. Several workers have reported that calf birth-weight is reduced when beef cows are uderfed in late pregnancy (Clanton, Zimmerman and Matsushima 1961; Renbarger *et al* 1964; Hight 1966, 1968; Tudor 1972), but the literature appears to contain no reference to a possible effect of early pregnancy nutrition on calf birth-weight.

Low calf birth-weight may be associated with poor vitality, reduced stimulus to suck, and hence higher mortality (Reid 1960). Thus, the effect of early pregnancy nutrition on calf birth-weight could have practical significance although, in the present investigation, the extent of the reduction in calf birth-weight caused by the low plane of nutrition of the dam was not great and would be unlikely to be associated with an increase in the incidence of calf mortality.

Calf performance

This experiment has demonstrated that increasing the energy intake of lactating beef cows increases their level of milk production, albeit a small increase in milk production in relation to the amount of energy required. In beef cows the benefit of higher levels of milk production will only be realised if the performance of the suckled calves is improved or if their intake of supplementary feed is reduced.

In the current investigation, plane of nutrition of the dam influenced the growth rates of the calves between birth and 150 days of age. This observation is in agreement with previous workers (Lamond, Holmes and Haydock 1969; Wilson *et al* 1969) who found that the higher the plane of nutrition of the dam, the greater the growth rate of the calf. In the present investigation, the average daily live-weight gain of the calves suckled by dams on the low plane of nutrition was nine per cent less than that of their contemporaries suckled by high plane dams. The medium group of calves had the lowest daily live-weight gain between birth and 150 days of age but this was ascribed to the scour problem which was more severe in this particular group of calves than in the other two groups.

Between 150 days of age and weaning the average daily live-weight gain of the low plane calves was seven per cent greater than that of the high group although the difference was not statistically significant. This suggests that compensatory growth occurred in the low group of calves at grass and by weaning, the average live-weights of the three groups of calves were not significantly different. Therefore, the higher milk yields obtained by increasing the plane of nutrition of the dam during lactation did not result in an increase in calf weaning weight.

Plane of nutrition of the dam did not appear to influence the development of concentrate intake in the calves which was broadly similar in each of the three groups. Although the evidence was not conclusive there was an indication, however, that the hay intakes of the calves suckled by medium and low plane dams was greater than that of the high plane group of calves. It is possible, therefore, that suckled calves are able to compensate for a reduction in milk intake by consuming more hay if this is made available.

It should be noted that the solid food consumed by the calves involved in this investigation supplied a significant proportion of their total energy and protein intake. At 100 days of age, for example, the energy consumed in the form of solid food represented approximately 55 per cent and 60 per cent of the total energy intake of the high and low plane calves respectively. Had the calves been offered less solid food, or solid food of poorer quality, then the reduction in the milk intake of the low group of calves would have resulted in a bigger percentage reduction in their total energy intake. Thus, the response of suckled calves to differences in milk intake resulting from differences in the energy intake of their dams may be greatly influenced by the amount and quality of solid food available. The interaction between the milk and solid food intake of a suckled calf and its growth rate is in need of careful examination.

Conclusions

In conclusion, this experiment has confirmed that, during lactation, energy deficient beef cross dairy suckler cows will attempt to maintain milk production at the expense of body reserves. A reduction in daily ME intake of 46 per cent resulted in only a 13.5 per cent reduction in daily milk yield during the first 150 days of lactation. It also appears that substantial live-weight and condition score losses can be incurred without fertility being markedly reduced. Furthermore, when supplementary solid food is made available to the suckled calves, their weaning weight appears unaffected by the plane of nutrition of the dam.

CONCLUSIONS, SUGGESTIONS FOR AREAS OF FUTURE RESEARCH, AND PRACTICAL MANAGEMENT AND FEEDING RECOMMENDATIONS FOR BEEF COWS

CONCLUSIONS AND SUGGESTIONS FOR AREAS OF FUTURE RESEARCH

The purpose of this section is to summarise the conclusions reached from the experiments reported in this thesis and to identify those areas where knowledge is still deficient.

In the first experiment, machine-milking beef cows twice a day provided a significantly ($P < 0.05$) more variable estimate of their milk production than did a calf-suckling technique. A similar experiment, reported in Appendix 2, also suggested that the variability of the milk production of machine-milked beef cows is further increased when the cows have low levels of body reserves at parturition. It was concluded that the calf-suckling technique described is a more reliable and precise method of measuring the milk production of beef cows than is machine-milking. It was also concluded that, compared to machine-milking twice a day, the estimates of milk production provided by the calf-suckling technique are more representative of the levels of milk production sustained by beef cows in normal systems of husbandry.

There are four aspects of the calf-suckling technique, however, which it is suggested warrant careful consideration. The technique depends upon the accurate recording of relatively small increases in the live-weight of a calf, and this necessitates the use of highly sensitive weighing equipment. Sophisticated and accurate equipment is now available for measuring and recording the weight, or more correctly the mass, of live animals. While the equipment is more costly than the traditional type of balance which was used in the present investigation, a more accurate estimate of milk production should be obtained, particularly if only a limited number of observations were made. The Hill Farming Research Organisation record the live-weight of experimental sheep with equipment specifically designed to record the weights of live animals. Similar equipment should be developed to determine the pre- and post-suckling weights of calves involved in the calf-suckling technique.

When the calf-suckling technique is employed to measure milk production, the collection of representative milk samples presents a problem. In the present investigations, due to limited resources of labour, no milk samples were collected from cows whose milk production was measured by the calf-suckling technique. A modified version of a method originally devised by workers at the North of Scotland College of Agriculture (Economides 1972) was proposed, however, although before it can be recommended, the reliability and practicability of the method should be investigated.

The calf-suckling technique requires the imposition of suckling régimes which generally involve fewer sucklings than have been reported to occur under normal systems of husbandry. It would be advisable to establish, experimentally, that the suckling régimes adopted in a calf-suckling technique do not influence the level of milk production sustained by the cows.

In the experiments reported in this thesis, the calf-suckling technique was used to measure the milk production of beef cows kept indoors in close confinement. The technique appears less suitable for cows maintained under grazing conditions. It involves segregating cows from their calves and this may disturb their normal behavioural patterns, introduce a stress factor, and hence influence the level of milk production observed.

When beef cows are maintained under grazing conditions, the oxytocin technique, which was described in an earlier section, may prove a more suitable technique for measuring milk production. There is a need for research, however, to establish the accuracy and reliability of the oxytocin technique. More specifically, it is recommended that the following aspects be examined:

a) the potential problem of unresponsive cows;

b) the effect of different dosage rates;

c) the effect on milk composition;

d) the effect of an abnormally empty udder on milk secretion rate, and

e) the effect of regular injections of oxytocin over a prolonged period of beef cow's lactation.

Workers at the Hill Farming Research Organisation and at the Grassland Research Institute have recently examined some of these aspects.

The experiments reported in this thesis have demonstrated that energy deficient Hereford cross British Friesian suckler cows will attempt to sustain milk production at the expense of body reserves. In Experiment 1, a reduction in energy intake of 47 per cent resulted in a reduction in milk production of only 17.2 per cent and the corresponding figures in Experiment 2 were 46 per cent and 13.5 per cent respectively. Experiment 2 demonstrated that while calf growth rate is sensitive to a reduction in milk intake during the first 150 days of lactation, compensatory growth may occur at grass and the weaning weights of autumn-born suckled calves appear unaffected by the plane of nutrition received by their dams during the winter. Furthermore, the reproductive performance of the cows was not appreciably affected by their plane of nutrition in either of the two experiments reported.

It was suggested that a significant proportion of the energy required by a lactating beef cow can be supplied by mobilising body reserves without causing a reduction in performance. This may provide an opportunity to improve the economic efficiency of suckled calf production, depending upon the relative cost of feed supplies available at different stages of the annual production cycle.

These observations were based upon responses recorded in beef cows which had levels of protein intake during lactation similar to their estimated requirement and whose average condition scores at parturition were 2.6 and 2.7 in Experiments 1 and 2 respectively. Before definite conclusions can be reached as to the response of beef cows to different levels of feeding during lactation, further research is required to establish the influence of protein intake during lactation, and also different levels of body reserves at parturition.

The cows involved in the present investigations received a constant level of feeding during their first 150 days of lactation. This is contrary to the practice advocated in practical feeding recommendations for beef cows (see Table R.5) which generally involve a higher level of feeding during the first 12 weeks of lactation than thereafter. There is a need to evaluate the effect of different patterns of feeding during lactation with a view to establishing the optimum pattern of feeding for milk production and fertility.

MLC (1975) data clearly show the economic importance of maintaining high levels of fertility in beef cows. Unfortunately, it is very difficult to establish the relationship between nutrition and fertility experimentally, mainly because of the discrete nature of measures of fertility. In the experiments reported in this thesis, an attempt was made to determine the effect of the three planes of nutrition on the reproductive performance of the cows, but no important differences emerged. More data are required, however, and it is suggested that research be directed towards establishing the relationship between the nutrition of lactating beef cows and their reproductive performance. In particular, if it were possible to define a threshold condition score, above which the reproductive performance of beef cows is acceptable, then this would represent a major advance. In addition, however, the effect on fertility of changes in body condition at mating,and plane of nutrition at mating, require critical examination. Some of these aspects of fertility are currently the subject of investigation at The Edinburgh School of Agriculture and the results are awaited with interest.

While the experiments reported have demonstrated the ability of lactating beef cows to mobilise body reserves, it is equally important that beef cows are able to replenish these reserves when required. To reduce feed costs, autumn-calving beef cows are expected to mobilise body reserves during early and mid-lactation in successive production cycles. Unless they are given sufficient opportunity to replenish these reserves during late lactation and the latter part of pregnancy, the cows will suffer a progressive loss of body condition. This is likely to be associated with a deterioration in their reproductive and lactation performance.

There is a lack of information on the conditions necessary for beef cows to replenish different levels of body reserves and on the factors which influence the rate and amount of repletion which can occur, particularly under grazing conditions. Therefore, it is suggested that research be undertaken to investigate the many aspects of body reserve repletion.

Experimental evidence shows that the milk intake of a suckled calf is influenced by the plane of nutrition received by its dam during lactation. While there is a positive relationship between the milk intake and growth rate of suckled calves, the amount and quality of solid food available to the calves may modify this relationship. There is a lack of information on the interaction between the milk and solid food intakes of suckled calves in relation to their growth rate. Research is required to establish this relationship because it may indirectly influence the level of feeding required by beef cows during lactation.

Finally, before experimental findings based upon the individual feeding of beef cows may be translated into commercial practice, their validity under group-feeding conditions requires careful evaluation.

PRACTICAL MANAGEMENT AND FEEDING RECOMMENDATIONS FOR BEEF COWS

Introduction

The previous section represented the considered conclusions reached from the two experiments reported in this thesis and attempted to identify the areas where research should be directed. While the need for more fundamental research is accepted, it is still necessary to make management and feeding recommendations for beef cows based, not only upon the experimental evidence which is currently available, but also on the judgement and experience of workers in this field.

The current management and feeding recommendations made for beef cows by The Edinburgh School of Agriculture have been reported by Lowman and Somerville (1976) in a paper presented at the Meat and Livestock Commission National Beef Conference. Much of this paper was contributed by B.G. Lowman, particularly the sections dealing with the advantages and disadvantages of a compact calving period, to whom due acknowledgement is made. An abbreviated version of the paper appears in this concluding section.

Background

The management objective of a suckled calf producer can be defined as "to maximise the weight of weaned calf produced per 100 cows put to the bull, as cheaply as possible, every year".

In recent years considerable emphasis has been placed on increasing the output of beef herds by using larger breeds of bull, reducing calf mortality and increasing the number and weight of calves weaned. However, little attention has been paid to the wide range in feed costs incurred in commercial herds.

The major area of management control in beef herds is feeding. Feed costs represent over 50 per cent of the total variable costs of production in both spring- and autumn-calving herds and the cow consumes the major proportion of total feed used. Due to the importance of cow feed costs, especially winter feed which may account for 75 per cent of the total cost of keeping a beef cow for a year, research has been undertaken at The Edinburgh School of Agriculture which examined the effect of level of feeding during the first five months of lactation on the performance of autumn-calving Blue-Grey and Hereford cross British Friesian beef cows. After six years of research a general pattern has emerged.

The results in Table D.3 relate to Hereford cross British Friesian cows suckling Charolais cross calves. Machine-milked Blue-Grey cows showed a similar response, although at a level of milk production only two-thirds of that recorded in the Hereford cross cows. In essence, the results show that feeding beef cows approximately 60 per cent of their estimated energy requirements for maintenance and milk production will reduce milk yields by only 13 per cent. This is achieved at the expense of body reserves and an 18 per cent greater live-weight loss was recorded in underfed cows compared to contemporaries fed at a level which corresponded to their estimated requirements.

Suckled calves whose dams were underfed during the winter were approximately 11 kg lighter in the spring (late April) than calves whose dams had been better fed, but by weaning in July there was no difference in the weights of the two groups of calves. This was because the calves whose dams were underfed during the winter had a greater daily live-weight gain during the grazing season.

TABLE D.3: Performance of Hereford cross British Friesian cows offered three planes of nutrition during their first 150 days of lactation

	Plane of nutrition		
	High	Medium	Low
Daily energy intake (MJME)	95.8	71.5	52.1
150-day cumulative milk yield (kg)	1355	1258	1187
Live-weight loss of cow between calving and 150 days *post partum*	41	100	140
150-day weight of calf (kg)	210	196	199
Weaning weight of calf (kg)	343	333	336
Percentage of barren cows	4	8	18

The substantial live-weight losses incurred in early lactation by cows on the low plane of nutrition coincided with their mating period and was associated with an 18 per cent barren cow rate. It is essential, therefore, to limit the extent to which cows mobilise body reserves to sustain milk production until they are safely in calf.

Recommended management practices

Five years ago, The Edinburgh School of Agriculture advised suckled calf producers to feed autumn-calving beef cows on the basis that their level of milk production averaged approximately 7 kg a day during the first five months of lactation (see Stewart *et al* 1972). However, with the large numbers of breeds and crosses involved in suckled calf production, and the finding that calf birth-weight can influence milk production, milk yields may vary considerably. Furthermore, winter rations which suit a 500 kg cow in good body condition may be unsuitable for a 450 kg cow in poor body condition. In view of the importance of a cow's body reserves of fat, a method was developed for describing body condition on a 0 to 5 scale. A condition score of 1 is awarded to cows in very poor condition and a condition score of 5 to cows which are very fat. Condition scoring is particularly useful for assessing the adequacy of feeding levels received by beef cows. On a particular level of feeding, cows consuming more than their requirements for maintenance, milk production and pregnancy will improve in body condition. Conversely, cows will deteriorate in body condition if they are consuming insufficient feed to meet their daily requirement.

Therefore, advice for rationing beef cows is based on feeding to achieve target condition scores at specific stages of the reproductive cycle, rather than on a single level of feeding for all herds. This is illustrated diagrammatically in Figure D.1. It is recommended that the management and feeding of beef herds should be organised to ensure that the cows are in the correct condition at weaning, calving and particularly mating. Special attention should be given to the management and feeding of those cows which are in much better or poorer condition than is required.

The condition of a whole herd, or individuals within a herd, can be altered by changing either levels of feeding, stocking pressures, rates of fertiliser application or dates of weaning.

It is suggested that the management of beef cows to achieve these target condition scores will enable output to be maximised at mininum cost. In practice, however, the majority of producers cannot implement this advice and cannot control the feeding of their herd. The reason is that a protracted calving period is a common failing in suckler herds.

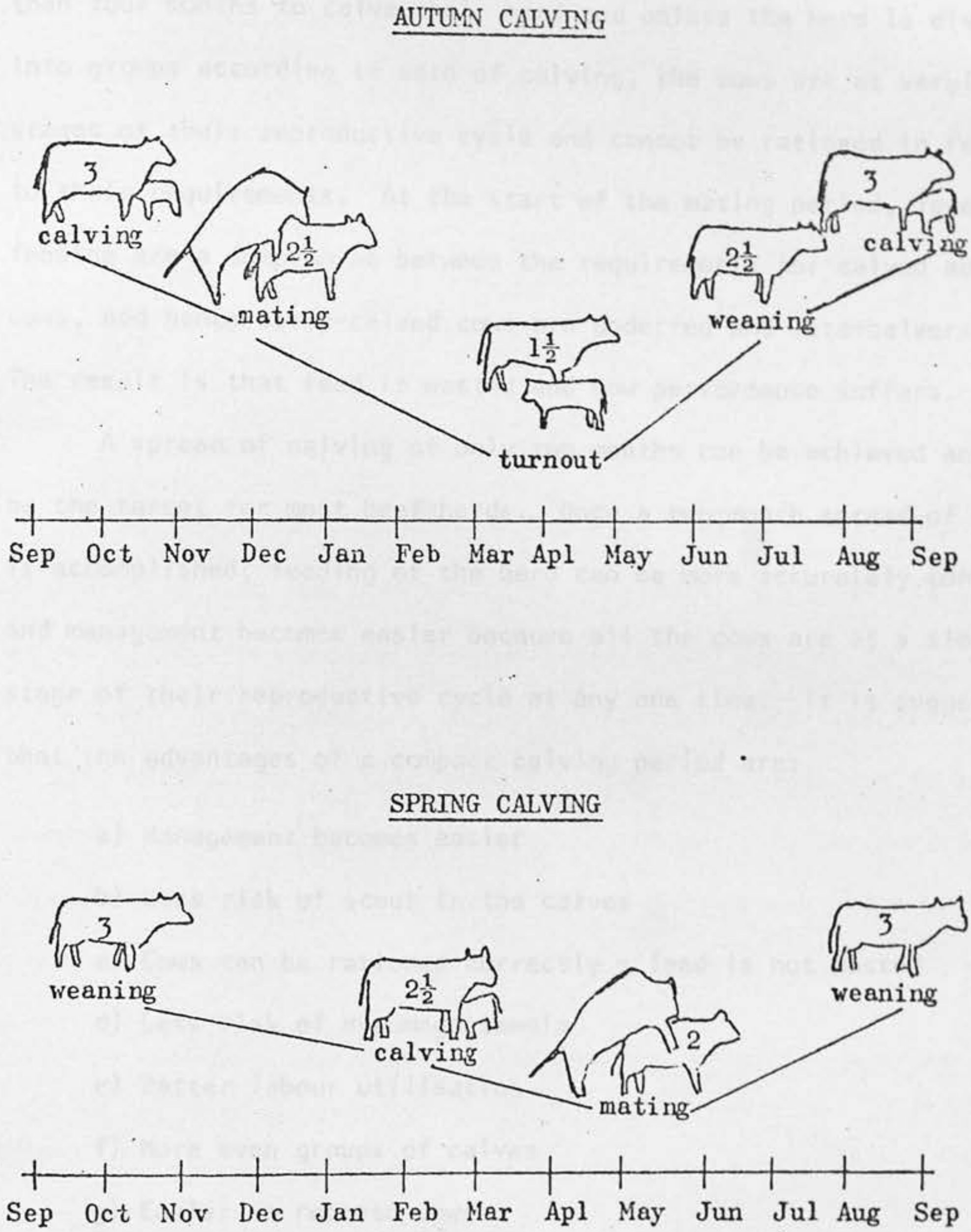


FIGURE D.1: Target condition scores for different stages of the reproductive cycle in autumn- and spring-calving suckler herds

Spread of calving

More than three quarters of suckled calf producers take longer than four months to calve their herd and unless the herd is divided into groups according to date of calving, the cows are at varying stages of their reproductive cycle and cannot be rationed in relation to their requirements. At the start of the mating period, levels of feeding are a compromise between the requirements for calved and uncalved cows, and hence early-calved cows are underfed and late-calvers overfed. The result is that feed is wasted and cow performance suffers.

A spread of calving of only two months can be achieved and should be the target for most beef herds. Once a two-month spread of calving is accomplished, feeding of the herd can be more accurately controlled and management becomes easier because all the cows are at a similar stage of their reproductive cycle at any one time. It is suggested that the advantages of a compact calving period are:

a) Management becomes easier

b) Less risk of scour in the calves

c) Cows can be rationed correctly - feed is not wasted

d) Less risk of Hypomagnasaemia

e) Better labour utilisation

f) More even groups of calves

g) Easier to rebreed cows

MLC (1975) have shown that herds with a spread of calving in excess of five months have gross margins per cow £16 lower than herds with a spread of calving of four months (Table D.4).

One of the obvious factors which improves the gross margin in herds with a compact calving period is the average age of the calves at weaning and its effect on weaning weight.

TABLE D.4: Relationship between spread of calving and gross margin per cow (*after* MLC 1975)

Spread of calving (No. of days)	Average gross margin per cow 1974 (£)
<90	58.4
90 - 119	58.7
120 - 149	52.8
150 - 179	42.4
180 - 209	40.7
>210	40.4

The calving date of a herd should be planned to make the best use of available feed supplies and other resources. Herds with a wide spread of calving usually have their first cows calving at or around the planned date of calving, but a proportion of the cows calve three to five months later. Management and feeding is organised to be adequate for the early-calving group but output from the herd as a whole is reduced because of the number of later born calves which are younger and therefore lighter at weaning (Table D.5).

TABLE D.5: Effect of month of birth on the age and weight of calves at weaning

	Month of birth				
	Sept	Oct	Nov	Dec	Jan
Age at weaning in July (months)	10.5	9.5	8.5	7.5	6.5
[1]Weight at weaning	320	293	266	239	212

[1]assuming birth-weight 36 kg and live-weight gain per day 0.9 kg

A more important factor, however, is the effect of date of calving, within a calving period, on fertility. In experiments undertaken at Edinburgh results are available from over 200 matings. Since 1972 the calving period of the cows has been restricted to 100 days, from 1st September to 10th December, which corresponds to a mating period of 22nd November to 28th February. Table D.6 shows the effect of month of calving on the percentage of barren cows and the percentage of cows conceiving to first service.

TABLE D.6: Effect of month of calving within the calving period on the fertility of beef cows

	Month of calving		
	Sept	Oct	[1]Nov/Dec
Percentage barren	6	4	26
Conceived to first service	70	54	41

[1]1st November to 10th December

There was a general decline in "fertility" as cows calved later in the calving period with an unacceptably high barren cow percentage in the group which calved between 1st November and 10th December. Several factors may have contributed towards this:

a) cows losing live-weight rapidly at mating;

b) late-calving cows being served at first oestrus;

c) the shorter mating period for late-calving cows.

The mating period of late-calving cows coincides with their period of live-weight loss in early lactation and this appears to be associated with a low conception rate. In addition, late-calving cows are mated at their first oestrus after calving and conception rates may be lower at first oestrus than at a second or subsequent oestrus. Finally, cows that calve in the first month of the calving period will have completed their first oestrous cycle (at approximately 40 days after calving) before the beginning of the mating period and should be cycling regularly throughout the mating period. Conversely, cows calving in the last month will calve after the beginning of the mating period and it will be approximately 40 days later before they come into oestrus for the first time. Thus, the length of their effective mating period is shorter than that of the early-calving cows.

All these factors may contribute to reduce the fertility of cows calving in the third and subsequent months of the calving period. Whatever the explanation, however, the reproductive performance of late-calving cows is poorer than that of the early-calving cows and there is a considerable financial incentive to reduce spread of calving. The question is - how?

Strategies for reducing spread of calving

a) Split-calving

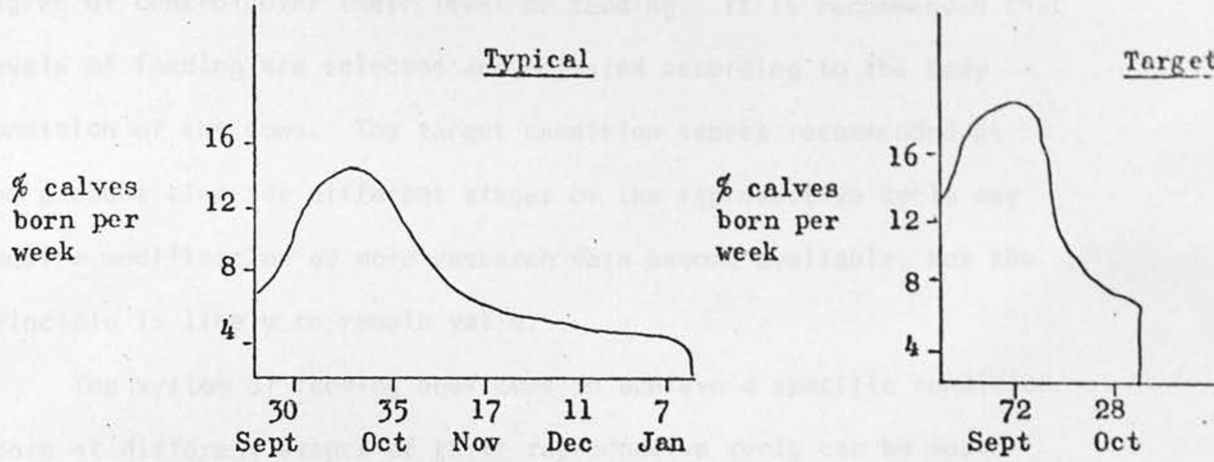
On farms with a spread of calving longer than five months a split herd should be considered, i.e. separate autumn- and spring-calving herds. This allows two herds, both with compact two-month calving periods, to be established quickly and at little cost. This can reduce the number of bulls required and ease winter housing problems. Where a split herd is run, autumn-calving cows should be pregnancy diagnosed two months after the end of the mating period and any barren cows transferred into the spring-calving herd. (Care must be taken that well grown, autumn-born heifer calves are not mated when they and their dams are moved into the spring herd. If necessary, they can be weaned at turnout). Any cows not in-calf after the two-month mating period of the spring herd should be culled. As there is always a tendency for cows to slip from autumn- to spring-calving, heifers should only be introduced into the autumn-calving herd.

In herds with a spread of calving longer than two months but shorter than five months, or where a split herd is not practical, reducing the spread of calving to two months is difficult to accomplish. In recent years, the importance of feeding the cow correctly, the condition of the cow at mating, bull to cow ratio, etc, have all been emphasised as means of improving fertility and hence shortening the calving spread. However, it is difficult to obtain more than a marginal reduction in the calving spread by better mating management alone. More direct action is required.

b) Replacement of late-calving cows with early-calving heifers

Close examination of the pattern of calving within a typical herd with a five-month spread of calving shows that, on average, 70 per cent of the cows calve within the first nine weeks of the calving period and that the later born calves account for only 30 per cent of the total number of calves born (Figure D.2). The most effective way of reducing the spread of calving in a 100-cow herd is to replace the 30 cows which would calve in the last three months of the next calving period with 30 heifers mated to calve in the first two months.

Although heifers' calves are lighter at weaning than calves from cows calving at the same time, because the heifers are replacing late-calving cows, their calves will be, on average, two months older at weaning. The overall effect of the change will be to maintain the average weaning weight of the calves in the herd at the same level.



[1]Weaning weight of calves (kg)	320	293	266	239	212	320	293
Age of calves at weaning (months)	10.5	9.5	8.5	7.5	6.5	10.5	9.5
Average weight at weaning (kg)			268			315	

[1]assuming birth-weight 36 kg and live-weight gain per day 0.9 kg

FIGURE D.2: Effect of two calving patterns on the weaning weight of the calves produced

Conclusions

There is considerable scope to improve the profitability of beef cows by better management, and in particular by exercising a greater degree of control over their level of feeding. It is recommended that levels of feeding are selected and adjusted according to the body condition of the cows. The target condition scores recommended at the present time for different stages of the reproductive cycle may require modification as more research data become available, but the principle is likely to remain valid.

The system of feeding beef cows to achieve a specific condition score at different stages of their reproductive cycle can be most effectively applied in herds with a compact calving period. Suckled calf producers should be made aware of the many advantages which accrue from minimising the spread of calving in beef herds.

A P P E N D I C E S

APPENDIX 1

THE FREQUENCY AND DURATION OF SUCKLING IN SINGLE-SUCKLED BEEF COWS

SUMMARY

Three separate 48 hr observations were made of the suckling behaviour of

1. Hereford x British Friesian cows under grazing conditions,
2. Blue-Grey cows housed, and
3. Blue-Grey cows under grazing conditions.

All the cows were suckled by Charolais cross calves. The mean suckling frequencies recorded were 5.5, 9.1 and 5.5 times per 24 hr in the first, second and third study respectively. A trend for older calves to be suckled less frequently was observed in all three studies, although this was not statistically significant. Milk yield of the cow was considered a possible factor involved in determining suckling frequency. A uniform distribution of sucklings occurred in a 24 hr period in the second and third study, with three peaks of suckling activity apparent in the first study. The mean duration of sucklings was 6.9, 10.6 and 10.7 min in the first, second and third study respectively.

INTRODUCTION

There is little objective information available relating to the milk yield of single-suckled beef cows, and consequently the milk intake of a suckled calf. One technique which has been used by Neville (1962), Melton, Riggs, Nelson and Cartwright (1967), Economides *et al* (1973) and others to determine the milk intake of a suckled calf involves weighing the calf immediately before and after suckling. This method necessitates the separation of cow from calf and the supervised release of the calf to allow suckling by the dam. In order to impose a controlled suckling régime, knowledge is required of the natural duration and frequency of suckling in similar animals.

The natural nursing behaviour of grazing cattle has been studied by Hutchison *et al* (1962) in Tanganyika, Walker (1962) in New Zealand and Drewry, Brown and Honea (1959) in the USA. Ewbank (1969) has reported the frequency and duration of nursing periods in single-suckled Hereford cows under English field conditions. The main results of studies reported in the literature are summarised in Table 1. Walker (1962), however, reported breed differences and there appears to be no published data on the suckling behaviour of Charolais cross calves or of housed beef cattle.

As it was intended to use the calf-suckling technique to determine the milk yield of beef cows with Charolais cross calves in nutritional experiments at The Edinburgh School of Agriculture, studies were undertaken to determine the natural frequency and duration of nursing periods in:

1. Single-suckled Hereford x Friesian cows and their Charolais cross calves under grazing conditions.
2. Single-suckled Blue-Grey cows and their Charolais cross calves housed.
3. Single-suckled Blue-Grey cows and their Charolais cross calves under grazing conditions.

TABLE 1: Summarised results of studies of suckling behaviour reported in the literature

Author(s)	Breed	No. of calves observed	Age of calves (days)	Duration of ind. sucklings (min)	Suckling frequency per 24 hr
Drewry, Brown & Honea 1959	Aberdeen Angus	27	17 74 198	8.2 11.1 10.7	4.7 6.0 3.1
	"	21	20 84 209	8.7 13.1 9.6	4.5 3.2 2.9
	"	48	18 78 203	8.4 11.7 10.2	4.6 4.8 3.0
Hutchison, Woof, Mabon, Salehe & Robb 1962	Shorthorn Zebu	5	17 78 139	10.0 8.6 8.7	9.5 7.1 5.2
Walker 1962	Aberdeen Angus	9	39 68 95 132	[1]10.0	3.4 4.4 3.7 4.6
	Hereford x Aberdeen Angus with Aberdeen Angus x calves	10	21 80 108 141	[1]9.0	4.2 4.4 4.7 4.2
Ewbank 1969	Hereford	12	7 21 35 49 63 77	6.3 8.9 13.2 8.7 8.1 7.0	7.8 6.8 5.2 5.8 4.8 5.0

[1]mean duration of sucklings at all observations

MATERIALS AND METHODS

The first study commenced at 12.00 hr on 24th October and terminated at 12.00 hr on 26th October 1972. Five Hereford x British Friesian cows and their Charolais cross calves were continuously observed for 48 hr. The animals grazing permanent pasture were keel-marked to aid identification and neither the presence of observers or the use of lights at night appeared to disturb them.

The second study commenced at 08.00 hr on 2nd April and terminated at 08.00 hr on 4th April 1973. Nine Scottish Blue-Grey (White Shorthorn ♂ x Galloway ♀) cows and their Charolais cross calves were continuously observed for 48 hr. The cows, housed in a straw-bedded court, were identified by means of permanent freeze brands and the calves by Large Ritchey ear tags (Ritchey Tagg Ltd, High Burton, Yorkshire).

The third study commenced at 08.00 hr on 30th May and terminated at 08.00 hr on 1st June 1974. Seven Scottish Blue Grey cows and their Charolais cross calves were continuously observed for 48 hr. The animals grazing permanent pasture were keel-marked to aid identification.

In none of the studies was supplementary feeding (other than grass in studies 1 and 3) available to the calves.

In all studies the time and duration of every suckling was recorded for each cow and calf. The end of the suckling periods proved indefinite with the cow usually terminating the suckling by moving away and starting to graze or browse. The calf frequently followed the cow and attempted to continue suckling, but for the purpose of recording this second phase of "attempted suckling" was ignored and only the duration of the intense suckling period timed.

RESULTS AND DISCUSSION

The main results of the three studies are summarised in Table 2.

TABLE 2: Frequency and duration of sucklings

	[1]1st Study	[2]2nd Study	[3]3rd Study
Number of calves observed	5	9	7
Average age of calves (days)	33	18	53
Mean duration of sucklings (min) ±SD	6.9 ± 1.52	10.6 ± 2.43	10.7 ± 2.06
Suckling frequency per 24 hr ±SD	5.5 ± 0.71	9.1 ± 2.01	5.5 ± 0.96
Correlation coefficient: age *v* suckling frequency (pooled r = -0.33 NS)	-0.79 NS	-0.59 NS	-0.33 NS

[1]Charolais x Hereford x Friesian calves; grazing

[2]Charolais x Blue-Grey calves; housed

[3]Charolais x Blue-Grey calves; grazing

Suckling frequency

Age of calf did not significantly affect suckling frequency in any of the three studies, but there was a trend apparent in all the studies for younger calves to suckle more frequently than older calves. The pooled regression of suckling frequency on age of calf was:

$$Y = 7.8 - 0.027x; \text{(NS)}; \quad \text{SE of regression coefficient} = \pm 0.019$$

where Y = suckling frequency per 24 hr

and x = age of calf in days

Hutchison *et al* (1962) and Ewbank (1969) also observed a reduction in suckling frequency as calf age increased. Walker (1962), however, did not observe this trend and Drewry, Brown and Honea (1959) recorded a decrease in suckling frequency as calf age increased in only one of their three studies.

The results of these and other studies indicate that, in general, the frequency of suckling decreases as calf age increases, although the work of Drewry, Brown and Honea (1959) suggests that in some situations suckling frequency first increases and then decreases as calves become older.

Walker (1962) reported a significant ($P < 0.05$) negative correlation between milk production of the dam and suckling frequency in calves up to 30 days of age. A similar trend was observed by Hutchison *et al* (1962) who reported that faster growing calves suckled less frequently than slower growing calves. They assumed that the faster growing calves had a higher daily milk consumption than the slower growing calves and, therefore, that a negative correlation existed between suckling frequency and milk production of the dam. This is contrary to the findings of Ewbank (1969) who found no relationship between suckling frequency and rate of live-weight gain in suckling calves.

If, however, milk production of the dam does influence suckling frequency this could account for breed differences in suckling frequency. In Table 2 it can be seen that younger Charolais x Hereford x Friesian calves had the same suckling frequency as Charolais x Blue-Grey calves which were 20 days older. The milk production of Hereford x Friesian cows has been found to be approximately 50 per cent greater than Blue-Grey cows maintained under similar conditions (Lowman and Somerville, unpublished data) and this may account for the similar suckling frequencies recorded in studies 1 and 3 with calves of different average age and breed.

However, the live-weights of the calves were not recorded and these may have been similar in both studies.

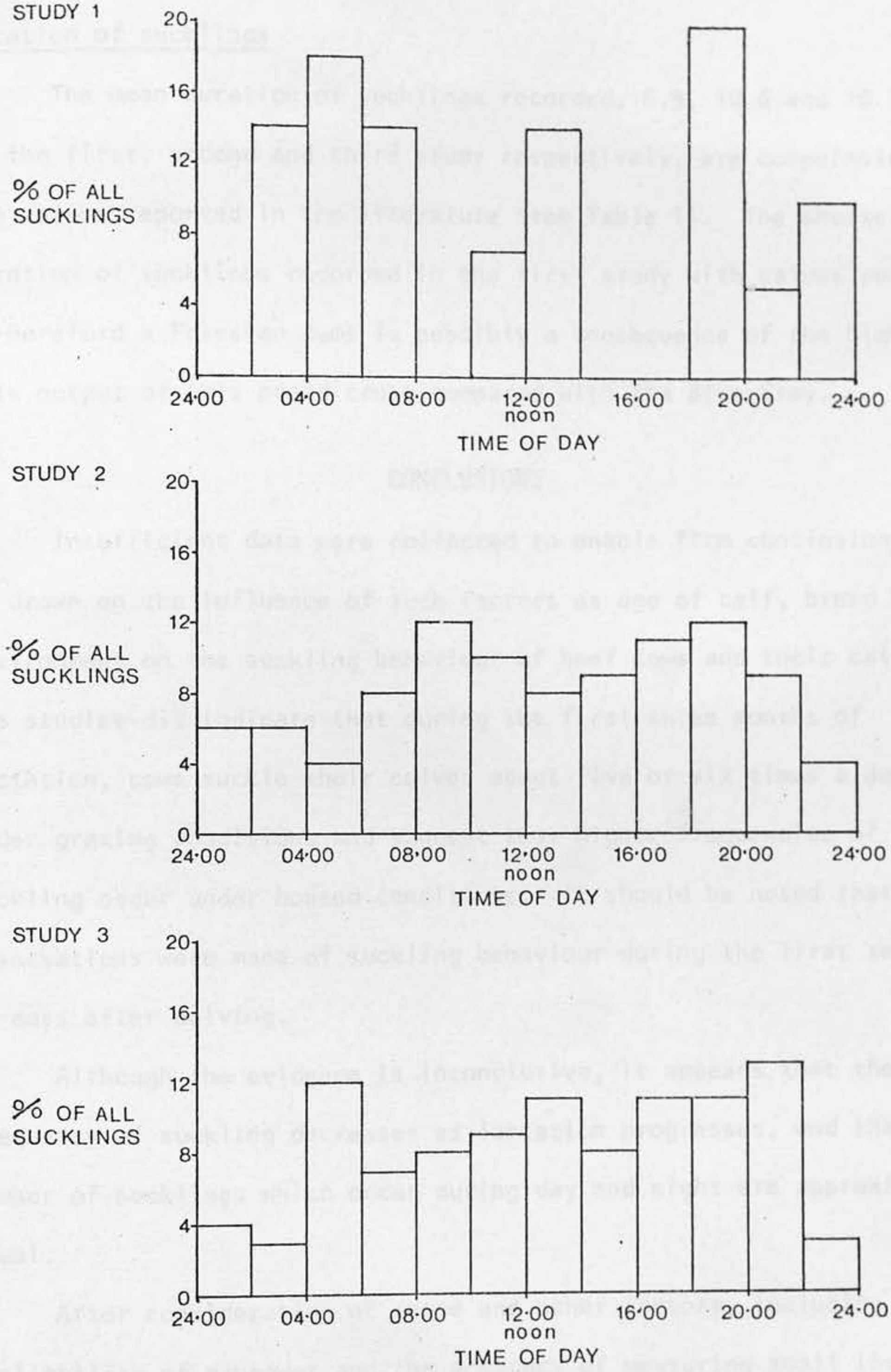
Any comparison of the suckling frequencies of housed *versus* grazing Charolais x Blue-Grey calves is confounded by the different average age of the two groups of calves involved in the second and third studies. A higher suckling frequency was recorded in the housed cows and calves (9.1 *v* 5.5 times per 24 hr) but the calves were 35 days younger. Nevertheless, the magnitude of this difference in suckling frequency was greater than could be attributed solely to the difference in the average age of the calves and it appears that when housed, beef cows suckle their calves more frequently than under grazing conditions.

Pattern of suckling

The distribution of sucklings throughout a 24 hr period (24.00 hr midnight to 24.00 hr midnight) was calculated for each of the three studies (Figures 1, 2 and 3). The number of sucklings recorded in each two-hour period was summed for both days of the observation and is expressed as a percentage of the total number of sucklings recorded in the 48 hr.

A relatively uniform distribution of sucklings throughout 24 hr was recorded in the second and third studies with approximately equal numbers of sucklings occurring during the "day" and "night". An approximately equal distribution of sucklings between day and night was also reported by Ewbank (1969).

In the first study three peaks of suckling activity were recorded; early morning, around midday and late evening. Peaks of suckling activity have also been reported by Walker (1962). The number of sucklings recorded during the "day" and "night" was approximately equal.



Figs. 1,2&3. Pattern of suckling throughout 24 hours in the three studies.

Duration of sucklings

The mean duration of sucklings recorded, 6.9, 10.6 and 10.7 min in the first, second and third study respectively, are comparable to the values reported in the literature (see Table 1). The shorter duration of sucklings recorded in the first study with calves suckled by Hereford x Friesian dams is possibly a consequence of the higher milk output of this breed cross compared with the Blue-Grey.

CONCLUSIONS

Insufficient data were collected to enable firm conclusions to be drawn on the influence of such factors as age of calf, breed and environment on the suckling behaviour of beef cows and their calves. The studies did indicate that during the first three months of lactation, cows suckle their calves about five or six times a day under grazing conditions and suggest that higher frequencies of suckling occur under housed conditions. It should be noted that no observations were made of suckling behaviour during the first seven to 10 days after calving.

Although the evidence is inconclusive, it appears that the frequency of suckling decreases as lactation progresses, and that the number of sucklings which occur during day and night are approximately equal.

After consideration of these and other factors, including the availability of manpower and the accuracy of measuring small increases in the live-weight of calves, it was decided to adopt the suckling régime shown in Table 3 when measuring the milk production of beef cows by the calf-suckling technique.

TABLE 3: Suckling régime adopted in the calf-suckling technique

Suckling frequency per 24 hr	Days after calving	Times of suckling (hr)
4	1 to 7	07.00, 11.30, 16.00, 22.00
3	8 - 42	07.00, -, 16.00, 22.00
2	43 - 150	07.00, -, 16.00, -
1	150+	07.00, -, -, -

APPENDIX 2

A PRELIMINARY STUDY OF THE EFFECT OF NUTRITION DURING LACTATION ON THE PERFORMANCE OF AUTUMN-CALVING BEEF COWS WITH EMPHASIS ON THE METHOD OF MILKING EMPLOYED

SUMMARY

In the first experiment described, 14 autumn-calving Hereford x British Friesian cows were offered one of three levels of nutrition during their second lactation. Milk production was measured by either machine-milking or a calf-suckling technique. Machine-milking significantly increased the number of cows drying-off within 150 days of calving ($P < 0.05$) and significantly reduced milk yields ($P < 0.01$) compared to calf-suckling. It was concluded that measuring the milk yield of beef cows by machine-milking may be unreliable, particularly when body reserves are low at calving.

In a second experiment, 16 autumn-calving Hereford x British Friesian cows, suckled by Charolais cross calves, had a daily intake of either 116.7 MJME and 940 g DCP (high) or 62.8 MJME and 700 g DCP (low) per head during their third lactation. The milk yields of the cows, measured by a calf-suckling technique, were not significantly affected by plane of nutrition and the 150-day cumulative yields were 1390 and 1290 kg on the high and low planes respectively. Plane of nutrition in lactation had a highly significant effect ($P < 0.001$) on the live-weight and condition score changes of the cows. After 150 days of lactation, the mean live-weight and condition score of the high plane cows were similar to their *post partum* weight and score. Cows on the low plane, however, mobilised 25 per cent of their *post partum* weight during the first 150 days of lactation and 1 kg live-weight loss was estimated to provide the equivalent of 29 MJ dietary ME. The

nutritional level of the cows did not significantly affect calf growth rate between birth and 150 days. The daily weight gains of calves suckled by high and low plane dams were 1.17 and 1.08 kg respectively. Calf growth rate and milk intake were highly correlated ($r = +0.81$; $P < 0.001$).

INTRODUCTION

The feed requirements of a beef cow are at a maximum in the first hundred days of lactation and it is during this period that the cow is expected to conceive for a subsequent cycle. Traditionally, in the United Kingdom, beef cows calved in the spring because this allowed the period of maximum feed requirements to coincide with the period of maximum grass growth and quality. Recently, however, there has been an increase in the number of beef cows calving in the autumn (Department of Agriculture and Fisheries for Scotland 1974). This had led to the development of a system which allows the cow to lay down body reserves of fat during the summer, at relatively low cost. These reserves may be mobilised during the winter months permitting a reduction in winter feed costs. The success of this system depends on achieving satisfactory calf performance and on maintaining a high level of fertility in cows, although they may be losing live-weight and condition during the breeding period.

Many factors influence calf performance, but a number of workers (Neville 1962; Furr and Nelson 1964; Gleddie and Berg 1968; Totusek, Arnett, Holland and Whiteman 1973) have reported high correlations between the milk intake and growth rate of calves, demonstrating the importance of the milk yield of beef cows as a determinant of the pre-weaning performance of suckled calves.

Lamond (1970) has reviewed the effect of under-nutrition on reproduction in the cow and the experimental evidence indicated that under-nutrition of cows, resulting in live-weight and condition loss, impairs the ability of the cow to breed.

There is a lack of detailed information on the extent to which lactating beef cows may be underfed and lose live-weight during the winter months and the effect that this may have on milk yield, calf performance, and fertility. Estimation of the milk yield of beef cows has, however, presented certain problems and several techniques have been used including hand-milking (Howes, Hentges, Warnick and Cunha 1958), machine-milking (Economides *et al* 1973), a calf-suckling technique (Neville 1962), the use of oxytocin (Lamond, Holmes and Haydock 1969), and more recently tritiated water (Yates, Macfarlane and Ellis 1971).

The purpose of the two preliminary experiments reported here was to compare two methods of measuring the milk yield of beef cows (machine-milking and a calf-suckling technique) and to examine the effect of two levels of nutrition during lactation on the milk yield, live-weight and condition score changes of autumn-calving beef cows and on the growth rates of their calves.

MATERIALS AND METHODS

In Experiment 1, treatments were imposed on lactating beef cows from parturition in the autumn 1973 until 15 April 1974, and in Experiment 2 from parturition in the autumn 1974 until 17th April 1975. The cows calved over a period of 110 days and 117 days in Experiments 1 and 2 respectively. As a result of this spread of calving, the length of time individual cows were subject to experimental treatment varied and results are presented for the first 150 days of lactation only.

Animals

a) Cows

Fourteen Hereford x British Friesian cows in their second lactation were used in Experiment 1 and 16 in their third lactation in Experiment 2. The 16 cows used in Experiment 2 included 13 previously involved in Experiment 1.

The cows were weighed, and condition scored according to the method outlined by Lowman, Scott and Somerville (1973), approximately 12 hr *post partum*. In Experiment 1, the mean (±SD) *post partum* live-weight of the 14 cows was 448 ± 60 kg and their mean (±SD) condition score 1.6 ± 0.8.

At the end of Experiment 1 the machine-milked cows were dried-off and the calf-suckling cows had their calves weaned. The cows grazed hill pasture during the summer until calving at the start of Experiment 2 when they were heavier and in better condition than at the start of Experiment 1. In Experiment 2, the mean (±SD) *post partum* live-weight of the 16 cows was 575 ± 41 kg and their mean (±SD) condition score 3.0 ± 0.30.

b) Calves

The calves involved in both experiments were sired by one Charolais bull with the exception of the calves suckled by the three cows introduced in Experiment 2 which were sired by a seven-eighths Charolais bull. In Experiment 1, calves were weaned at the end of the experiment at approximately six months of age. In Experiment 2, the cows continued to suckle their calves at grass until weaning on 21st July 1975. The average age of the calves at turnout to grass was 188 days, and at weaning 284 days.

Experimental design

In Experiment 1, the cows were divided into two groups of seven, balanced on the basis of condition score, and 12 of the available 14 cows were assigned at random, within condition score group, to one of six treatments arranged in a two times three factorial design. The factors considered were method of milking (machine-milking and the calf-suckling technique) and nutritional level in lactation (high, medium and low) to give two replicates per treatment. The additional two cows (one from each group) were assigned to the calf-suckling medium level of nutrition to give four replicates on this treatment.

In Experiment 2, each cow, from the pairs of cows which had received the same treatment in Experiment 1, was randomly assigned to one of two nutritional levels in lactation (high and low) to give eight replicates per treatment.

Treatments - methods of milking

a) Machine-milking

In Experiment 1, the six cows assigned to machine-milking had their calves removed approximately 12 hr *post partum*. Subsequently, the cows were machine-milked twice daily at 07.00 and 15.00 hr using Alfa-Laval bucket units. The milk produced by each cow was weighed to the nearest 0.10 kg on a suspended balance and the yield recorded at every milking.

The milking procedure followed was similar to that used for dairy cows and included washing the udder, examining the fore-milk for mastitis and, following milk removal, teat dipping with an iodine-based compound.

Milking was reduced to once daily if a cow yielded less than 0.25 kg at each of three consecutive milkings. Milking of the cow continued once daily at 07.00 hr unless the yield was less than 0.25 kg at three consecutive milkings when milking was discontinued.

The first six milkings were sampled to determine the composition of colostral milk and thereafter aliquot samples were taken from the morning and afternoon milkings on three consecutive days per week, bulked and analysed for butter fat (BS 696 Pt II 1969), and total solids (BS 1741 1963).

b) *The calf-suckling technique*

The calf-suckling technique involved weighing a calf before and after suckling to determine, by weight difference, its milk intake and hence the milk production of the dam.

From 12 hr *post partum* onwards, calves were kept tied behind their dams and were only released to allow suckling. At each suckling, young calves were not removed from their dams until teat-sucking had ceased. In older calves, rapid changing from teat to teat was used to signify the end of suckling. The frequencies of suckling imposed at different stages of lactation are shown in Table 1.

The recording of milk yield by the calf-suckling technique commenced approximately 24 hr *post partum*.

From one to seven days *post partum*, milk yields were determined daily by weighing calves before and after each of the four sucklings per day. The daily yield was calculated as the sum of the four calf weight-increments recorded on that day. From eight days *post partum* onwards, milk yields were based on measurements made on two consecutive days each week. The calves were weighed on an Avery platform balance (Avery scales, Birmingham, Warwickshire) with a weighing accuracy of 0.25 kg.

TABLE 1: Suckling frequency per day and times of suckling at different stages of lactation

Suckling frequency per 24 hr	Days *post partum*		Times of suckling (hr)
	Experiment 1	Experiment 2	Experiments 1 and 2
4	1 to 7	1 to 7	07.00, 11.30, 16.00, 22.00
3	8 - 42	8 - 56	07.00, - 16.00, 22.00
2	43 - 150	57 - 150	07.00, - 16.00, -
1	151+	151+	07.00, - - -

Nutritional level in lactation

The nutritional levels were imposed on the cows from 24 hr *post partum* onwards and were designed to provide either 175 (high), 125 (medium) or 90 (low) per cent of the energy requirement of a cow for maintenance. The estimated maintenance requirement of each cow (0.5 MJME/kg$^{0\cdot75}$ per day) was based on the mean of two live-weight measurements made approximately 12 hr *post partum*. In Experiment 1, cows were individually offered either the high, medium or low level of nutrition and in Experiment 2, the high or low level only.

In both experiments the rations offered to the cows consisted of grass silage and a concentrate supplement combined to give a ration energy concentration (M/D) of 10.3.

The concentrate supplements offered on each treatment differed in digestible crude protein (DCP) content in an attempt to ensure that the minimum DCP intake was 636 g per day, sufficient to meet the daily requirement of a 500 kg cow for maintenance and the production of 7 kg of milk. The concentrate supplements contained added minerals and vitamins.

In both experiments the silage offered to the cows was sampled daily and the concentrate supplements every 28 days for laboratory analysis. The dry matter (DM), metabolisable energy value (ME) and digestible crude protein content (DCP) of the concentrates and silages are shown in Table 2.

TABLE 2: Composition of the foods

Treatment	Concentrates DM (g/kg)	Concentrates ME (MJ/kgDM)	Concentrates DCP (g/kgDM)	Silages [1]DM (g/kg)	Silages [2]ME (MJ/kgDM)	Silages [3]DCP (g/kgDM)
Experiment 1:						
(High	849	13.0	134)			
(Medium	853	12.6	188)	231	8.7	63
(Low	852	12.1	284)			
Experiment 2:						
(High	871	13.1	83)	262	10.1	80
(Low	860	10.6	331)			

[1]Determined from toluene distillation *after* Dewar and McDonald (1961)

[2]ME = 17.4 - 0.02 MAD-F; modified acid detergent fibre (MAD-F) determined *after* Clancy and Wilson (1966)

[3]DCP = 0.09115 CP - 3.67; crude protein (CP) determined *after* Watson and Nash (1960)

Management

The cows were individually tied in a byre and bedded on sawdust. An individual cow's silage and concentrate allowance was offered once daily between 09.00 and 11.00 hr and water was available at all times. Silage refusals were collected and weighed daily.

The cows were released into an exercise yard for approximately one hour a day and observed for signs of oestrus. Between 22nd November and 28th February any cow seen in oestrus was mated to a Charolais bull on the day of oestrus, and artificially inseminated with semen from the same bull the following day.

The calves were offered a concentrate supplement up to a maximum of 2 kg per head per day and hay and water *ad libitum*. In both experiments all male calves remained entire.

Recording of live-weights and condition scores

The cows were weighed and condition scored twice, approximately 12 hr *post partum*, and subsequently cow live-weights were recorded weekly and condition scores every 14 days throughout both experiments. Two experienced operators, working in conjunction, condition scored the cows according to the method described by Lowman, Scott and Somerville (1973) in both experiments.

Calf live-weight changes were calculated from the mean of two pre-suckling weights recorded at 07.00 hr on two consecutive days each week. In Experiment 2, calf weaning weights were adjusted for age by the method described by Koch *et al* (1959).

Statistical methods

An equation developed by Wood (1969) was fitted to the observations of daily milk yield for each cow. The form of equation used was:

$$Y = an^b e^{-cn}$$

where Y = milk yield per day in kg

n = days *post partum*

e = base of natural logarithms

and a), b), c) = coefficients defining lactation curve

Cubic regression equations were fitted to the live-weight and condition score data of each cow and linear regression equations to the live-weight data of each calf. The use of these procedures allowed the estimation of milk yield, live-weights and condition scores, based on successive measurements. Calf live-weights and live-weight gains were adjusted for sex by covariance analysis.

Chi-squared tests were made to compare the incidence of drying-off on the two methods of milking in Experiment 1 and the number of services required for conception by cows on the high and low plane of nutrition in Experiment 2. All other data were statistically evaluated by analysis of variance, Student's t-tests and the determination of simple and partial correlation coefficients.

RESULTS

Health

The general health of the cows and calves in both experiments was good. One case of clinical mastitis was identified in a machine-milked cow in Experiment 1, but it occurred when the cow was nearly dry and any effect on milk yield was likely to be minimal. In both experiments individual calves had scour for short periods, but all cases rapidly responded to treatment. The scour was associated with a temporary reduction in the appetite of the calves for milk, but at no time during the experiments was the milk intake of a calf deliberately restricted.

Feed intakes

The mean daily intakes of fresh silage and concentrates, DM, DCP and ME of the cows in the experiments are shown in Table 3.

TABLE 3: Mean daily intakes of silage, concentrates, dry matter (DM), digestible crude protein (DCP), and metabolisable energy (ME) in the experiments

Treatment	Mean daily intakes Silage (kg)	Conc (kg)	DM (kg)	DCP (g)	ME (MJ)	[1]Percentage of maintenance requirement
Experiment 1:						
High	27.5	2.55	8.41	700	80.9	169
Medium	19.5	1.81	5.97	540	57.2	116
Low	13.7	1.29	4.21	490	39.5	82
Experiment 2:						
High	37.7	1.50	10.70	940	116.7	197
Low	19.9	0.90	5.87	700	62.8	108

[1]Mean daily energy intake expressed as percentage of estimated maintenance requirement (0.5 MJME/$W^{0\cdot75}$ *post partum*)

The energy intake of the cows on each treatment is expressed as a percentage of their estimated maintenance requirement in Table 3 which shows that the average daily energy intake of the cows was less in Experiment 1 and more in Experiment 2 than had been intended.

Although a minimum average DCP intake of 636 g per day was achieved in Experiment 2, the DCP intake of cows on the medium and low levels of nutrition in Experiment 1 was less than 636 g per day.

Lactation lengths, milk yields and live-weight and condition score changes

Experiment 1

The lactation lengths, milk yields and live-weight changes of individual cows in Experiment 1 are shown in Table 4. By 150 days *post partum* four of the six machine-milked cows had dried-off whereas all eight calf-suckling cows were still lactating ($P < 0.05$). The mean 150-day cumulative milk yield of the calf-suckling cows was significantly higher than the yield of the machine milked cows ($P < 0.01$). This was

TABLE 4: Lactation lengths, milk yields, live-weight changes and reproductive performance of cows in Experiment 1

	Machine-milking (MM)							Calf-suckling technique (CST)									Treatment effect MM v CST
	High		Medium		Low			High		Medium				Low			
Cow number	1	2	3	4	5	6	Mean	7	8	9	10	11	12	13	14	Mean	
Lactation length (days)	19	96	62	150+	26	150+	84	150+	150+	150+	150+	150+	150+	150+	150+	150+	*
150-day lactation yield (kg)	70	140	60	1200	25	420	320	1205	1170	1320	1325	1145	970	950	990	1135	**
Condition score at parturition	0.85	1.37	1.56	2.83	1.02	1.13	1.46	1.35	1.49	3.68	1.52	1.22	0.91	2.52	1.03	1.72	
Live-weight at parturition (kg)	446	449	465	487	377	421	441	434	426	586	466	434	310	517	452	451	NS
Live-weight change to 150 days (kg)	+81	+107	+57	-76	-7	-77	+14	-9	-26	-87	-102	-85	+12	-130	-136	-70	*
Services per conception	2	1	1	1	1	2	1.3	1	1	1	2	1	1	1	-	1.1	NS
Calving interval[1] (days)	369	345	340	362	361	331	351	328	340	349	397	346	447	325	-	364	NS

[1]Adjusted to constant gestation length (286 days)

not solely attributable to differences in lactation length (84 *versus* 150 days) because the average daily yield of the calf-suckling cows was higher than that of the machine-milked cows (8.31 *versus* 2.65 kg) in the first 80 days of lactation.

The composition of the colostral milk and of the milk produced after the first six milkings is shown in Table 5.

TABLE 5: Composition of colostral and normal milk

	Butter fat (g/kg)	Solids-not-fat (g/kg)	Total solids (g/kg)
Colostral milk	23.2	98.3	121.4
Normal milk	32.3	82.0	114.3

The machine-milked cows recorded a mean weight increase of 14 kg between calving and 150 days *post partum* compared to a loss of 70 kg incurred by the calf-suckling cows over the same period ($P < 0.05$). This loss represented 15.5 per cent of the *post partum* weight of the calf-suckling cows.

Experiment 2

The lactation performance, live-weight and condition score changes of the cows in Experiment 2 are shown in Table 6. Nutritional level in lactation did not significantly affect either 150-day cumulative milk yield, peak milk yield or the stage of lactation at which peak yield occurred. The mean lactation curves of cows on the two treatments, based on individual curves constructed using equations of the form given by Wood (1969), are shown in Figure 1. The shapes of the lactation curves were similar.

TABLE 6: Lactation performance, live-weight and condition score changes in Experiment 2

	Treatment High	Treatment Low	SE of difference	Significance of difference
Lactation:				
150-day milk yield (kg)	1390	1290	73.8	NS
Peak yield (kg)	10.45	9.95	0.709	NS
Days *post partum* peak yield occurred	27	25	11.3	NS
Live-weight changes:				
Live-weight at parturition (kg)	582	567	21.7	NS
Maximum live-weight loss (kg)	48	144	8.4	***
Days *post partum* minimum live-weight occurred	68	125	9.6	***
Live-weight loss to 150 days *post partum* (kg)	2	141	12.8	***
Condition score changes:				
Condition score at parturition	3.1	3.0	0.16	NS
Maximum condition score loss	0.4	1.7	0.11	***
Days *post partum* minimum score occurred	65	138	9.9	***
Condition score loss to 150 days *post partum*	0.03	1.64	0.163	***

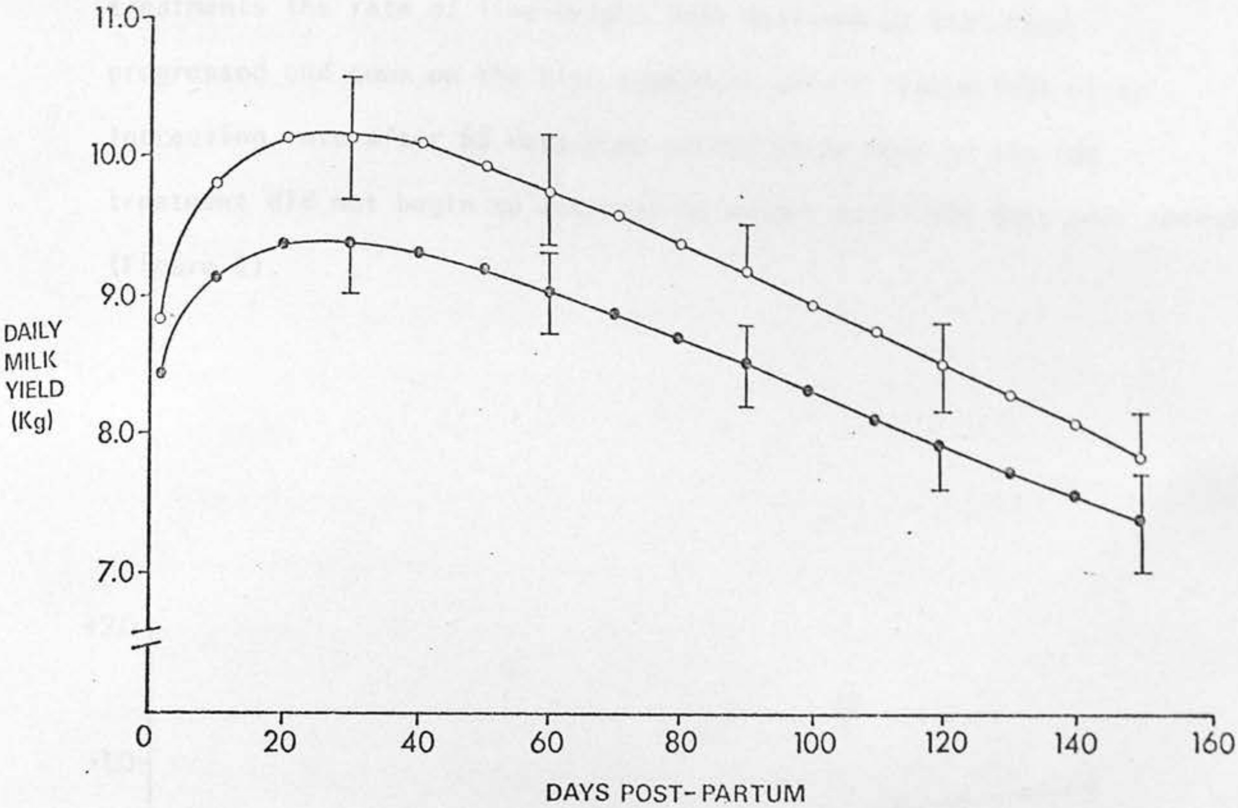


FIGURE 1. DAILY MILK YIELD OF BEEF COWS AT TWO LEVELS OF NUTRITION IN LACTATION
o—o HIGH TREATMENT; ●—● LOW TREATMENT; ⫯ SE OF MEAN.

Nutritional level in lactation significantly affected the maximum live-weight loss recorded, the stage of lactation at which minimum live-weight occurred and the live-weight changes of the cows from calving to 150 days *post partum* ($P < 0.001$). By 150 days *post partum*, the live-weight of the cows on the high treatment was similar to their weight *post partum*. Cows on the low treatment, however, mobilised approximately 25 per cent of their *post partum* weight in the first 125 days of lactation and at 150 days *post partum* were 141 kg lighter than at calving.

Between parturition and the stage of lactation at which minimum live-weight was recorded, cows on the low treatment lost weight at a faster rate than cows on the high treatment ($P < 0.001$). On both treatments the rate of live-weight loss declined as lactation progressed and cows on the high treatment gained live-weight at an increasing rate after 68 days *post partum* while cows on the low treatment did not begin to increase in weight until 125 days *post partum* (Figure 2).

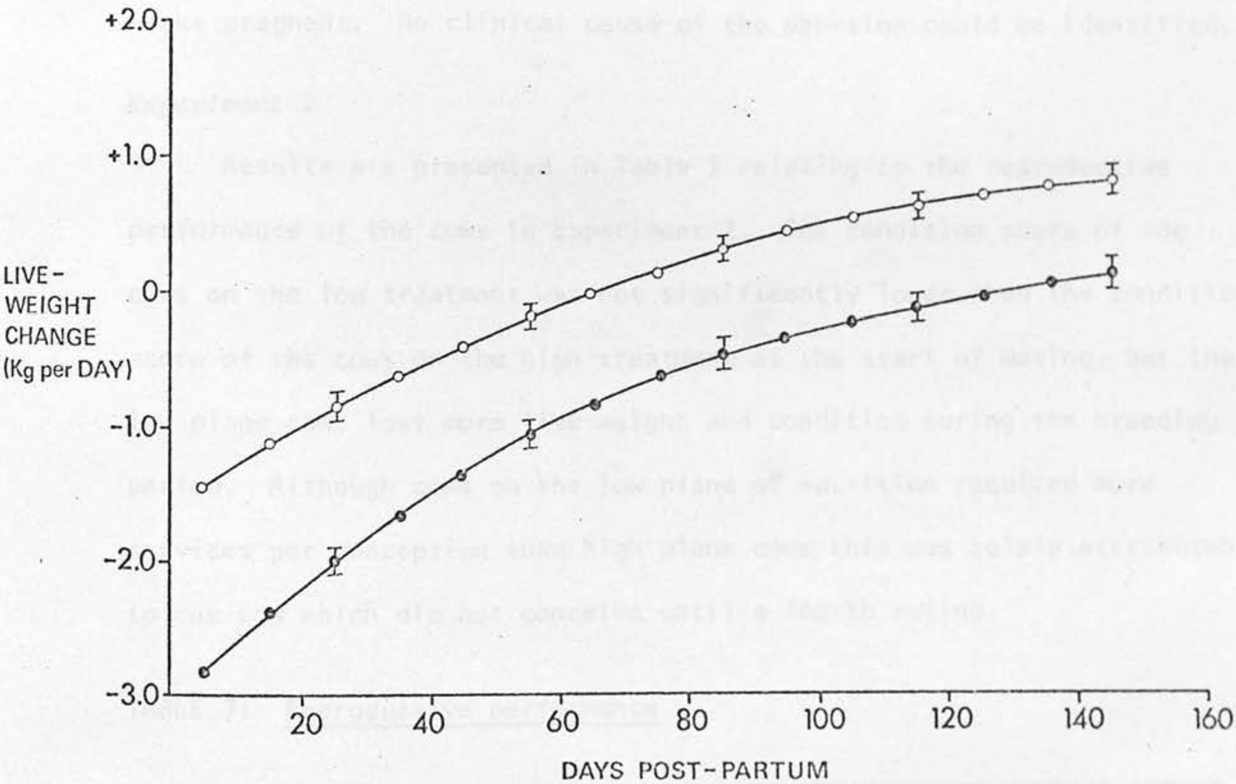


FIGURE 2. LIVE-WEIGHT CHANGES OF BEEF COWS AT TWO LEVELS OF NUTRITITION IN LACTATION

o—o HIGH TREATMENT; •—• LOW TREATMENT; SE OF MEAN.

Reproductive performance of cows

Calving interval was calculated by adding a constant gestation length (286 days) to the interval between calving and conception.

Experiment 1

Method of milking did not significantly affect the number of services required for conception or the calving intervals of the cows (Table 4).

One cow on the low treatment failed to re-breed. This cow conceived at a second insemination, but subsequently aborted when 12 weeks pregnant. No clinical cause of the abortion could be identified.

Experiment 2

Results are presented in Table 7 relating to the reproductive performance of the cows in Experiment 2. The condition score of the cows on the low treatment was not significantly lower than the condition score of the cows on the high treatment at the start of mating, but the low plane cows lost more live-weight and condition during the breeding period. Although cows on the low plane of nutrition required more services per conception than high plane cows this was solely attributable to one cow which did not conceive until a fourth mating.

TABLE 7: Reproductive performance

	Treatment High	Treatment Low	SE of difference	Significance of difference
Condition score at start of service period	2.73	2.34	0.48	NS
Number of barren cows	0	1	-	-
Services per conception	1.38	1.71	-	NS
[1]Calving interval (days)	367	379	15.8	NS

[1]Adjusted to constant gestation length (286 days)

One cow on the low treatment was mated twice, but failed to conceive on each occasion. No physiological explanation could be found for the failure of this cow to re-breed.

Performance of calves

Experiment 1

From birth to 150 days the daily live-weight gains of the calves were 1.11 ± 0.09 kg (mean ± SD). There was a significant positive correlation between growth rate and milk intake ($r = 0.90$; $P < 0.01$) over the 150-day period.

Experiment 2

The birth-weights of the calves at the start of the experiment, growth rates to 150 days, 150-day weights and weaning weights are shown in Table 8.

TABLE 8: Effect of level of nutrition of the dam during lactation on the live-weight changes of the calves in Experiment 2

	Treatment		SE of difference	Significance of difference
	High	Low		
Calf birth-weight (kg)	40.7	41.7	2.94	NS
Calf daily weight gain to 150 days (kg)	1.18	1.07	0.05	NS
Calf 150-day weight (kg)	217	203	8.7	NS
Calf daily weight gain from 150 days to weaning (kg)	0.91	0.99	0.068	NS
[1]Calf weaning weight (kg)	340	334	17.3	NS

[1]Adjusted for age (284 days)

The nutritional level of the cow during lactation did not significantly influence calf performance, although the difference between the treatments in calf daily live-weight gain to 150 days approached significance at the 5 per cent level of probability. Simple correlations between daily live-weight gain to 150 days and milk intake were +0.80 and +0.76 for bull and heifer calves respectively ($P < 0.05$).

The observations relating calf growth rate to milk intake in both experiments were pooled and, when the effects of year and sex of calf were eliminated, the partial correlation between calf growth rate and milk intake was +0.81 ($P < 0.001$). The partial regression of calf live-weight gain on milk intake was:

$$Y = 95 + 0.078\,x \quad (P < 0.001)$$

where Y = live-weight gain of calves between birth and 150 days of age in kg

X = milk intake of calves between birth and 150 days of age in kg

SE of constant = ± 13.9

SE of regression coefficient = ± 0.0127

It should be noted that, in addition to their milk intake, calves had access to concentrates and hay.

DISCUSSION

In Experiment 1, machine-milking proved an unsatisfactory method of measuring the milk yield of beef cows. Four of the six machine-milked cows dried-off within 100 days of calving and of the two which lactated for 150 days, only one had a cumulative milk yield comparable to that of the calf-suckling cows. In this experiment the cows were lean at calving and it appears that the combination of low body reserves and machine-milking resulted in early drying-off and low milk yields. This did not occur in the calf-suckling cows and apparently the stimulus of suckling a calf was greater than the stimulus associated with machine-milking.

Premature drying-off was not reported by Economides *et al* (1973) who machine-milked seven beef heifers for 72 days in mid-lactation, but Abadia and Brinks (1972) recorded an average lactation length of only 93 days in 68 Hereford heifers which they machine-milked from calving to 150 days *post partum* or "until lactation essentially ceased". The milking procedure adopted in Experiment 1 has been used by B.G. Lowman and R.A. Edwards (personal communication) with mature Shorthorn cross Galloway cows maintained under the same conditions and on the same nutritional levels as obtained in Experiment 1. In four of the 70 lactations recorded by Lowman and Edwards the cow dried-off in the first 150 days of lactation, even although the levels of body reserves of the cows at calving were greater than the cows in Experiment 1.

It is concluded that machine-milking may be an unreliable method of measuring the milk yield of beef cows, particularly when body reserves are low at calving.

In Experiment 1, because the number of animals involved was small and the response of the machine-milked cows variable, statistical evaluation of the results relating to the effects of nutrition on performance was not justified. Although, on average, the calf-suckling cows had low body reserves at calving, their 150-day cumulative milk yields were approximately 1130 kg and the average growth rate of their calves was in excess of 1 kg per day.

Experiment 2 demonstrates the capacity of underfed beef/dairy crossbred cows to maintain milk production by depleting body reserves. A reduction in energy and protein intake of 46 and 25 per cent respectively resulted in only a seven per cent reduction in 150-day milk yield which was not statistically significant.

The cows on the low plane of nutrition drew heavily upon body reserves to sustain milk production in early lactation. The data relating to the period between 10 and 110 days *post partum* were used to estimate the ME value of live-weight loss. The period between calving and 10 days *post partum* was excluded from the calculation because it was considered that live-weight losses in this period would reflect gut-fill and fluid changes rather than body tissue mobilisation. After 110 days *post partum* individual low plane cows started to increase in weight.

Between 10 and 110 days *post partum* the eight cows on the low plane of nutrition, on average, produced 8.94 kg milk per day, mobilised 1.09 kg body-weight per day and had a mean live-weight of 465 kg. Assuming a dietary ME requirement of 5 MJ for each kg of milk produced and an average maintenance requirement of 0.5 MJME/kg$^{0.75}$, the average daily energy requirement of the cows was approximately 94.7 MJME.

The daily dietary ME intake of the cows (62.8 MJ) represented only 66 per cent of the cows' requirements and the amount of energy (±SD) supplied by body reserves was estimated to be 31.9 MJME per day, equivalent to approximately 29 ± 2.34 MJ dietary ME per kg live-weight mobilised. This is in reasonable agreement with estimates of the energy value of live-weight loss reported for dairy cows by Bath, Ronning, Meyer and Lofgreen (1965), and in Technical Bulletin No. 33 (1975).

The numbers of cows involved in these experiments were such that the results relating to fertility must be considered as indicative of trends rather than as conclusive evidence. In Experiment 1, there was no indication that method of milking had any influence on fertility which is contrary to the findings of Wiltbank and Cook (1958) and Saiduddin *et al* (1967) who recorded lower fertility in suckling cows compared with machine-milked contemporaries.

In Experiment 2, a low plane of nutrition in lactation, resulting in substantial live-weight losses, had no adverse effect on the fertility of six of the eight cows. The low plane of nutrition may have contributed to the inability of one cow to re-breed and the failure of a second cow to conceive until a fourth mating. There is need for further investigation to substantiate this and particularly to evaluate the cumulative effects of under-nutrition in lactation on the reproductive performance of beef cows over a number of years.

In both experiments there was a close relationship between the milk intake and growth rate of the calves. Differences in milk intake accounted for 66 per cent of the variation in calf daily weight gain to 150 days, which is higher than most of the values reported in the literature (Gifford 1953; Drewry, Brown and Honea 1959; Melton, Riggs, Nelson and Cartwright 1967; Wilson *et al* 1969), but in agreement with the findings of Neville (1962) and Furr and Nelson (1964).

In Experiment 2, plane of nutrition of the dam did not significantly influence calf performance although there was an indication that growth rates to 150 days were lower in calves suckled by cows on the low plane of nutrition. Between 150 days of age and weaning, the live-weight increase of these calves was higher, however, than calves suckled by high plane dams and the weaning weights of the two groups were similar.

It is concluded from these preliminary studies that the calf-suckling technique is a more reliable method of measuring the milk production of beef cows than is machine-milking, and that underfeeding beef/dairy crossbred cows during lactation will have more effect on live-weight changes than on milk yields or calf weaning weights.

APPENDIX 3

PROBLEMS ASSOCIATED WITH SUCKLER COW EXPERIMENTATION AND COMMENTS ON THE EXPERIMENTAL TECHNIQUES EMPLOYED

Introduction

In this appendix some of the problems experienced in the two experiments reported in this thesis are briefly discussed. Also discussed are the ways in which it was attempted to overcome these problems.

Experimental design

One of the first problems to arise when setting up any experiment is the choice of a suitable experimental design. The two experiments described in this thesis represented the first and second "year" of a three-year investigation and the experimental design of the three-year investigation was decided upon at the outset.

In a previous study involving machine-milked Blue-Grey cows it appeared that the milk yields of beef cows were variable and the observed coefficient of variation of milk yield was 25 per cent. On the basis of this figure it was estimated that, using a conventional factorial design, to detect statistically significant ($P < 0.05$) treatment differences in milk yield of 10 per cent would have required approximately 17 cows per nutritional treatment in each of the three years. In view of the number of cows required to overcome the expected problem of variation in milk yields, and also because it was anticipated that there would be a close relationship between the first, second and third lactation milk yields of the cows, it was decided to adopt a serial factorial design.

Essentially, a serial factorial design involves comparing the response of the same animal to the different experimental treatments imposed rather than comparing the response of different animals. This type of analysis is useful under circumstances similar to those discussed above, i.e. where the particular characteristic being measured is expected to show considerable variation between animals, but where there is little variation in the characteristic when it is measured in the same animal in different time-periods.

A serial factorial design was adopted in the three-year investigation on the basis of two assumptions which were subsequently proved invalid by the first two years' experimentation. In the two experiments reported in this thesis, it was found that the milk yields of beef cows, measured by a calf-suckling technique, were less variable than was anticipated on the basis of yield data obtained by machine-milking. Furthermore, there was no evidence of a relationship between the first and second lactation milk yields of the cows.

In retrospect, it is considered that a more suitable experimental design would have involved allocating the heifers at random to the three nutritional levels and allowing each heifer to remain on the same plane of nutrition in the three experiments/years. This would have provided information on the cumulative effects of the three planes of nutrition imposed in successive lactations. The serial factorial design adopted permitted this important aspect to be examined in only one-third of the cows involved in the investigation.

Animals

Hereford cross British Friesian cows were selected for the experiments because as the product of a mating between a beef bull and a dairy cow, this cross is representative of a type of suckler cow which is becoming increasingly popular in the United Kingdom. Furthermore, although objective information is lacking on the breed structure of the national suckler herd, the Hereford cross British Friesian is probably one of the most prevalent crosses or breeds of suckler cow in the United Kingdom.

Heifers were purchased for the experiments in preference to cows for two reasons. Firstly, Brucellosis problems were considered less likely in heifers and secondly, it was thought that the nutritional and environmental régimes experienced by the heifers prior to the experimental period would be less likely to influence their response to the experimental treatments imposed, particularly the different milking treatments.

Unfortunately, the response of heifers to different experimental treatments may not be representative of the response of cows. Furthermore, the age, live-weight and body reserves of heifers at their first parturition may exert an influence on their response to any experimental treatments imposed in their first lactation.

To minimise any sire effects on the reproductive performance of the cows and the growth characteristics of the calves, only one sire was used in each of the two experiments.

Facilities

The facilities used for the experiments were specifically designed for the purpose and generally proved satisfactory. Their only limitation was that it was not possible to measure the hay intakes of the calves individually, and this meant that valuable data on the relationship between the milk, concentrate, and hay intakes of suckled calves were not available.

Methods of measuring milk production

The primary purpose of the experiments reported in this thesis was to examine the response of beef cows to different planes of nutrition during lactation. This necessitated the selection of a technique for measuring the milk production of beef cows and five techniques were evaluated on the basis of evidence reported in the literature.

The estimation of milk production by an equation of calf growth rate or from the body-water turnover of the suckled calf was considered unsuitable, firstly because both techniques appeared relatively inaccurate, and secondly, because they could only be used in the early part of lactation. The oxytocin technique was also rejected because there was evidence in the literature which suggested that certain cows were unresponsive to injections of exogenous oxytocin. Furthermore, there was no information on the possible effects on milk production of regular injections of oxytocin over a prolonged period of lactation. Therefore, it was decided to examine experimentally the two remaining methods which were machine-milking twice a day and a calf-suckling technique.

Method of defining nutritional treatments

In both the experiments reported in this thesis, the nutritional treatments imposed on the cows were defined as multiples of estimated maintenance requirement. Each cow's maintenance requirement was assessed individually on the basis of the particular cow's metabolic live-weight measured 12 hr *post partum*.

The deficiencies of this method of defining nutritional treatments were described in some detail in the discussion of the results of Experiment 1, but an alternative method was not proposed.

It is suggested that under experimental conditions nutritional treatments should be defined without reference to the live-weight of the cow, or any other factor, and that all cows within a particular nutritional treatment should receive precisely the same levels of nutrient intake. If it proves necessary to make adjustments to the responses observed, e.g. as a result of differences in live-weight at the beginning of the experimental period, these can be made retrospectively by covariance analysis, provided it can be demonstrated that live-weight at the beginning of the experimental period significantly ($P < 0.05$) influenced the responses observed. This is preferable to confounding the effect of nutritional level and live-weight at the beginning of the experimental period by defining the former in terms of the latter.

Regrettably, nutritional levels had been defined as multiples of maintenance requirement in investigations undertaken prior to the experiments reported here, and, although its deficiencies were recognised, the method was adopted to give continuity to the investigational programme.

Live-weights

The deficiencies of using live-weight measurements to provide an index of body-tissue changes are well documented and have been referred to earlier in this thesis. One problem is that the live-weight of an animal is subject to transient fluctuations and this can create problems when attempting to interpret live-weight data, particularly if only a limited number of observations are available.

In an attempt to overcome this particular problem, a cubic regression equation was fitted to all the observations of live-weight available for each cow. Thus, the estimated live-weight of a cow at a specific stage of lactation was based upon a number of successive measurements of live-weight, rather than on a single observation.

A number of different types of equation were tested on live-weight data available from a previous investigation and these were assessed on the basis of their goodness of fit, i.e. the percentage variation accounted for by the equations. It was established empirically that a cubic regression equation best fitted both the live-weight and the condition score data.

It was found, however, that the variation accounted for by a cubic regression equation could be significantly ($P < 0.05$) improved by making additional observations at the beginning and end of the experimental period. This involved recording the live-weights and condition scores of the cows twice, 12 hr *post partum*, and then once each day for the next three days at the beginning of the experimental period; once on three consecutive days immediately before the end of the experimental period, and twice on the final day. On average, the cubic regression equation accounted for 88 per cent of the variation in the live-weight of the cows and 75 per cent of the variation in their condition score.

Gut-fill

An increase or decrease in the weight of the contents of the alimentary tract, i.e. gut-fill change, can markedly affect the observed live-weight changes of cows. In the present investigation, differences in gut-fill change undoubtedly contributed to the different mean live-weight changes recorded on each plane of nutrition.

It was considered impractical to attempt to minimise the effect of differences in gut-fill change by determining the starved live-weights of the cows at regular intervals throughout the experimental period. Nevertheless, it is now regretted that a starved live-weight was not determined at the end of each experimental period. This, when compared with the live-weights of the cows 12 hr *post partum*, would have provided a more reliable measure of the live-weight changes of the cows over the experimental period for the purpose of comparing the mean live-weight changes on the different planes of nutrition.

APPENDIX 4

FURTHER DETAILS OF PROCEDURES AND SUPPLEMENTARY RESULTS

4.1 CHEMICAL ANALYSES OF CONCENTRATES AND HAY AND THE ESTIMATION OF THEIR ME AND DCP VALUES

The following methods were used in the analysis of the concentrate supplements:

Dry matter	- oven drying to constant weight at 100°C.
Tri-chloro-acetate-fibre (CF)	- *after* Whitehouse, Zarrow and Shay (1945).
Ether extract (EE)	- *after* The Fertiliser and Feeding Stuffs Regulations (1973).
Crude protein (CP)	- micro-Kjeldahl digestion using potassium sulphate and mercuric oxide as catalysts; nitrogen determined *after* Crooke and Simpson (1971).
Nitrogen-free extractives (NFE)	- calculated by difference.

The equations used to calculate the DCP and ME of the concentrate supplements offered on the high, medium and low planes of nutrition were as follows:

Experiment 1

DCP = 0.076 CP (high)
DCP = 0.079 CP (medium)
DCP = 0.085 CP (low)

Experiment 2

DCP = 0.076 CP (high)
DCP = 0.081 CP (medium) (DCP and CP in g/kg DM)
DCP = 0.090 CP (low)

Experiment 1

$$ME = 0.0116\ CP + 0.027\ EE + 0.0072\ CF + 0.0145\ NFE\ (high)$$
$$ME = 0.0120\ CP + 0.028\ EE + 0.0076\ CF + 0.0142\ NFE\ (medium)$$
$$ME = 0.0129\ CP + 0.030\ EE + 0.0083\ CF + 0.0132\ NFE\ (low)$$

Experiment 2

$$ME = 0.0116\ CP + 0.027\ EE + 0.0072\ CF + 0.0145\ NFE\ (high)$$
$$ME = 0.0137\ CP + 0.0318\ EE + 0.0091\ CF + 0.0122\ NFE\ (medium)$$
$$ME = 0.012\ CP + 0.0291\ EE + 0.0078\ CF + 0.0137\ NFE\ (low)$$

(ME in MJ/kg DM; CP, EE, CF and NFE in g/kg DM)

The digestibility coefficients for crude protein, assumed in the equations used to estimate DCP, were based on the relative proportion of barley and soya bean meal contained in each supplement. The digestibility coefficients assumed for barley and soya bean meal were 0.76 and 0.90 respectively (Ministry of Agriculture, Fisheries and Food 1975).

The equations used to estimate ME values were adapted from a general equation proposed in Technical Bulletin No. 33 (1975) using digestibility coefficients calculated on the basis of the relative proportion of the various constituents in the supplements.

Samples of the hays offered to the calves in the experiments were analysed for CF, CP and ash by the same methods as were described for silage. The equations used to estimate the ME and DCP values of the hays were adapted from those proposed by Morgan (1972) and were:

$$DCP = 0.092\ CP - 3.8$$
$$ME = 14.3 + 0.0167\ CP - 0.0192\ CF$$

(DCP, CP and CF in g/kg DM; ME in MJME/kg DM)

4.2 METHOD OF ESTIMATING CUMULATIVE MILK YIELDS, AND DAILY MILK YIELD AT SPECIFIC STAGES OF LACTATION

For reasons which have been described in the Materials and Methods section, an equation developed by Wood (1969) was fitted to the observations of daily milk yield for each cow. The form of equation used was:

$$Y = an^{b} e^{-cn}$$

where Y is daily milk yield on day n of lactation, e is the base of natural logarithms, and a, b and c are coefficients defining the particular lactation curve.

An account of the properties of this model of the lactation curve, and of the method of obtaining estimates of the coefficients has been given by Wood (1967, 1968, 1969, 1976). A natural logarithmic transformation allows a least squares estimation of a, b and c, viz:

$$\log_e (Yn) = \log_e a + b \log_e n - cn$$

The a coefficient is the scaling factor, b the parameter of pre-peak curvature, and c the parameter of post-peak curvature (Wood 1967). An example of this equation fitted to the observations of daily milk yield for a calf-suckling cow is shown in Figure 1.

The equation was fitted to all the available observations of daily milk yield made during the experimental period and not only to those observations made during the first 150 days of lactation. This enabled the lactation curve of each cow to be defined more precisely because more observations were available on which to fit the equation.

The equation developed by Wood (1969) was also used to estimate the 150-day cumulative milk yields of five cows which failed to complete

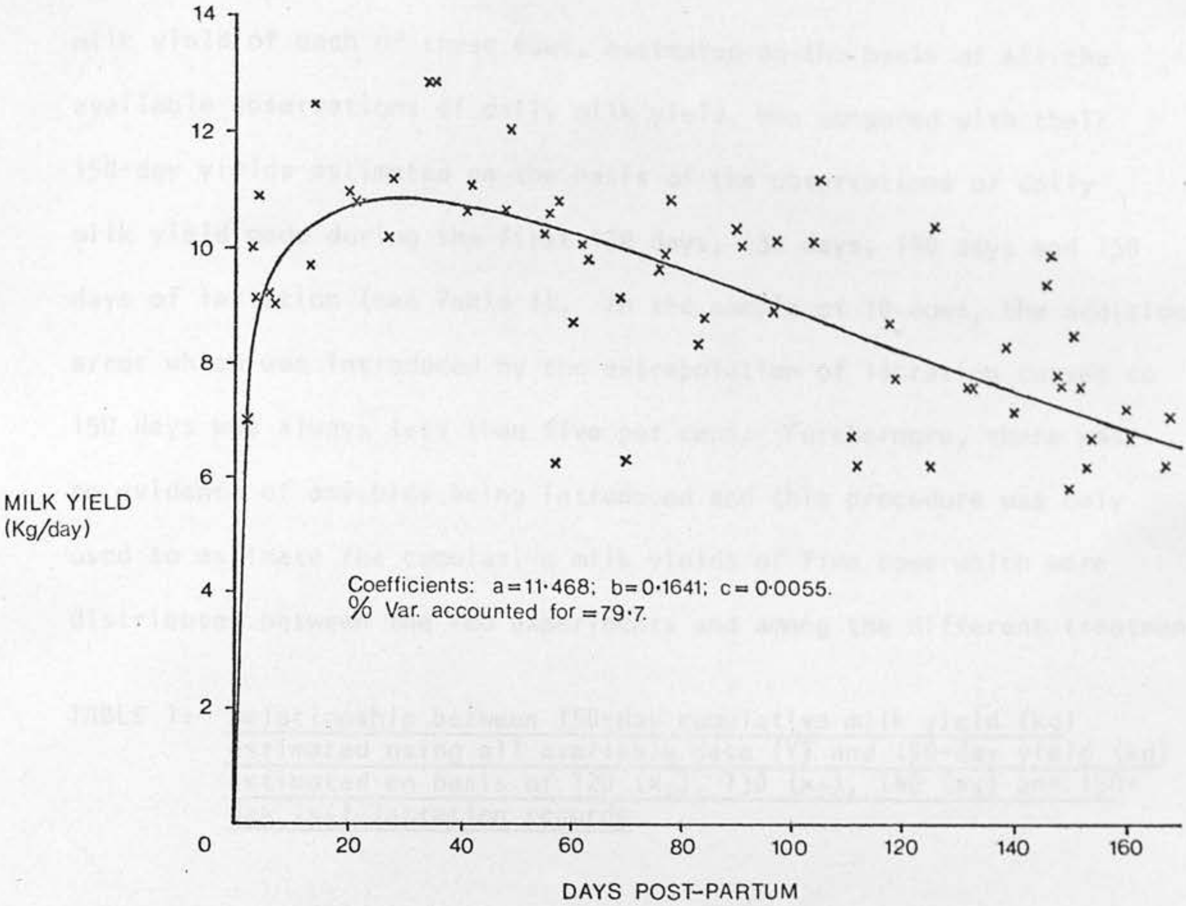


Fig. 1 Example of Wood's (1969) equation fitted to the observations of daily milk yield for one cow.

150 days on experimental treatment. These five cows were subject to experimental treatments for 119, 124, 135, 144 and 148 days. The least squares estimation of the a, b and c coefficients was obtained for each cow, on the basis of the available observations of daily milk yield, and these coefficients were then used to estimate 150-day cumulative milk yield.

This procedure was validated by estimating the 150-day cumulative milk yields of a random sample of 10 cows, all of which had been subject to experimental treatments for more than 150 days. The 150-day cumulative milk yield of each of these cows, estimated on the basis of all the available observations of daily milk yield, was compared with their 150-day yields estimated on the basis of the observations of daily milk yield made during the first 120 days, 130 days, 140 days and 150 days of lactation (see Table 1). In the sample of 10 cows, the additional error which was introduced by the extrapolation of lactation curves to 150 days was always less than five per cent. Furthermore, there was no evidence of any bias being introduced and this procedure was only used to estimate the cumulative milk yields of five cows which were distributed between the two experiments and among the different treatments.

TABLE 1: Relationship between 150-day cumulative milk yield (kg) estimated using all available data (Y) and 150-day yield (kg) estimated on basis of 120 (x_1), 130 (x_2), 140 (x_3) and 150-day (x_4) lactation records

Cow No	Y	x_1	% error	x_2	% error	x_3	% error	x_4	% error
1	819	838	+ 2.3	849	+ 3.7	841	+ 2.4	823	+ 0.5
2	873	853	- 2.3	860	- 1.5	869	- 0.5	869	- 0.5
3	965	938	- 2.8	952	- 1.3	952	- 1.3	972	+ 0.7
4	976	991	+ 1.5	987	+ 1.1	996	+ 1.1	1002	+ 2.7
5	1175	1147	- 2.4	1153	- 1.9	1166	- 0.8	1173	- 0.2
6	1183	1172	- 0.9	1175	- 0.7	1170	- 1.1	1176	- 0.6
7	1316	1284	- 2.4	1304	- 0.9	1314	- 0.2	1322	+ 0.5
8	1389	1361	- 2.0	1385	- 0.3	1394	+ 0.4	1398	+ 0.6
9	1466	1511	+ 3.1	1511	+ 3.1	1488	+ 1.5	1484	+ 1.2
10	1472	1542	+ 4.8	1530	+ 3.9	1529	+ 3.9	1512	+ 2.7
	Average		2.45		1.84		1.32		1.02

4.3 FORMAT OF THE ANALYSES OF VARIANCE TABLES

TABLE 2: Example of the format of the analysis of variance table used in the analyses of the lactation performance, live-weight and condition score changes of the heifers in Experiment 1

Source of variation	Degrees of freedom
Nutritional level	2
linear component	1
quad component	1
Method of milking	1
Method x nutritional level	2
method x linear component of N	1
method x quad component of N	1
Covariate	1
Residual	28
Total	34
Grand total	*34*

TABLE 3: Example of the format of the analysis of variance table used in the analyses of the lactation performance, live-weight and condition score changes of the cows in Experiment 2

Source of variation	Degrees of freedom
Method of milking	1
Nutritional level, Exp 2	2
linear component	1
quad component	1
Method x nutritional level, Exp 2	2
method x linear component of N, Exp 2	1
method x quad component of N, Exp 2	1
Nutritional level, Exp 1	2
Nutritional level Exp 2 x Nutritional level Exp 1	4
linear deviations	2
quad deviations	2
Covariate	1
Residual	23
Total	35
Grand total	*35*

4.4 VARIATION IN THE COMPOSITION OF THE SILAGE OFFERED DURING THE EXPERIMENTAL PERIODS AND EXAMPLES OF THE RESULTANT VARIATION IN THE DRY MATTER, METABOLISABLE ENERGY AND DIGESTIBLE CRUDE PROTEIN INTAKES OF THE COWS

In both experiments, the dry matter, metabolisable energy and digestible crude protein content of the silage offered each day were estimated from the samples of silage collected daily. The mean dry matter, metabolisable energy value and digestible crude protein content of the silage offered during 10-day periods, together with the standard errors of selected means are shown in Figure 2.

For both experiments, one cow was selected at random from each of the three planes of nutrition and their mean daily intakes of dry matter, metabolisable energy and digestible crude protein calculated for each 10-day period during the first 150 days of lactation.

The variation between 10-day periods in the mean daily intakes of each of these cows is shown in Figures 3 and 4. It should be noted that the intakes were composed of both silage and concentrates.

The difference between the DM, ME and DCP of the silage estimated from core samples removed prior to the beginning of the experiment and the DM, ME and DCP estimated from the samples collected daily, while the silage was being apportioned among the cows, is shown overleaf.

TABLE 4: Estimated composition of the silages based on core samples *versus* daily grab samples

	Experiment 1			Experiment 2		
	Pre-dicted[1]	Actual[2]	Difference as % of actual	Pre-dicted[1]	Actual[2]	Difference as % of actual
DM (g/kg)	231.6	230.9	+ 0.3	239.6	262.1	-9
ME (MJ/kgDM)	9.5	8.7	+ 9	10.0	10.1	-1
DCP (g/kgDM)	56	63	-11	85	83	-2

[1]estimated composition from core samples

[2]estimated composition from daily samples

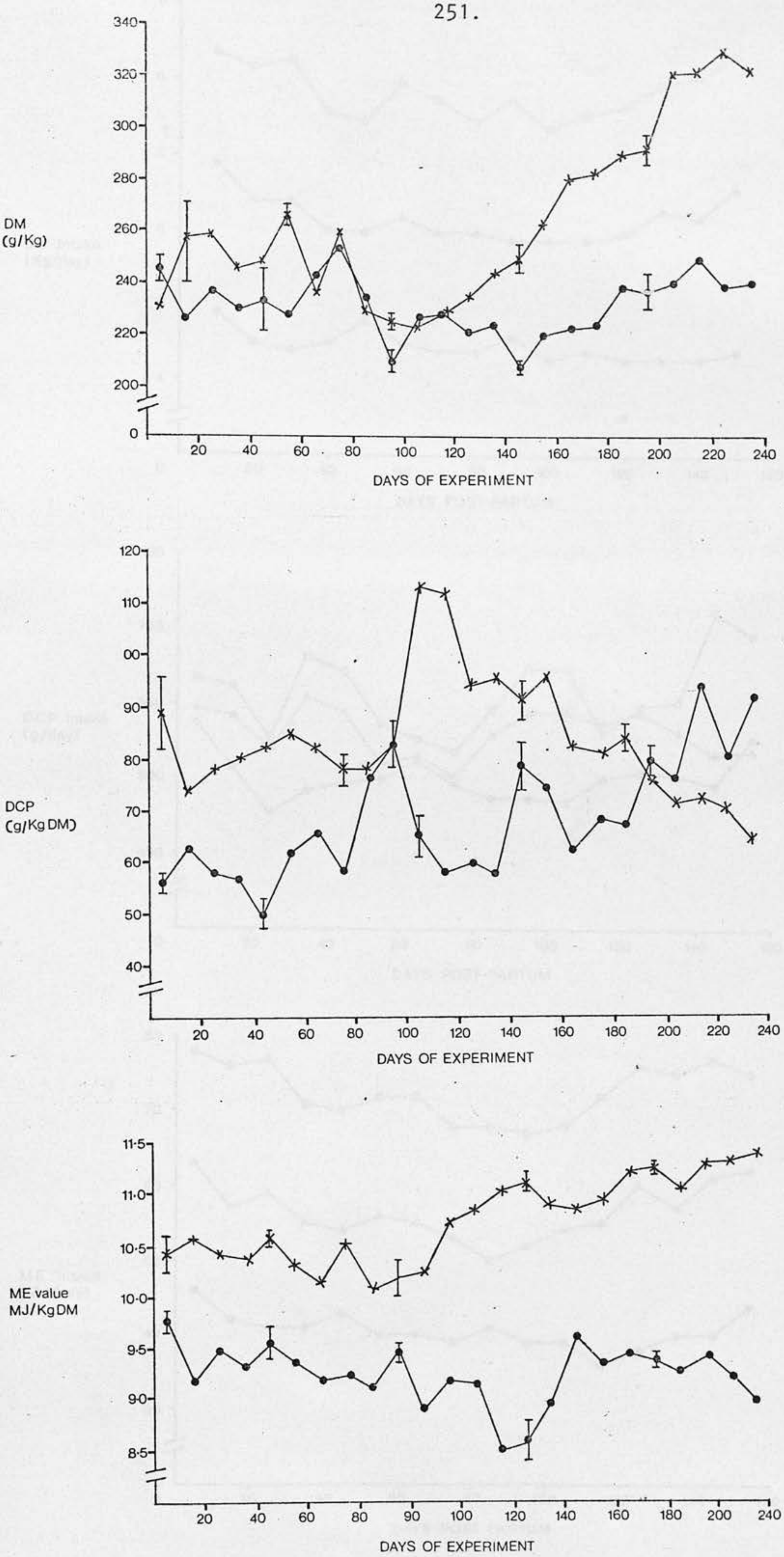


Fig.2 Variation in the dry matter (DM), digestible crude protein (DCP) and metabolisable energy (ME) of the silages as the experiments progressed, based on 10-day mean values (± SE)

●——● Experiment 1 x——x Experiment 2

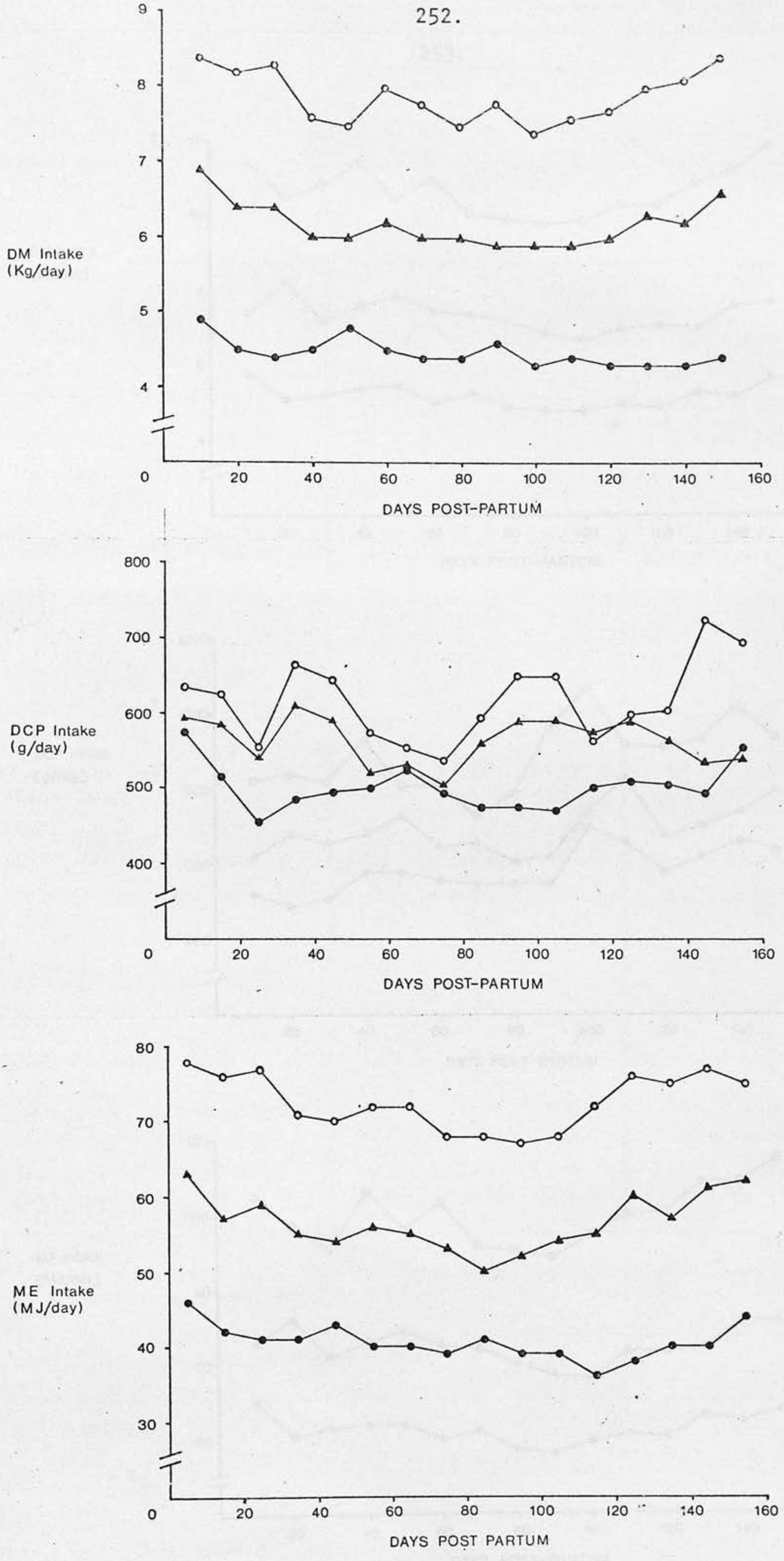


Fig.3 Variation in intake of dry matter (D M), digestible crude protein (D C P), metabolising energy (M E), on the three planes of nutrition, based on mean intakes in 10-day periods (Experiment 1)
○—○ High ▲—▲ Medium ●—● Low plane of nutrition.

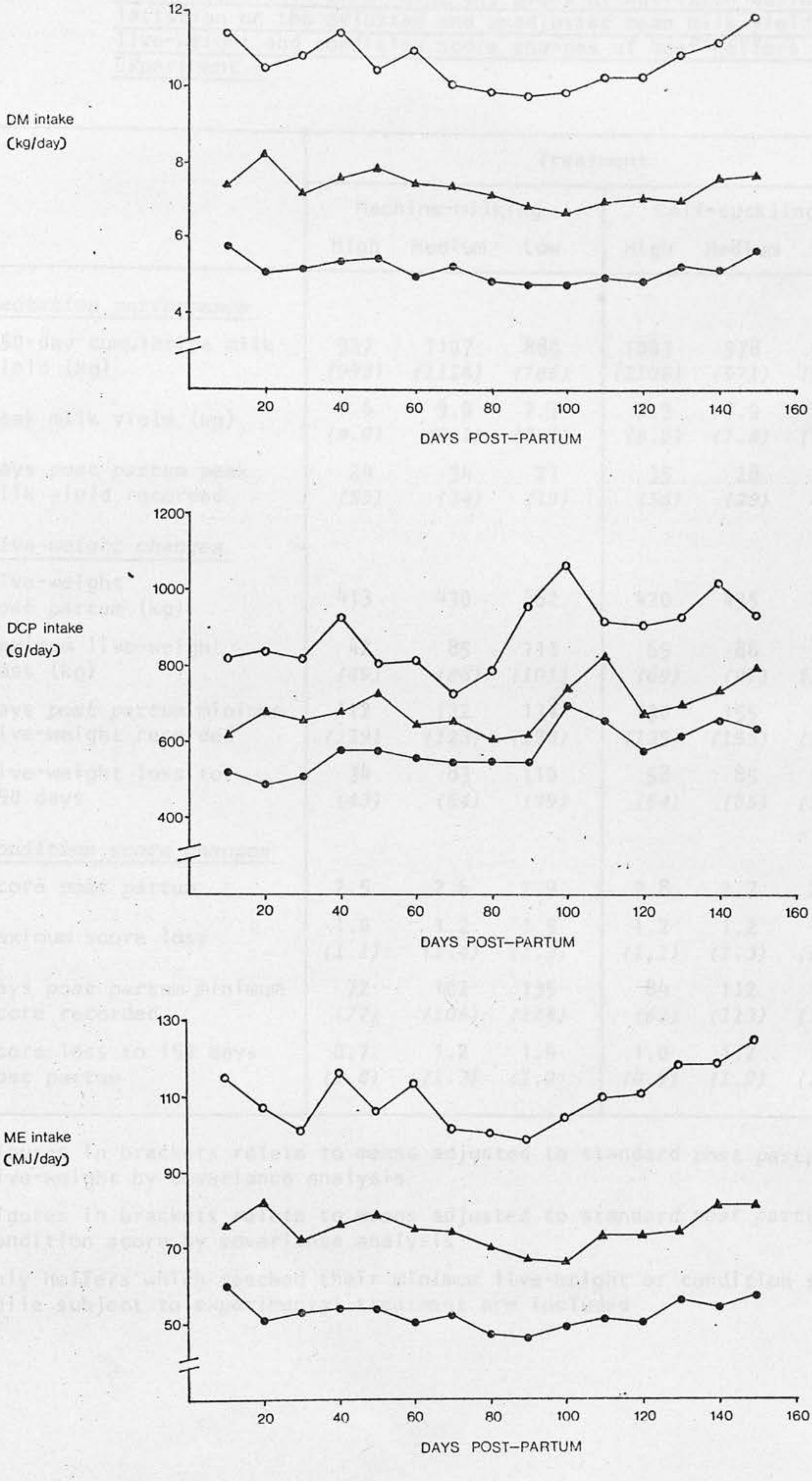


Fig.4 Variation in intake of dry matter (DM), digestible crude protein (DCP), metabolisable energy (ME) on the three planes of nutrition based on mean intakes in 10-day periods (Experiment 2)
o—o High ▲—▲ Medium ●—● Low plane of nutrition

4.5 SUPPLEMENTARY RESULTS

TABLE 5: Effect of method of milking and plane of nutrition during lactation on the adjusted and unadjusted mean milk yields, live-weight and condition score changes of beef heifers in Experiment 1

	Treatment					
	Machine-milking			Calf-suckling		
	High	Medium	Low	High	Medium	Low
[1]*Lactation performance*						
150-day cumulative milk yield (kg)	927 *(993)*	1107 *(1116)*	880 *(786)*	1063 *(1106)*	978 *(971)*	920 *(902)*
Peak milk yield (kg)	7.6 *(8.0)*	9.0 *(9.1)*	7.7 *(7.1)*	7.9 *(8.2)*	7.9 *(7.8)*	7.4 *(7.3)*
Days *post partum* peak milk yield recorded	24 *(25)*	34 *(34)*	21 *(19)*	35 *(36)*	28 *(28)*	21 *(20)*
[1]*Live-weight changes*						
Live-weight *post partum* (kg)	413	430	462	420	435	438
Maximum live-weight loss (kg)	42 *(49)*	85 *(86)*	111 *(101)*	65 *(69)*	88 *(87)*	122 *(120)*
[3]Days *post partum* minimum live-weight recorded	112 *(119)*	122 *(123)*	131 *(120)*	130 *(135)*	155 *(155)*	143 *(141)*
Live-weight loss to 150 days	34 *(43)*	83 *(84)*	110 *(99)*	58 *(64)*	85 *(85)*	119 *(113)*
[2]*Condition score changes*						
Score *post partum*	2.5	2.6	2.9	2.8	2.7	2.7
Maximum score loss	1.0 *(1.1)*	1.2 *(1.4)*	1.5 *(1.3)*	1.2 *(1.1)*	1.2 *(1.3)*	1.7 *(1.7)*
[3]Days *post partum* minimum score recorded	72 *(77)*	102 *(106)*	135 *(128)*	84 *(82)*	112 *(113)*	108 *(108)*
Score loss to 150 days *post partum*	0.7 *(0.8)*	1.2 *(1.3)*	1.4 *(1.2)*	1.0 *(0.9)*	1.2 *(1.2)*	1.5 *(1.4)*

[1]figures in brackets relate to means adjusted to standard *post partum* live-weight by covariance analysis

[2]figures in brackets relate to means adjusted to standard *post partum* condition score by covariance analysis

[3]only heifers which reached their minimum live-weight or condition score while subject to experimental treatment are included

TABLE 6: Regressions of independent variables on the covariates used to adjust treatment means in Experiment 1; with standard errors and levels of significance

Independent variable (Y)	Covariate (X)	Regression of Y on X ± SE
150-day cumulative milk yield (kg)	*Post partum* live-weight (kg)	3.3 ± 0.95 **
Peak milk yield (kg)	"	0.02 ± 0.007 **
Days *post partum* peak milk yield recorded	"	0.14 ± 0.082 NS
Maximum live-weight loss (kg)	"	0.35 ± 0.141 *
Days *post partum* minimum live-weight recorded	"	0.38 ± 0.132 **
Live-weight loss to 150 days *post partum*	"	0.39 ± 0.157 **
Maximum score loss	*post partum* score	0.84 ± 0.076 ***
Days *post partum* minimum score recorded	"	30 ± 13.4 *
Score loss to 150 days *post partum*	"	0.83 ± 0.079 ***

TABLE 7: Effect of plane of nutrition on the milk yield and live-weight losses of beef heifers evaluated within each of the two methods of milking, independently

	[1]150-day cumulative milk yield (kg)	[1]Live-weight loss to 150 days *post partum* (kg)
Machine-milking		
High	1013	43
Medium	1125	85
Low	776	99
Significance	NS	lin*
Calf-suckling		
High	1090	64
Medium	968	85
Low	902	114
Significance	lin*	lin**

[1]adjusted to a standard live-weight *post partum* by covariance analysis

TABLE 8: Composition and gross energy value of the colostral milk produced by beef heifers

	Plane of nutrition			Residual SD	Significant linear effect
	High	Medium	Low		
Butter fat (g/kg)	30.1	36.5	30.5	12.93	NS
Solids-not-fat (g/kg)	111.2	114.6	111.1	14.03	NS
Total solids (g/kg)	141.4	151.1	141.6	15.39	NS
Gross energy (MJ/kg)	3.43	3.74	3.44	1.40	NS

TABLE 9: Effect of plane of nutrition during lactation on the composition and gross energy value of the milk produced by beef heifers at different stages of lactation

	Stage of lactation (days *post partum*)	Plane of nutrition			Residual SD	Significant linear effect
		High	Medium	Low		
Butter fat (g/kg)	0 to 50	38.2	41.4	43.2	4.68	NS
	50 - 100	35.3	34.9	33.7	4.74	NS
	100 - 150	35.2	34.2	34.3	2.72	NS
Solids-not-fat (g/kg)	0 - 50	87.7	85.3	83.5	2.11	***
	50 - 100	86.3	82.8	77.1	5.78	**
	100 - 150	85.9	81.6	80.7	1.68	***
Total solids (g/kg)	0 - 50	125.9	126.7	126.7	5.86	NS
	50 - 100	121.7	117.8	110.7	9.92	NS
	100 - 150	121.2	115.8	115.0	3.41	**
Gross energy (MJ/kg)	0 - 50	3.04	3.11	3.15	0.203	NS
	50 - 100	2.90	2.82	2.65	0.285	NS
	100 - 150	2.89	2.76	2.75	0.067	NS

TABLE 10: Effect of plane of nutrition during lactation on the reproductive performance of beef cows (combined results of Experiment 1 and Experiment 2)

	Plane of nutrition High	Medium	Low	Residual SD	Significant linear effect
Number barren	2	1	3	-	-
Services/effective mating	1.5	1.3	1.6	0.63	NS
Calving interval (days)	362	359	365	26.7	NS

TABLE 11: Regressions of independent variables on the covariates used to adjust treatment means in Experiment 2; with standard errors and levels of significance

Independent variable (Y)	Covariate (X)	Regression of Y on X ± SE
150-day cumulative milk yield (kg)	Calf birth-weight (kg)	14.8 ± 4.26 **
Peak milk yield (kg)	"	0.13 ± 0.044 **
Days *post partum* peak milk yield recorded	"	-1.1 ± 0.75 NS
Maximum live-weight loss (kg)	*Post partum* live-weight (kg)	0.14 ± 0.065 *
Days *post partum* minimum live-weight recorded	"	-0.09 ± 0.065 NS
Live-weight loss to 150 days *post partum*	"	0.07 ± 0.078 NS
Maximum score loss	*Post partum* score	0.03 ± 0.139 NS
Days *post partum* minimum score recorded	"	3 ± 20 NS
Score loss to 150 days *post partum*	"	-0.14 ± 0.143 NS

TABLE 12: Effect of plane of nutrition during lactation on the milk yields of beef cows at different stages of lactation (Experiment 1 and Experiment 2)

Stage of lactation (days *post partum*)	Plane of nutrition High	Medium	Low	Residual SD	Significant linear effect
Experiment 1					
0 to 50	372	367	330	78.1	NS
50 - 100	363	355	289	75.2	*
100 - 150	311	313	221	64.2	**
Experiment 2					
0 - 50	469	460	433	58.5	NS
50 - 100	484	437	408	43.4	***
100 - 150	431	403	383	80.8	NS

TABLE 13: Effect of sex on the weights and weight changes of 35 suckled calves (Experiment 2)

	Mean of heifers	Advantage (±SE) of bulls
Birth-weight (kg)	38.8	1.6 ± 2.11 NS
Daily weight gain to 150 days of age (kg)	1.05	0.10 ± 0.035 **
150-day weight (kg)	195	16 ± 6.4 *
[1]Daily weight gain from 150 days to weaning (kg)	0.91	0.21 ± 0.040 ***
Calf weaning weight (kg)	317	45 ± 9.5 ***

[1]the sexes were grazed separately over most of this time period

TABLE 14: Summary of combined results of three-year investigation[1]

Parameter	Plane of nutrition High	Medium	Low	SE of difference HvL	MvHorL	Significance of linear effect
Daily feed intakes						
Fresh silage (kg)	33.6	24.9	17.3	0.46	0.55	***
Fresh conc. (kg)	1.37	1.18	1.07	0.025	0.032	***
Dry matter (kg)	9.43	7.11	5.25	0.132	0.163	***
ME (MJ)	95.8	71.5	52.1	1.37	1.68	***
DCP (g)	813	665	660	11.8	14.7	***
Lactation performance						
150-day cum. milk yield (kg)	1355	1258	1187	25.4	28.1	***
Peak milk yield (kg)	10.1	10.0	9.2	0.25	0.29	***
Days to peak	35	25	26	4.3	5.1	*
Live-weight and condition score changes						
Live-weight *post partum* (kg)	521	528	524	11.2	13.7	NS
Max weight loss (kg)	62	108	143	4.6	5.0	***
Min live-weight (kg)	464	417	383	4.0	4.9	***
Days to min weight	91	120	130	4.8	5.8	***
Weight loss to 150 days (kg)	41	100	140	5.3	6.2	***
Score *post partum*	2.54	2.53	2.47	0.088	0.099	NS
Max score loss	0.55	0.88	1.33	0.062	0.062	***
Min score	1.99	1.65	1.20	0.061	0.062	***
Days to min score	69	114	123	6.1	7.4	***
Score loss to 150 days	0.25	0.77	1.26	0.069	0.060	***
Calf performance						
Milk intake to 150 days (kg)	1336	1253	1191	32.4	38.2	***
Total conc intake to 150 days (kg)	140	139	138	5.0	6.1	NS
Age max intake reached (days)	106	105	106	3.2	3.5	NS
Estimated hay intake to 150 days (kg)	95	112	107	-	-	-
Birth-weight (kg)	39.8	39.3	40.4	1.2	1.4	NS
DLWG to 150 days	1.13	1.04	1.06	0.021	0.027	**
150-day weight (kg)	210	196	199	3.8	4.8	**
DLWG 150 days to weaning	0.93	1.00	1.02	0.031	0.036	**
Weaning weight (kg)	343	333	336	6.5	8.1	NS

[1]This table shows the results of the three-year investigation of which the two experiments described in this thesis represented the first and second year, and is based upon 122 individual lactations.

BIBLIOGRAPHY

ABADIA, D. and BRINKS, J.S. (1972). Milk production of Hereford heifers. J. Anim. Sci. *34*:886 (Abstr.).

AGRICULTURAL RESEARCH COUNCIL (1965). The Nutrient Requirements of Farm Livestock. No. 2. Ruminants. Agricultural Research Council, London.

ALEXANDER, G. and DAVIES, H.L. (1959). The relationship of milk production to the numbers of lambs born or suckled. Aust. J. agric. Res. *10*:720.

ANDERSON, H. and PLUM, M. (1965). Gestation length and birth weight in cattle and buffaloes. J. Dairy Sci. *48*:1224.

ANTHONY, W.B., PARKS, P.F., MAYTON, E.L., BROWN, L.V., STARLING, J.G. and PATTERSON, T.B. (1959). A new technique for securing milk production data for beef cows nursing calves in nutrition studies. J. Anim. Sci. *18*:1541 (Abstr.).

ARNETT, D. and TOTUSEK, R. (1963). The influence of moderate vs. very high levels of nutrition on the performance of twin beef females. J. Anim. Sci. *22*:239 (Abstr.).

B.S. 1741 (1963). Methods for the chemical analysis of liquid milk and cream. Br. St. Inst., London.

B.S. 696, Pt 2 (1969). Gerber method for the determination of fat in milk and milk products. Br. St. Inst., London.

BAILEY, G.L. and BROSTER, W.H. (1954). The influence of live weight on milk production during the first lactation. J. Dairy. Res. *21*:5.

BAKER, R.D., BALL, C., KILKENNY, J.B., WALSH, A. (1972). Beef Production: Suckled Calves. Joint Beef Production Committee Handbook No. 3. Meat and Livestock Commission, Bletchley, Bucks.

BAKER, R.D. and BARKER, J. (1972). Unpublished work cited by Baker, R.D., Large, R.V. and Spedding, C.R.W. (1973). Proc. Br. Soc. Anim. Prod. (New Series) *2*:35.

BAKER, R.D., LARGE, R.V. and SPEDDING, C.R.W. (1973). Size of animal in relation to productivity with special reference to the ruminant - economic aspects. Proc. Br. Soc. Anim. Prod. (New Series) *2*:35.

BALCH, C.C. (1972). Milk composition. *In* Handbuch der Tierernahrung (ed. Lenkett, W., Breirem, K. and Crasemann, E.). Vol. 2, p. 259. Parey. Hamburg.

BALL, C., BROADBENT, P.J. and DODSWORTH, T.L. (1971). Energy and protein supplements for straw-based winter diets for beef cows. Anim. Prod. *13*:237.

BARNICOAT, C.R., LOGAN, A.G. and GRANT, A.I. (1949). Milk-secretion studies with New Zealand Romney ewes. J. agric. Sci., Camb. *54*:353.

BARTON, R.A. (1959). *In* Quality Beef Production. Palmerston North N.Z. Massey Agric. Coll. 2nd edit.

BATH, D.L., RONNING, M., MEYER, J.H. and LOFGREEN, G.P. (1965). Calorific equivalent of live weight loss of dairy cattle. J. Dairy Sci. *48*:374.

BEEVER, D.E., THOMSON, D.S. and HARRISON, D.G. (1974). Microbial protein synthesis in the rumen of sheep fed forage diets. Conf. Proc. 4th Int. Symp. on Digestion and Metabolism in the Ruminant. Sydney, Australia. August 1974.

BELLOWS, R.A. (1967). Some factors affecting reproductive performance of beef herds bred via natural service. A.I. Digest No. 3. *15*:6.

BENEDICT, F.G. and RITZMAN, E.G. (1927). The metabolism of the fasting steer. Carnegie Inst. of Washington. Publ. 377.

BENSON, G.K. and FOLLEY, S.J. (1957). The effect of oxytocin on mammary gland involution in the rat. J. Endocrinol. *16*:189.

BLAXTER, K.L. (1949). Energy feeding standards for dairy cattle. Nutr. Abstr. Rev. *20*:1.

BLAXTER, K.L. (1956). Starch equivalents, ration standards and milk production. Proc. Brit. Soc. Anim. Prod. 1956-58:3.

BLAXTER, K.L. (1962). The Energy Metabolism of Ruminants. Hutchison, London.

BLAXTER, K.L. and GRAHAM, N.M. (1955). Plane of nutrition and starch equivalents. J. agric. Sci., Camb. *46*:292.

BOND, J. and WILTBANK, J.N. (1970). Effect of energy and protein on estrus, conception rate, growth and milk production of beef females. J. Anim. Sci. *30*:438.

BOND, J., WILTBANK, J.N. and COOK, A.C. (1958). Cessation of estrus and ovarian activity in a group of beef heifers on extremely low levels of energy and protein. J. Anim. Sci. *17*:1211 (Abstr.).

BOND, J., WILTBANK, J.N., WARWICK, E.J., LEHMANN, R.P. and KINNEY, T.B. (1964). Feed intake and milk production of beef cows. J. Anim. Sci. *23*:901 (Abstr.).

BROSTER, W.H. (1971). The effect on milk yield of the cow of the level of feeding before calving. Dairy Sci. Abstr. *33*:253.

BROSTER, W.H. (1972a). Effect on milk yield of the cow of the level of feeding during lactation. Dairy Sci. Abstr. *34*:265.

BROSTER, W.H. (1972b). Protein requirements of cows in lactation. *In* Handbuch der Tierernahrung (ed. Lenkett, W., Breirem, K. and Crasemann, E.) Vol. 2, p. 292. Parey, Hamburg.

BROSTER, W.H., BROSTER, V.J. and SMITH, T. (1969). Experiments on the nutrition of the dairy heifer. VIII. Effect on milk production of level of feeding at two stages of lactation. J. agric. Sci., Camb. *72*:229.

BRUMBY, P.J., WALKER, D.K. and GALLAGHER, R.M. (1963). Factors associated with growth of beef cattle. N.Z. J. agric. Res., *6*:526.

BURT, A.W.A. (1956). The influence of level of feeding during rearing and in late pregnancy upon the productivity of the dairy cow. Dairy Sci. Abstr. *18*:883.

BURT, A.W.A. (1957). The influence of level of feeding during lactation upon the yield and composition of milk. Dairy Sci. Abstr. *19*:435.

BURT, A.W.A. and BELL, E.O. (1962). Effect of the level and concentration of liquid milk substitutes fed to early weaned calves. J. agric. Sci., Camb. *58*:131

BUTTERWORTH, M.H., HOUGHTON, T.R., MacCARTNEY, J.C., PRIOR, A.J., MIDDLEMIS, C.P. and EDMONDS, D.E. (1968). Some observations on the lactation of Blackhead ewes and the growth of lambs: the composition and yield of milk. J. agric. Sci., Camb. *70*:203.

CARTWRIGHT, T.C. and CARPENTER, J.A.Jr. (1961). Effect of nursing habits on calf weights. J. Anim. Sci. *20*:904 (Abstr.).

ČERNOV, G.A. (1969). Some biological and economic tracts of Canadian Herefords and Aberdeen-Angus imported into the south-east of the U.S.S.R. Mater. I Kouf. Molod. Uchen. Genet. Razved. Sel'. - Khoz. Zhivot., Tom I. Pushkin. Nauchno-issled. Lab. Razved. Sel'. - Khoz. Zhivot, Lenningrad. 66.

CHOW, G., RIGGS, J.K. and SCHAKE, L.M. (1967). Frequency of milking and milk yields of beef cows. J. Anim. Sci. *26*:202 (Abstr.).

CHRISTIAN, L.L., HAUSER, E.R. and CHAPMAN, A.B. (1965). Association of preweaning and postweaning traits with weaning weight in cattle. J. Anim. Sci. *24*:652.

CLANCY, M.H. and WILSON, R.K. (1966). Development and application of a new chemical method for predicting the digestibility and intake of herbage samples. Proc. Xth int. Grassld. Congr., Helsinki, Section 2, Paper No. 22, p 445.

CLANTON, D.C., ZIMMERMAN, D.R. and ALBIN, R.C. (1964). Effect of protein and energy on growth and pubertal age in beef heifers. J. Anim. Sci. *23*:870 (Abstr.).

CLANTON, D.C., ZIMMERMAN, D.R. and MATSUSHIMA, J. (1961). Growth and production in beef heifers as affected by protein and energy intake during gestation. J. Anim. Sci. *20*:928 (Abstr.).

CLARK, R.D. and TOUCHBERRY, R.W. (1962). Effect of body weight and age at calving on milk production in Holstein cattle. J. Dairy Sci. *45*:1500.

COLE, L.J. and JOHANSSON, I. (1933). The yield and composition of milk from Aberdeen Angus cows. J. Dairy Sci. *16*:565.

COOMBE, J.B., WARDROP, I.D. and TRIBE, D.E. (1960). A study of the milk production of the grazing ewe, with emphasis on the experimental technique employed. J. agric. Sci., Camb. *54*:353.

COOP, I.E. (1966). Effect of flushing on reproductive performance of ewes. J. agric. Sci., Camb. *67*:305.

COWIE, A.T. and FOLLEY, S.J. (1961). The mammary gland and lactation. *In* Sex and Internal Secretions (ed. Young, W.C.). 3rd edit. *1*. p.590. The Williams and Wilkins Co., Baltimore.

CROOKE, W.M. and SIMPSON, W.E. (1971). Determination of ammonium in Kjeldahl digests of crops by an automated procedure. J. Sci. Fd. Agric. *22*:9.

DAVIES, H.L. (1958). Milk yield of Australian Merino ewes and lamb growth under pastoral conditions. Proc. Aust. Soc. Anim. Prod. *2*:15.

DAVIES, H.L. (1963). The milk production of Merino ewes at pasture. Aust. J. agric. Res. *14*:824.

DAWSON, W.M., COOK, A.C. and KNAPP, B. (1960). Milk production of beef Shorthorn cows. J. Anim. Sci. *19*:502.

DEPARTMENT OF AGRICULTURE AND FISHERIES FOR SCOTLAND (1974). Agric. Statistics. H.M.S.O. Edinburgh.

DEUTSCHER, G.H. and WHITEMAN, J.V. (1971). Productivity as two-year olds of Angus-Holstein crossbreds compared to Angus heifers under range conditions. J. Anim. Sci. *33*:337.

DEWAR, W.A. and McDONALD, P. (1961). Determination of dry matter in silage by distillation with toluene. J. Sci. Fd. Agric. *12*:790.

DICKEY, J.R., KOGER, M., FRANKE, D.E. and BURNS, W.C. (1970). Milk production in beef cattle. J. Anim. Sci. *30*:317 (Abstr.).

DONKER, J.D. and DALTON, H.L. (1955). A comparison of milk yields and estimated secretion rates when between-milking intervals were varied. J. Dairy Sci. *38*:618 (Abstr.).

DONKER, J.D., DALTON, H.L. and CARMON, J.L. (1960). Lactation studies. II. Comparison of techniques to measure true milk and fat secretion rate in dairy cattle as applied to between milking intervals of various lengths of time. J. Dairy Sci. *43*:1287.

DRENNAN, M.J. (1971). Single suckled beef production. 1. Influence of stocking rate during the grazing season, creep grazing of calf and double-suckling on liveweight changes and milk production of cows. Ir. J. agric. Res. *10*:287.

DRENNAN, M.J. (1974). Effect of plane of nutrition for beef cows during late pregnancy on subsequent cow and calf performance. Proc. Brit. Soc. Anim. Prod. (New Series) *34*:88 (Abstr.).

DREWRY, K.J., BROWN, C.J. and HONEA, R.S. (1959). Relationships among factors associated with mothering ability of beef cattle. J. Anim. Sci. *18*:938.

DUNN, T.G., INGALLS, J.E., ZIMMERMAN, D.R. and WILTBANK, J.N. (1969). Reproductive performance of 2-year-old Hereford and Angus heifers as influenced by pre- and post-calving energy intake. J. Anim. Sci. *29*:719.

DUNN, T.G., WILTBANK, J.N., ZIMMERMAN, D.R. and INGALLS, J.E. (1965). Dam's energy intake, milk production and calf gains. J. Anim. Sci. *24*:586 (Abstr.).

ECONOMIDES, S.J. (1972). The effects of undernutrition on lactating beef cows. Ph.D. Thesis, Univ. Aberdeen.

ECONOMIDES, S.J., MILLER, T.B., TOPPS, J.H., GELMAN, A.L. and KEITH, D.G. (1971). An assessment of the nutritional status of the lactating beef cow. Proc. Nutr. Soc. *30*:36 (Abstr.).

ECONOMIDES, S.J., MILLER, T.B., TOPPS, J.H., GELMAN, A.L. and KEITH, D.G. (1973). A preliminary study of the milk production, bodyweight changes and some blood characteristics of underfed beef cows. Br. Vet. J. *129*:63.

ELLIOT, G.M. (1959a). The direct effect of milk accumulation in the udder of the dairy cow upon milk secretion rate. Dairy Sci. Abstr. *21*:435.

ELLIOT, G.M. (1959b). The effect on milk yield of the length of milking intervals used in twice a day milking, twice and three times a day milking and incomplete milking. Dairy Sci. Abstr. *21*:481.

ELLIOT, G.M. (1961). The effect on milk yield of three times a day milking and of increasing the level of residual milk. J. Dairy Res. *28*:209.

ERB, R.E. (1962). Relationship between size of cow and relative efficiency of milk energy production. J. Dairy Sci. *45*:699.

EVANS, R.M. (1960). Rations for Livestock. Ministry of Agriculture, Fisheries and Food. Bull. No. 48. H.M.S.O., London.

EVERETT, R.W. and WADELL, L.H. (1970). Relationship between milking intervals and individual milk weights. J. Dairy Sci. *53*:548.

EVERITT, G.C. and PHILLIPS, D.S.M. (1971). Calf rearing by multiple suckling and the effects on lactation performance of the cows. Proc. N.Z. Soc. Anim. Prod. *31*:22.

EWBANK, R. (1969). The frequency and duration of the nursing periods in single suckled Hereford beef cows. Br. Vet. J. *2*:IX.

FERTILISER AND FEEDING STUFFS REGULATIONS (1973). Agric. No. 1521. pp 77 and 86. H.M.S.O., London.

FISHER, R.A. (1958). Statistical Methods for Research Workers. Oliver and Boyd, London.

FLATT, W.P., MOE, P.W., MUNSON, A.W. and COOPER, T. (1969). Energy utilisation by high-producing dairy cows. *In* Energy Metabolism of Farm Animals (ed. Blaxter, K.L.). p 235. Eur. Assoc. Anim. Prod. Oriel Press Ltd., Newcastle upon Tyne.

FOLEY, R.C., BATH, D.L., DICKINSON, F.N. and TUCKER, H.A. (1972). Dairy Cattle: Principles, Practices, Problems, Profits. Lea and Febiger, Philadelphia.

FURR, R.D. and NELSON, A.B. (1964). Effect of level of supplemental winter feed on calf weight and on milk production of fall-calving range beef cows. J. Anim. Sci. *23*:775.

GAINES, W.L., DAVIS, H.P. and MORGAN, R.F. (1947). Within cow regression of milk energy yield on age and liveweight. J. Dairy Sci. *30*:273.

GALUKANDE, E.B., MAHADEVAN, P. and BLACK, J.G. (1962). Milk production in East African zebu cattle. Anim. Prod. *4*:329.

GIFFORD, W. (1949). Importance of high milk production in beef cows found overestimated. J. Anim. Sci. *8*:605 (Abstr.).

GIFFORD, W. (1953). Records of performance of beef cattle in breeding herds: Milk production of dams and growth of calves. Ark. Agric. Exp. Sta. Bull. No. 531.

GILLOOLY, J.E., WILSON, L.L., THOMSON, C.E., RUGH, M.C., LONG, T.A. and PURDY, H.R. (1967). Effects of energy level and cow size on milk yield and calf gain. J. Anim. Sci. *26*:1468 (Abstr.)

GLEDDIE, V.M. and BERG, R.T. (1968). Milk production in range beef cows and its relationship to calf gains. Can. J. Anim. Sci. *48*:323.

GRAF, G.C., ELLIOT, C.S. and RANDY, H.A. (1970). Effects of continuous infusion of oxytocin on milk secretion and composition. J. Dairy Sci. *53*:662 (Abstr.).

GUNN, R.G., DONEY, J.M. and RUSSEL, A.J.F. (1969). Fertility in Scottish Blackface ewes as influenced by nutrition and body condition at mating. J. agric. Sci., Camb. *73*:289.

HALL, J.S. and BUCKET, M. (1969). Milk Quality. Advis. Bull. No. 7. H.M.S.O., Edinburgh.

HAMMOND, J., MASON, I.L. and ROBINSON, T.J. (1971). Hammond's Farm Animals. 4th edit. Edward Arnold Ltd. London.

HANSSON, A. (1956). Influence of rearing intensity on body development and milk production. Proc. Brit. Soc. Anim. Prod. 1956:51.

HEYNS, H. (1960). The growth of the Afrikaner calf in relation to the production and composition of the milk of its dam. S. Afr. J. agric. Sci. *3*:349 and 517.

HIGHT, G.K. (1966). The effects of undernutrition in late pregnancy on beef cattle production. N.Z. J. agric. Res. *9*:479.

HIGHT, G.K. (1968). Plane of nutrition effects in late pregnancy and during lactation on beef cows and their calves to weaning. N.Z. J. agric. Res. *11*:71.

HODGSON, J. (1971). The development of solid food intake in calves. 5. The relationship between liquid and solid food intake. Anim. Prod. *13*:593.

HOHENBOKEN, W.D., HAUSER, E.R., CHAPMAN, A.B. and CUNDIFF, L.V. (1972). Partitioning lactation T.D.N. consumption in Herefords between maintenance, gain and milk production. J. Anim. Sci. *34*:152.

HOLMES, W. (1973). Size of animal in relation to productivity. Nutritional aspects. Proc. Brit. Soc. Anim. Prod. (New Series) *2*:27.

HOWES, J.R., HENTGES, J.F., WARNICK, A.C. and CUNHA, T.J. (1958). Yield and composition of milk from Brahman and Hereford heifers fed two levels of protein, and the correlated calf growth. J. Anim. Sci. *17*:1222 (Abstr.).

HUGHES, J.G. (1976). Short-term variation in animal live weight and reduction of its effect on weighing. Anim. Br. Abstr. *44*:111.

HUME, I.D. and PURSER, D.B. (1975). Ruminal and post-ruminal protein digestion in sheep fed on subterranean clover harvested at four stages of maturity. Aust. J. agric. Res. *26*:199.

HUTCHISON, H.G., WOOF, R., MABON, R.M., SALEHE, I. and ROBB, J.M. (1962). A study of the habits of zebu cattle in Tanganyika. J. agric. Sci., Camb. *59*:301.

ǏOTSOV, S. (1956). Relationship between milk secretion and the composition of blood and milk in dairy cows. Izv. Inst. eksp. vet. Med. *5*:123.

JEFFERY, H.B. and BERG, R.T. (1971). Evaluation of milk variables as measures of milk effect on preweaning performance of beef cattle. Can. J. Anim. Sci. *51*:21.

JEFFERY, H.B., BERG, R.T. and HARDIN, R.T. (1971a). Factors influencing milk yield of beef cattle. Can. J. Anim. Sci. *51*:551.

JEFFERY, H.B., BERG, R.T. and HARDIN, R.T. (1971b). Factors affecting preweaning performance in beef cattle. Can. J. Anim. Sci. *51*:561.

JOHANSSON, I. (1952). Studies on udder evacuation in dairy cows. II The amount and composition of the residual milk after normal milkings. Acta. Agric. scand. *2*:82.

JOHANSSON, I. (1964). The relation between body size, conformation and milk yield in dairy cattle. Anim. Breed. Abstr. *32*:421.

JOHNSTONE-WALLACE, D.B. and KENNEDY, K. (1944). Grazing management practices and their relationship to the behaviour and grazing habits of cattle. J. agric. Sci., Camb. *34*:190.

JOUBERT, D.M. (1954). Influence of winter nutritional depression on the growth, reproduction and production of cattle. J. agric. Sci., Camb. *44*:5.

JOUBERT, D.M. (1963). Puberty in female farm animals. Anim. Breed. Abstr. *31*:295.

KAIL, J., AMIR, S. and BLEIBERG, M. (1968). Influence of the level of crude fibre in the ration of dairy cows on conception. J. Dairy Sci. *51*:954 (Abstr.).

KING, J.O.L. (1968). The relationship between the conception rate and changes in bodyweight, yield and SNF content of milk in dairy cows. Vet. Rec. *83*:492.

KING, J.O.L. (1971). Nutrition and fertility in dairy cows. Vet. Rec. *89*:320.

KLEIBER, M. (1965). Metabolic body size. *In* Energy Metabolism (ed. Blaxter, K.L.) E.A.A.P. Publication, No. 11, p. 427.

KLETT, R.H., MASON, T.R. and RIGGS, J.K. (1965). Milk production of beef cows and its relationship to the weaning weight of their calves. J. Anim. Sci. *24*:586 (Abstr.).

KNAPP, B.Jr. and BLACK, W.H. (1941). Factors influencing rate of gain of beef calves during suckling period. J. agric. Res. *63*:249.

KOCH, R.M., GREGORY, K.E., INGALLS, J.E. and ARTHAUD, R.L. (1959). Evaluating the influence of sex on birth weight and preweaning gain in beef cattle. J. Anim. Sci. *18*:738.

KROPP, J.R., STEPHENS, D.F., HOLLOWAY, J.W., WHITEMAN, J.V., KNORI, L. and TOTUSEK, R. (1973). Performance on range and in drylot of two-year-old Hereford, Hereford x Holstein and Holstein females as influenced by level of winter supplementation. J. Anim. Sci. *37*:1222.

LAM, C.F., LAMOND, D.R., HILL, J.R. and LOADHOLT, C.B. (1969). Three techniques for estimating milk production of beef cows. J. Anim. Sci. *29*:109 (Abstr.).

LAMOND, D.R. (1970). The influence of undernutrition on reproduction in the cow. Anim. Breed. Abstr. *38*:359.

LAMOND, D.R., HOLMES, J.H.G. and HAYDOCK, K.P. (1969). Estimation of yield and composition of milk produced by grazing beef cows. J. Anim. Sci. *29*:606.

LAMPKIN, G.H. and LAMPKIN, K. (1960). Studies on the production of beef from zebu cattle in East Africa. II Milk production in suckled cows and its effect on calf growth. J. agric. Sci., Camb. *55*:233.

LANE, G.T., DILL, C.W., ARMSTRONG, B.C. and SWITZER, L.A. (1970). Influence of repeated oxytocin injections on the composition of dairy cow's milk. J. Dairy Sci. *53*:427.

LARGE, R.V. (1965). The effect of concentration of milk substitute on the performance of artificially-reared lambs. Anim. Prod. *13*:325.

Le DU, Y.L.P. and BAKER, R.D. (1974). The effect of level of milk consumption on the herbage intake and live-weight change of calves. Proc. Brit. Soc. Anim. Prod. (New Series) *3*:101 (Abstr.)

Le DU, Y.L.P. and BAKER, R.D. (1975). The effect of level of milk intake and length of milk feeding period upon the herbage intake and live-weight change of calves. Proc. Brit. Soc. Anim. Prod. (New Series) *4*:108 (Abstr.).

LING, E.R., KON, S.K. and PORTER, J.W.G. (1961). *In* Milk: the Mammary Gland and its secretion (ed. Kon, S.K. and Cowie, A.T.) Vol. 2, p 236. Academic Press, New York and London.

LOWMAN, B.G. and EDWARDS, R.A. (1974). Personal communication.

LOWMAN, B.G., SCOTT, N.A. and SOMERVILLE, S. (1973). Condition scoring of cattle. East of Scotland College of Agriculture. Bull. No. 6.

LOWMAN, B.G. and SOMERVILLE, S. (1976). *In* Proc. Meat and Livestock Commission Nat. Beef Conf., Harrogate. Nov. 1976. In press.

LUCAS, H.L. (1960). Critical features of good dairy feeding experiments. J. Dairy Sci. *43*:193.

MacFARLANE, W.V. and HOWARD, B. (1970). The physiological ecology of water. *In* The Physiology of Digestion and Metabolism in Ruminants (ed. Phillipson, A.T.) p 362. Oriel Press, Aberdeen.

MacFARLANE, W.V., HOWARD, B. and SIEBERT, B.D. (1969). Tritiated water in the measurement of milk intake and tissue growth of ruminants in the field. Nature, Lond. *221*:578.

MASON, I.L. (1971). Comparative beef performance of the large cattle breeds of Western Europe. Anim. Breed. Abstr. *39*:1.

McCANCE, I. (1959). The determination of milk yield in the Merino ewe. Aust. J. agric. Res. *10*:839.

McCARRICK, R.B. and CROWLEY, J.P. (1967). An Foras Talúntais. Anim. Prod. Div. Ann. Rep. p 16.

McDONALD, P., EDWARDS, R.A. and GREENHALGH, J.F.D. (1973). Animal Nutrition. Longman Group Ltd., London.

McGINTY, D.D. and FRERICHS, W.G. (1971). Milk yields and calf performance from crossbred and Hereford cows. J. Anim. Sci. *33*:210.

McKAY, W.M. (1957). Some problems of colonial animal husbandry. 2. Brit. Vet. J. *113*:316.

MEAT AND LIVESTOCK COMMISSION (1973). Breed comparisons in suckler herds. Beef Improvement Services, November 1973. Meat and Livestock Commission, Bletchley, Bucks.

MEAT AND LIVESTOCK COMMISSION (1975). Results for suckler herds 1974. Records Rep. No. 35. Meat and Livestock Commission, Bletchley, Bucks.

MELTON, A.A., RIGGS, J.K., NELSON, L.A. and CARTWRIGHT, T.C. (1967). Milk production, composition and calf gains of Angus, Charolais and Hereford cows. J. Anim. Sci. *26*:804.

MIELKE, H. (1968). Investigations into the dose-dependent effect of oxytocin on the secretion and composition of cow's milk. I Effect on milk secretion rate. Arch. exp. Vet. Med. *22*:535.

MILLER, T.B., ECONOMIDES, S.J., TRIGG, T.E. and TOPPS, J.H. (1974). Milk production of suckler cows and calf performance in relation to feeding in late pregnancy and breed of calf. Proc. Brit. Soc. Anim. Prod. (New Series) *3*:87 (Abstr.).

MILK MARKETING BOARD (1966). Rep. Breed. Prod. Org. Milk Mktg. Bd. 1965-66 p 90.

MILK MARKETING BOARD (1976). U.K. Dairy Facts and Figures. Milk Mktg. Bd.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1975). Tables of Feed Composition and Energy Allowances for Ruminants. Ministry of Agriculture, Fisheries and Food (Publications), Pinner, Middlesex.

MOE, P.W., TYRRELL, H.F. and FLATT, W.P. (1971). Energetics of body tissue mobilisation. J. Dairy Sci. *54*:548.

MORAG, M. (1968). A galactopoeitic effect from oxytocin administered between milkings in the cow. Annls. Biol. Anim. Biochem. Biophys. *8*:27.

MORAG, M. (1973). Two and three times a day milking of cows. I The use of the half-udder technique in milking frequency studies. Acta. Agric. Scandinavica *23*:252.

MORGAN, D.E. (1972). *In* Ann. Rep. of ADAS Sci. Arm 1972. p 98.

MUNRO, J. and INKSON, R.H.E. (1957). The effects of different suckling frequencies on the quantity of milk consumed by young lambs. J. agric. Sci., Camb. *49*:169.

NATIONAL RESEARCH COUNCIL (1963). Nutrient Requirements of Domestic Animals. 4. Nutrient requirements of beef cattle. Nat. Acad. Sci. Nat. Res. Council Pub., Washington D.C.

NATIONAL RESEARCH COUNCIL (1970). Nutrient Requirements of Domestic Animals. Nutrient requirements of beef cattle. Nat. Acad. Sci. Nat. Res. Council Pub., Washington D.C.

NEVILLE, W.E.Jr. (1962). Influence of dam's milk production and other factors on 120- and 140-day weight of Hereford calves. J. Anim. Sci. *21*:315.

OWEN, J.B. (1957). A study of the lactation and growth of hill sheep in their native environment and under lowland conditions. J. agric. Sci., Camb. *48*:387.

PEARSON, L., WAUGH, R.K., SALAZAR, B., BOTERO, F.M. and ACOSTA, O. (1968). Milking performance of Blanco Orejinegro and Jersey crossbred cattle. J. agric. Sci., Camb. *70*:65.

PEART, J.N. (1967). The effect of different levels of nutrition during late pregnancy on the subsequent milk production of Blackface ewes and on the growth of their lambs. J. agric. Sci., Camb. *68*:365.

PETERSON, R.A. and WOOLFOLK, E.J. (1955). Cited by Ewbank, R. (1969). Br. Vet. J. *2*:IX.

PETTYJOHN, J.D., EVERETT, J.P.Jr. and MOCHRIE, R.D. (1963). Response of dairy calves to milk replacer fed at various concentrations. J. Dairy Sci. *46*:710.

PLUM, M. and HARRIS, L. (1971). Holstein cows and calves under beef cattle management. J. Dairy Sci. *54*:1086.

POPE, L.S., SMITHSON, L., STEPHENS, D.F., PINNEY, D.O. and VALASCO, M. (1963). Factors affecting milk production of range beef cows. Oklahoma State Univ. 37th Ann. Livestock Feeders Day. Misc. Pub. 70.

POWELL, T.L. (1974). Feeding levels for single suckler cows in late pregnancy and early lactation. Proc. Brit. Soc. Anim. Prod. (New Series) *3*:87 (Abstr.).

PRESTON. T.R. and WILLIS, M.B. (1974). Intensive Beef Production. Permagon Press Ltd., Oxford.

REID, J.T. (1960). Cited by Tudor, G.D. (1972). Aust. J. agric. Res. *23*:389.

REID, J.T., LOOSLI, J.K., TRIMBERGER, G.W., TURK, K.L., ASDELL, S.A. and SMITH, S.E. (1964). Causes and prevention of reproductive failure in dairy cattle. 4. Effect of plane of nutrition during early life on growth, reproduction, production, health and longevity of Holstein cows. Cornell Univ. Agric. Exp. Sta. Bull. No. 987.

RENBARGER, R.E., SMITHSON, J.J., STEPHENS, D.F. and POPE, L.S. (1964). Effect of nutrition before and after calving on performance of beef heifers. J. Anim. Sci. *23*:293.

RESEARCH INVESTIGATIONS AND FIELD TRIALS (1970-71). North of Scotland College of Agric. Pub.

RESEARCH INVESTIGATIONS AND FIELD TRIALS (1972-73). North of Scotland College of Agric. Pub.

REYNOLDS, W.L., De ROUEN, T.M. and MEYERHOEFFER, D.C. (1967). Milk production of Angus, Brahman and zebu cross cows. J. Anim. Sci. *26*:206 (Abstr.).

ROBERTSON, A. (1973). Body size and efficiency. Proc. Brit. Soc. Anim. Prod. (New Series) *2*:15.

ROBINSON, J.J., FOSTER, W.H. and FORBES, T.J. (1968). An assessment of the variation in milk yield of ewes determined by the lamb-suckling technique. J. agric. Sci., Camb. *70*:187.

ROBINSON, J.J., FOSTER, W.H. and FORBES, T.J. (1969). The estimation of the milk yield of ewes from body weight data on the suckling lamb. J. agric. Sci., Camb. *72*:103.

ROOK, J.A.F. (1961). Variations in the chemical composition of the milk of the cow. Dairy Sci. Abstr. *24*:251 and 303.

ROY, J.H.B. (1970). The Calf. Vol. 2. Nutrition and Health. Iliffe Books, London.

ROY, J.H.B., SHILLAM, K.W.G., HAWKINS, G.M. and LANG, J.M. (1958). The milk requirements of the newborn calf. Br. J. Nutr. *12*:123.

RUTLEDGE, J.J., ROBISON, O.W. and LEGATES, J.E. (1970). Influence of milk yield and other factors on 205-day weight of beef calves. J. Anim. Sci. *31*:167 (Abstr.).

RUTLEDGE, J.J., ROBISON, O.W., AHLSCHWEDE, W.T. and LEGATES, J.E. (1971). Milk yield and its influence on 205-day weight of beef calves. J. Anim. Sci. *33*:563.

RUTLEDGE, J.J., ROBISON, O.W., AHLSCHWEDE, W.T. and LEGATES, J.E. (1972). Estimating the milk yield of beef cows. J. Anim. Sci. *34*:9.

SAIDUDDIN, S., RIESEN, J.W., GRAVES, W.E., TYLER, W.J. and CASIDA, L.E. (1967). Effect of suckling on the interval from parturition to first oestrus in dairy cows. J. Anim. Sci. *26*:950 (Abstr.).

SCHAKE, L.M. and RIGGS, J.K. (1969). Activities of lactating beef cows in confinement. J. Anim. Sci. *28*:568.

SCHAKE, L.M., RIGGS, J.K., McGINTY, D.D. and MARION, P.T. (1966). Effects of feed intake levels upon yield and composition of milk from confined beef cows. J. Anim. Sci. *25*:248 (Abstr.).

SCHWULST, F.J. (1969). Heterosis effects on milk production of beef cows. Diss. Abstr. *30*:7.

SCHWULST, F.J., SUMPTION, L.J., SWIGER, L.A. and ARTHAUD, V.H. (1966). Use of oxytocin for estimating milk production of beef cows. J. Anim. Sci. *25*:1045.

SERWANJA, J.C., WELCH, J.A. and KIDDER, H.E. (1969). Dam's milk yield and composition on growth of Angus calves. J. Anim. Sci. *29*:198 (Abstr.).

SOMERVILLE, S.H., LOWMAN, B.G. and EDWARDS, R.A. (1976). A preliminary study of the effect of nutrition during lactation on the performance of autumn-calving beef cows with emphasis on the method of milking employed. (see Appendix 2).

SPEDDING, C.E.W. (1962). Modern trends in animal health and husbandry: The agricultural ecology of sheep grazing. Brit. Vet. J. *118*:461.

SPRINGHALL, P.H. (1968). Water content and water turnover in cattle. Aust. J. agric. Res. *19*:129.

STARKE, J.S. (1953). Studies of the inheritance of milk production in sheep. S. Afr. J. Sci. *49*:245.

STEEL, R.G.D. and TORRIE, J.H. (1960). Principles and Procedures of Statistics. McGraw-Hill Book Co. Inc., London.

STEWART, A.G.D., RUNCIE, K.V., LOWMAN, B.G., ROWBOTTOM, J.D. and SMITH, R.S. (1972). Suckled Calf Production. East of Scotland College of Agric. Bull. No. 4.

SUMPTION, L.J., BRINKS, J.S., CARTWRIGHT, T.C., DEARSBORN, D. and KOGER, M. (1970). Ingredients for cattle breeding - a look at North America's Seedstock. Better Beef Business. *11*:25.

SVENDSEN, P. (1974). An Introduction to Animal Physiology. Medical and Technical Publishing Co. Ltd., Lancaster.

SWANSON, E.W. (1960). Effect of rapid growth with fattening of dairy heifers on their lactational ability. J. Dairy Sci. *43*:377.

TAYLOR, St.C.S. (1973). Genetic differences in milk production in relation to mature body weight. Proc. Brit. Soc. Anim. Prod. (New Series) *2*:27.

TECHNICAL BULLETIN, Number 33 (1975). Energy allowances and feeding systems for cattle. H.M.S.O., London.

TODD, J.C., RIGGS, J.K. and SMITH, J.C. (1968). Milk yields and calf weights from Brahman, Hereford and crossbred cows in the Gulf Coast prairie. J. Anim. Sci. *27*:286 (Abstr.).

TOPPS, J.H., ECONOMIDES, S.J. and MILLER, T.B. (1974). Milk consumption and growth of suckled calves. Proc. Brit. Soc. Anim. Prod. (New Series) *3*:101 (Abstr.).

TOTUSEK, R., ARNETT, D.W., HOLLAND, G.L. and WHITEMAN, J.V. (1973). Relation of estimation method, sampling interval and milk composition to milk yield of beef cows and calf gain. J. Anim. Sci. *37*:153.

TREACHER, T.T. (1967). Effects of nutrition on milk production in the ewe. Ph.D. Thesis, Univ. Reading.

TUDOR, G.D. (1972). The effect of pre- and post-natal nutrition on the growth of beef cattle. I. The effect of nutrition and parity of the dam on calf birth weight. Aust. J. agric. Res. *23*:389.

TURNER, H.G. (1955). Changes in capacity of the udder of the dairy cow during the course of lactation. Aust. J. agric. Res. *6*:145.

TYRREL, H.F. and REID, J.T. (1965). Prediction of the energy value of cow's milk. J. Dairy Sci. *48*:803.

VALITOK, I.G. (1970). Factors controlling milk secretion in the udder. Dokl. uses. Akad. selskokhoz. Nauk. *10*:26.

WAITE, R. (1961). A note on a method of overcoming the effect of udder disease or injury in experiments involving milk yield and composition. J. Dairy Res. *28*:75.

WAITE, R., WHITE, J.C.D. and ROBERTSON, A. (1956). Variations in the chemical composition of milk with particular reference to the solids-not-fat. I The effect of stage of lactation, season of year and age of cow. J. Dairy Res. *23*:65.

WALKER, D.E.K. (1962). Suckling and grazing behaviour of beef heifers and calves. N.Z. J. agric. Res. *5*:331.

WALKER, D.E.K. and POS, H.G. (1963). Milk production of beef heifers. N.Z. J. Agric. *107*:277.

WALLACE, L.R. (1948). The growth of lambs before and after birth in relation to the level of nutrition. J. agric. Sci., Camb. *38*:93.

WALSH, J.P. (1974). Milk secretion in machine-milked and suckled cows. Ir. J. agric. Res. *13*:77.

WATSON, S.J. and NASH, M.J. (1960). The Conservation of Grass and Forage Crops. Oliver and Boyd Ltd., Edinburgh.

WHEELOCK, J.V. and DODD, F.H. (1969). Non-nutritional factors affecting milk yield in dairy cattle. J. Dairy Res. *36*:479.

WHEELOCK, J.V., ROOK, J.A.F. and DODD, F.H. (1965a). The effect of incomplete milking, or of an extended milking interval on the yield and composition of cow's milk. J. Dairy Res. *32*:237.

WHEELOCK, J.V., ROOK, J.A.F. and DODD, F.H. (1965b). The effect of intravenous injections of oxytocin during milking and the removal of residual milk on the composition of cow's milk. J. Dairy Res. *32*:255.

WHITEHOUSE, K., ZARROW, A. and SHAY, H. (1945). Rapid method for determining crude fibre in distiller's dried grains. J. Assoc. Off. Agric. Chem. *28*:147.

WIKTORSSON, H. (1971). Studies on the effects of different levels of nutrition to dairy cows. Swedish J. agric. Res. *1*:83.

WILSON, L.L., GILLOOLY, J.E., RUGH, M.C., THOMSON, C.F. and PURDY, H.R. (1969). Effects of energy intake, cow body size and calf sex on composition and yield of milk by Angus-Holstein cows and the preweaning growth rate of their progeny. J. Anim. Sci. *28*:789.

WILSON, L.L., RUGH, M.C., STOUT, J.M., SIMPSON, M.J., VARELA-ALVAREZ, H. and PURDY, H.R. (1971). Correlations among yield and composition of milk of Angus-Holstein cows and consumption and growth rate of progeny. J. Dairy Sci. *54*:425.

WILSON, R.F., TILLEY, J.M.A. and STEEMERS, M.A. (1964). Comparison of oven drying and toluene distillation in the determination of the dry-matter content of silage. J. Sci. Fd. Agric. *15*:197.

WILTBANK, J.N., BOND, J. and WARWICK, E.J. (1965). Influence of total feed and protein intake on reproductive performance of the beef female through second calving. U.S. Dep. Agric. Tech. Bull. 1314.

WILTBANK, J.N. and COOK, A.C. (1958). The comparative reproductive performance of nursed and milked cows. J. Anim. Sci. *17*:640.

WILTBANK, J.N., COOK, A.C., DAVIS, R.E. and WARWICK, E.J. (1957). The effect of different combinations of energy and protein on the occurrence of estrus, length of the estrus period and time of conception in beef heifers. J. Anim. Sci. *16*:1100 (Abstr.).

WILTBANK, J.N., GREGORY, K.E., SWIGER, L.A., INGALLS, J.E., ROTHLISBERGER, J.A. and KOCH, R.M. (1966). Effects of heterosis on age and weight at puberty in beef heifers. J. Anim. Sci. *25*:744.

WILTBANK, J.N., KASSON, C.W. and INGALLS, J.E. (1969). Puberty in crossbred and straightbred beef heifers on two levels of feed. J. Anim. Sci. *29*:602.

WILTBANK, J.N., ROWDEN, W.N., INGALLS, J.E. and ZIMMERMAN, D.R. (1964). Influence of *post partum* energy level on reproductive performance of Hereford cows restricted in energy intake prior to calving. J. Anim. Sci. *23*:1049.

WILTBANK, J.N., ROWDEN, W.W., INGALLS, J.E., GREGORY, K.E. and KOCH, R.M. (1962). Effect of energy level on reproductive phenomena of mature Hereford cows. J. Anim. Sci. *21*:219.

WISTRAND, G.C. and RIGGS, J.K. (1966). Milk production of Santa Gertrudis cows measured by calf-nursing and machine-milking methods. J. Anim. Sci. *25*:263 (Abstr.).

WITT, H.G., WARNICK, A.C., KOGER, M. and CUNHA, T.J. (1958). The effect of level of protein intake and alfalfa meal on reproduction and gains in beef cows. J. Anim. Sci. *17*:1211 (Abstr.).

WOOD, P.D.P. (1967). Algebraic model of the lactation curve in cattle. Nature, Lond. *216*:164.

WOOD, P.D.P. (1968). Factors affecting persistency of lactation curve in cattle. Nature, Lond. *218*:894.

WOOD, P.D.P. (1969). Factors affecting the shape of the lactation curve in cattle. Anim. Prod. *11*:307.

WOOD, P.D.P. (1976). Algebraic models of the lactation curves for milk, fat and protein production with estimates of seasonal variation. Anim. Prod. *22*:35.

YATES, N.G., MacFARLANE, W.V. and ELLIS, R. (1971). The estimation of milk intake and growth of beef calves in the field using tritiated water. Aust. J. agric. Res. *22*:291.

ZIMMERMAN, D.R., CLANTON, D.C. and MATSUSHIMA, J.K. (1961). *Post partum* reproductive performance in beef heifers as affected by protein and energy intake during gestation. J. Anim. Sci. *20*:957 (Abstr.).