Managing dairy cows for optimal performance

D.E. Beever

CEDAR–ADAS (Reading), Department of Agriculture, The University of Reading, Reading RG6 6AJ, UK
d.e.beever@reading.ac.uk

Summary

Many factors affect the overall performance and hence profitability of dairying systems, with nutrition, genetics and animal environment being key determinants. This paper examines some of the issues that currently face dairying in developed countries and from this analysis some key factors are discussed in more detail. Of principal concern is that modern dairy cows have considerably greater milk yield potential than their ancestors. The rate of improvement in milk secretion has outpaced any increase in feed intake and failure of the cow to meet her nutrient requirements, especially energy, in early lactation is giving rise to considerable loss of body condition and associated reductions in reproductive competence. Current knowledge is summarised to examine possible strategies for improving feed intake, aiming to reduce the energy deficit, whilst recognising that grazed or ensiled grass are likely to make relatively small contributions to overall nutrient demands.

The transition period from late gestation to early lactation is a period of considerable change within the cow. Research is currently active in this area and current knowledge is summarised to provide management guidelines to ensure successful lactations. The paper examines the potential of an alternative breed, emphasising the greater importance of milk solids output as the milk market moves to increased processing of milk with an associated increased demand for milk fat and protein. Brief reference is also made to the role of cross breeding and some caution is offered, suggesting that this current interest may be more directed towards overcoming problems than developing cows better fitted for the purpose, be it production of liquid milk or milk solids.

Keywords: dairy cattle, energy metabolism, feed intake, transition management, dairy breeds

Introduction

The primary objective of keeping dairy cows remains the production of milk but with continuing pressure from consumers and the media, increasing demands are being placed on the dairy farmer as a producer of human food, and ultimately on the dairy cow. Evermore conscious of possible health issues associated with the consumption of animal products, the 'consumer' stridently demands consistent products with respect to hygiene standards as well as auditable production systems, and payment schemes in many countries now reward milk of low somatic cell and total bacterial numbers. Similarly through health concerns along with increased knowledge and sophistication, consumer demand for alternative milk products is increasing as reflected in marginally more than 50% of UK milk being processed, over 50% of the liquid milk market being supplied as reduced fat content, and continued reluctance to purchase butter although cream and ice cream sales are buoyant. Inevitably, these issues make the milk processor more aware of the importance of milk composition (milk fat and protein levels) to optimise product yield per unit milk processed whilst recognising that product quality (e.g. cheese) may be affected when milk of substandard composition is used.

With such issues, it is not surprising that many dairy farmers still see the production of milk and milk solids as the sole objectives of their business and base assessments of overall farm profitability on direct input costs in relation to volume of milk sold. This however is a gross oversimplification of milk production. Before producing any milk, the replacement heifer must be reared successfully to gain target weight and body condition for breeding at around 15 months of age to ensure that the animal will calve for the first time at 2 years of age. This represents an enormous overhead on the subsequent production of milk and must be covered by achieving a lifetime milk production commensurate with the animal's genetic potential. Once lactating, the first–calved heifer still has to achieve mature breed size and lactational performance with respect to milk volume and composition must be balanced against the achievement of this growth whilst ensuring a successful pregnancy if overall lifetime productivity is to be uninterrupted. Continuation of the

365 d calving interval dogma necessitates that all newly calved cows become pregnant by day 90 of lactation. Most cows do not recommence cyclity until at least lactation day 20–25, whilst farmers generally impose a voluntary waiting period of 60 d. This provides an optimal breeding period of only 30 d, a remarkably short period in which to establish a successful pregnancy.

A further concern with the modern dairy cow is the control of body condition. Immediately post–calving, feed intake increases at a slower rate than milk yield, the outcome being that total nutrient supply, particularly energy, is not sufficient to meet the cow's demands to support milk production for several weeks into the lactation. The cow responds by mobilising body tissue with commensurate losses of body condition which in turn may affect the cow's subsequent fertility whilst heightening public concern over animal welfare. Periods of high body energy loss are invariably associated with compromised milk composition and may predispose the cow to nutritional disorders which can affect overall health, well–being and longer term productivity.

Overriding all of these issues, the modern dairy cow is considerably different from those that existed only one or two decades ago. Through rigorous genetic selection, especially in the Holstein breed but now being pursued in other breeds, milk yield expectations are much higher as breeders and farmers have focused heavily on this as a main selection criterion, seen by many to be the best approach to improve financial returns. Such changes in emphasis however have not occurred without some costs. Average cow longevity remains relatively short, failure of animals to rebreed is now a major issue, and lameness and mastitis are increasing; excessive loss of body condition has already been cited. Many factors contribute to the overall productivity of dairy cows and introduction of improved genetics is of little value unless accompanied by appropriate management changes. In this respect greater attention must be given to matching cow and management type, whilst profitability from dairy cows will only be optimised through a fuller recognition of all factors involved during the cow's lifetime, rather than being driven by milk yield and improved genetics alone.

Consideration of many of these aspects is beyond the remit of this paper but based on some of the issues currently facing the Australian dairy industry, several key areas have been identified and will be considered in more detail. Recent efforts at the CEDAR laboratory have focussed on energy metabolism in high yielding cows and this paper will summarise current findings, focussing on the partitioning of energy between milk and body tissue synthesis which by implication can result in significant loss of body condition in early lactation. Having established the importance of achieving high levels of energy intake, the paper will attempt to examine issues associated with the inclusion of forages in the ration and assess the role of grazed grass in the ration of high yielding cows. The paper will then focus on some of the changes which occur during the peri–parturient period by reviewing current information on transition management. This is an important period within the annual life cycle of the cow and illustrative of the important physiological and metabolic changes which occur within the animal, thus allowing management systems to be developed to meet these additional demands. Finally the paper will briefly consider the role of alternative breeds, including the current interest being shown in cross breeding, conscious that continued 'Holsteinisation' of the world's dairy cow population may not represent the ideal route for efficient milk production for all situations.

Energy metabolism

Provision of sufficient energy to meet all production demands remains the principal driving force behind achieving satisfactory yields of milk and milk solids, and represents the major challenge to the satisfactory feeding of the modern Holstein cow. Calorimetric evidence presented by Sutton *et al.* (1991) for modest yielding Friesians and recent data for higher yielding Holsteins (Beever *et al.* 2001, 2002) provide a useful comparison of the consequences of increased genetic selection for milk production on the energy demands of the modern dairy cow. With daily feed dry matter (DM) intake and milk yields of 21 and 33 kg respectively, Friesians consumed 250 MJ/d metabolizable energy (ME) and partitioned 105 and 130 MJ ME/d to milk and heat respectively, providing a residual sum (15 MJ/d), equivalent to 0.75 kg/d body tissue repletion. In contrast, Holsteins eating 26 kg feed DM/d and producing 52 kg milk/d consumed an additional 90 MJ gross energy/d, equivalent to an extra 45 MJ ME. In support of a higher milk output, 150 MJ ME/d was partitioned to milk with 160 MJ ME/d accounted for as heat, due to increased costs associated with higher levels of milk production and higher maintenance costs (Offer *et al.* 2002) given Holsteins tend to be larger than Friesians. In this respect, recent research in the UK (Kebreab *et al.* 2003) examined almost 700 individual calorimetric data sets for dairy cows and established that maintenance energy costs as proposed by AFRC (1993) were too low and should be increased by approximately 20 MJ/d for Holsteins. With an estimated energy output as heat and milk of 310 MJ/d there was a resultant loss of body energy of 15 MJ/d, or 0.75 kg body tissue/d. What is most striking is that the difference in body tissue repletion in Friesians and body tissue loss in Holsteins was relatively small (± 15 MJ/d), yet such differences can have major implications for overall lactational performance and is of major concern with respect to milk composition, cow fertility and reduced cow longevity.

Several studies in this laboratory have reported excessive body tissue loss in the modern dairy cow when lactational demands are high. What was most interesting about these data was not only the depth of this energy loss, particularly in the immediate post calving period, but also its duration. Calorimetric studies showed body energy loss continued up to week 14 of lactation, an observation subsequently ratified by examination of body condition score change from calving to week 24 of lactation. Consistently it has been shown that body energy loss at week 6 of lactation may be as much as 40 MJ/d. Furthermore, if the data of Sutter and Beever (2000) which examined energy metabolism for each of the first 8 weeks of lactation, albeit with lower yielding cows, are extended to higher yielding Holsteins it can be estimated that body energy loss in high yielding cows may approach or possibly exceed 60 MJ/d in the immediate post–calving period. This equates to a daily loss of 3 kg body tissue, presumed to be mainly as fat. Interestingly, Gibb *et al.* (1992) who examined body compositional changes in modest yielding Friesians by serial slaughtering between calving and week 29 of lactation noted a body fat loss of 37 kg by lactation week 8. Of this, 24 kg body fat was lost within the first 2 weeks of lactation, equivalent to 1.73 kg fat/d. At the same time, loss of body protein by week 8 of lactation amounted to only 5 kg, with losses during the first 2 weeks being less than 3 kg. Based on the observation by Gibb *et al.* (1992) that body fat represents the major loss of body energy during early lactation, Beever *et al.* (2001) used calorimetric data to provide estimates of body fat loss in relation to stage of lactation. By lactation week 10, a body fat loss of 60 kg was estimated. The next 10 weeks was a period of little overall change (+ 5 kg), with cessation of body tissue mobilisation by week 14, followed by relatively small gains. Extending this analysis for a further 10 weeks, body fat gain approximated to 28 kg, indicating significant body repletion, presumably due to reducing lactational demands whilst levels of ME intake were still relatively high. Of greater interest, however, is that by lactation week 30 these cows still had a net body fat loss of more than 25 kg. Assuming some of these cows would be dried off at lactation day 305 provides a target for total body fat repletion between lactation week 30 and drying off of 0.3 kg/d, which must not be confused with body weight gain, which includes changes in gut fill and the developing foetus. Whether or not this rate of tissue gain can be achieved is open to conjecture, especially when feed intake will be declining, whilst many of these cows are still capable of producing significant quantities of milk. Evidence from geneticists at Scottish Agricultural Colleges who scored the body condition of high and low genetic merit cows over their first three lactations suggests that full body condition score repletion is not always achieved and represents an accumulating overhead as cows move to subsequent lactations (Coffey *et al*. 2002).

To examine ways of manipulating nutrient partition during early lactation, Beever *et al*. (2002) considered feeding either increased dietary levels of starch or protein to high yielding cows for the first 20 weeks of lactation. Against a control total mixed ration containing 17% protein and 23% starch, protein or starch levels were increased to 20% and 28% respectively. A lactational study showed no overall effects between high protein and high starch rations in terms of feed intake, milk yield or milk protein content, but the high protein ration had significantly higher milk fat contents and a 14% improvement in milk fat yield. On the basis of calorimetric estimates of dietary ME contents, cows fed high protein were estimated to have a mean body energy loss during the first 20 weeks of lactation of 15 MJ/d compared with 5 MJ/d for cows fed high starch. Whilst this difference may appear relatively small, over 140 d it would amount to an increased loss of body fat of 35 kg for cows fed the high protein compared with high starch ration. Parallel calorimetric data with similar cows fed the same rations confirmed these effects. Measurements at 6 week intervals over the first 24 weeks of lactation indicated a milk yield response of 5 kg/d for high protein cows (51 vs 46 kg/d), more in line with normal expectations when feeding additional dietary protein. Milk fat content was unaffected but a substantial improvement in milk protein content was noted on the high starch ration (31.2 vs 29.0 g/kg). Overall production of milk protein as well as milk fat was however greater for high protein, equivalent to daily increases of 0.10 and 0.23 kg respectively. Measurement of ME intake showed no effect due to ration type (mean 284 MJ/d) from which it is concluded that the additional energy to support the increased output of milk solids (as expected milk lactose output was also increased on the high protein ration) was associated with increased mobilisation of body tissue. Cows fed high starch lost on average 0.4 MJ energy/d from calving to lactation week 24 while those fed high protein mobilised 12.6 MJ/d over the same period. Of greatest interest however was the extent of body tissue energy mobilisation measured at week 6 of lactation. Whilst high starch cows lost 12.1 MJ/d, those fed high protein mobilised 38 MJ/d. Similar responses to increased protein feeding during early lactation have been reported, albeit with lower yielding cows (Ørskov *et al.* 1987) and suggest that whilst high protein feeding can be justified in relation to immediate lactational effects, when longer term effects are considered, namely control of body condition during early lactation, it may not be the most appropriate strategy for achieving the collective aim of high milk solids output and control over body condition score loss.

Feed intake

Whilst there have been only limited studies to examine feed DM intake in high yielding cows, Clarke and Davies (1980) reported a DM intake of 38 g/kg liveweight for cows yielding almost 40 kg milk/d whilst Chase (1993) suggested a level in excess of 40 g/kg was required for cows producing more than 10 000 kg milk per 305 day lactation. Of equal importance is the level of DM intake achieved during the first weeks after calving. Studies by Hattan *et al.* (2001) indicated week

1 and 2 intakes equivalent to 0.76 of week 5 intake in high yielding cows, with a comparable value of 0.71 for lower yielding cows. In contrast Kertz *et al.* (1991) reported a value of 0.83 whilst Weiss (2001) found a value of only 0.67. Equally, Kertz *et al.* (1991) and Neilsen *et al.* (1983) reported maximum DM intake was not attained until week 8 to 15 of lactation, whilst Hattan *et al.* reported a value of 38.6 g/kg at week 6 with little evidence of any major increase thereafter. Comparable values for lower yielding cows in this study were 35.2 g/kg at week 6, declining marginally by weeks 18 and 24 (mean, 33.5 g/kg) in response to increased rates of body weight gain being noted in these cows.

Appropriate strategies to improve feed intake are available. Alterations in the forage component of the ration can have marked effects on total intake as demonstrated by Phipps *et al.* (1995) who replaced 33% on a DM basis of the grass silage component of total mixed rations with either whole crop wheat silage, brewers grains, fodder beet or maize silage; in each case they noted significant improvements in total feed DM intake with commensurate improvements in milk yield, often with associated improvements in milk composition, especially milk protein. Whilst the studies of Phipps *et al.* (1995) were not designed to determine the mechanisms involved it is generally concluded that inclusion of other forages will alter the consistency of rumen contents, and in particular the physical characteristics of the digesta raft which in turn is believed to improve rumen function and promote rumination. The impact of feeding increased starch rather than protein in relation to the control of body condition score has already been discussed, whilst increasing the fat content of the ration appears to be a relatively easy option for increasing total ME intakes. However, this strategy does not always result in increased tissue energy repletion, with evidence that such diets may promote milk yield and thus exacerbate rather than alleviate the problem of compromised energy intake. Problems of feeding grass silage to high yielding cows have also been recognised and in the UK it is becoming increasingly common practice to remove all of the grass silage from high specification rations designed for high yielding cows. The study by Beever *et al.* (2002) provided some insight to this issue. Using high genetic merit multiparous cows, two experimental objectives were examined. Based on a ration of similar composition to those used previously for high yielding cows, containing 28% starch but no grass silage, the first objective was to determine the lactational response to increasing dietary starch content to 32%. In both rations, the forage component comprised of maize silage, dried lucerne and chopped grass hay but no grass silage. The second objective examined the incremental replacement of the forage component of the control ration with grass silage, whilst maintaining overall ration starch content. From calving to lactation week 20 control cows had a mean DM intake of 22.8 kg/d whilst higher starch inclusion increased feed DM intake to 24.4 kg/d. Grass silage inclusion at 20% of the total forage component was found to cause a small stimulation of feed intake compared with the control, although this difference was not statistically significant. Thereafter as an increasing proportion of the forage component was supplied as grass silage (40 and 60% respectively) the total DM intake declined to 21 kg/d, equivalent to 86% of that achieved on the increased starch ration which was more indicative of the feed intake that high yielding cows should be achieving. Such changes were associated with an overall decline in milk yield (6 kg/d) and it was concluded that grass silage inclusion in the ration of high genetic merit cows should not exceed 25% of the forage DM component or 12% of total ration DM. It was interesting to note however that milk fat content increased with increasing grass silage inclusion and overall milk fat yield was maintained whilst milk protein content was unaffected but a reduction in milk protein yield was inevitable.

Whilst comparable data for high genetic merit cows grazing grass pasture are not available, feed intake from pasture is unlikely to sustain daily milk yields above 25–27 kg. Accepting these data were obtained with modest yielding Friesians, it may be that such thresholds would be higher in genetically improved Holsteins. However it should be recognised that the rate of improvement in milk yield over the last decade in such cows has not been matched by a similar rate of increase in appetite. Cows grazing adequate pasture with daily yields of 27 kg milk of standard composition and not mobilising body tissue can be estimated to be consuming 200 MJ ME/d. Assuming genetically improved Holsteins may consume an additional 15% feed DM as grazed pasture, this increased intake of ME (+ 30 MJ/d) must be balanced against increased maintenance costs (Kebreab *et al*. 2003), whilst recognising that the energy cost of producing milk of lower constituent content, as often occurs with higher yielding cows, would be reduced. On this basis, it is concluded that grazed grass alone is unlikely to support more than 32 kg milk/d in Holsteins and achievement of this target would necessitate a fresh forage intake approaching 100 kg/d.

Such levels of milk yield are considerably below expectations for many cows and is clear evidence of the limitations imposed on cows by the necessity to consume and process such large amounts of fresh forage within any one 24 h period. Based on the energy requirements for lactation as recently recommended in the UK, the quantities of feed needed to support higher levels of milk production have been computed and are presented in Table 1. On the basis of the quantities of ME needed to support levels of milk production between 27 and 52 kg/d and known relationships between the intake of forage and concentrates (substitution rate), the data aim to determine the quantities of forage and concentrates needed to meet total energy demands for maintenance and lactation, assuming no change in body tissue mass.

Assuming optimal forage quality (12 MJ ME/kg DM and low substitution rate), estimated ME requirements for maintenance and a daily milk output of 27 kg could, on theoretical grounds, be met by consuming 17 kg DM/d as fresh forage. To sustain this level of performance both grass quality and availability must be optimised, especially when attainment of this level of forage DM intake is associated with a fresh weight intake approaching 100 kg/d. Increasing outputs of milk will require additional ME intake and even assuming a relatively low rate of forage substitution, the amount of concentrate required increases markedly to almost 10 kgDM/d whilst total forage intake was estimated to decline by only 2 kg DM/d. This resulted in an estimated total intake of feed of 25 kg DM/d with forage supplying only 60% of total nutrients, a level of consumption that can only be achieved only by using optimal feed ingredients. Maintaining the ME content of grazed grass at 12 MJ/kgDM throughout the whole season is virtually impossible and when a lower ME density (11.5 MJ/kgDM) was assumed (Option 2, Table 1) it was evident that with increasing milk yields, the contribution from grazed forage falls dramatically. The need for additional concentrates increased progressively to 13.6 kg DM/d, with forage now providing only 46% of DM intake (25.2 kg/d), and a total DM intake equivalent to 42 g DM intake/kg body weight which for high yielding Holsteins must be approaching maximum achievable level. The factors governing forage substitution rate are reasonably well understood and it is probably unwise to assume a value of only 0.2 kg/kg concentrate supplied when much higher values have been frequently reported. In the third option presented in Table 1, substitution rate was increased to 0.4 kg/kg and at this level the most serious consequences with respect to the potential contribution of grazed forage to the high yielding cow can be noted, with estimated concentrate requirement increasing to over 16 kgDM/d to meet the energy demands of cows yielding 52 kg milk/d. Meanwhile, forage consumption fell to 8.5 kg DM/d and contributed only 34% of total ration DM. Such findings question keeping such animals at pasture and expecting them to harvest their own food when at least 70% of total ME requirements are being supplied as concentrates. Furthermore, in many grazing situations, the daily concentrate allowance is often supplied only at milking. The wisdom of this practice, in which the high yielding cow is expected to consume in excess of 50% of total daily ME requirements in less than 2% of the whole day should be challenged, and may partly explain why the incidence of acidosis is increasing in such cows. Overall, it is therefore not surprising that many high yielding cows lose significant amounts of body condition whilst at pasture. However, dogma still exists in many parts of the world that grazed grass is the cheapest and most ideal feed for dairy cows, when clearly it has serious limitations and is probably the most significant reason why pasture–based high genetic merit cows have compromised lactations.

Transition issues

Whilst the practice of 'steaming up' cows before calving has long been recognised, it is only over the last decade that scientific information has begun to replace anecdotal evidence. The period from drying off to calving is recognised as important in the annual cycle of milk production, through establishment of good appetites, acceptable milk yields and composition as well as minimisation of health and fertility problems. All are crucially important if profitable systems of milk

Table 1 The effect of grazed forage quality, forage substitution rate and levels of milk production on the contributions of forage and concentrates required to meet total metabolizable energy requirements for maintenance and milk production, assuming zero body tissue change.

Forage options[A]	Milk yield kg/d	ME intake MJ/d	Grass DMI kg/d	Concs[B] DMI kg/d	Total DMI kg/d	Forage content % total
1. Optimal forage quality	27	205	17.0	0	17.0	100
	37	249	16.2	4.2	20.4	79
	47	291	15.3	8.3	23.6	65
	52	309	15.0	9.9	24.9	60
2. Reduced ME content	37	249	14.5	6.3	20.8	70
	47	291	12.4	11.4	23.8	52
	52	309	11.6	13.6	25.2	46
3. Reduced ME and intake	37	249	11.4	9.1	20.5	56
	47	291	9.3	14.2	23.5	40
	52	309	8.5	16.3	24.8	34

[A]Forage options:
1. Grass ME 12 MJ/kgDM, optimal intake (no concs) 17 kg DM/d, forage substitution 0.2 kg DMI/kg conc DM fed
2. Grass ME 11.5 MJ/kgDM, optimal intake (no concs) 17 kg DM/d, forage substitution 0.4 kg DMI/kg conc DM fed
3. Grass ME 11.5 MJ/kgDM, optimal intake (no concs) 15 kg DM/d, forage substitution 0.4 kg DMI/kg conc DM fed

[B]Concentrate feed; 13 MJ ME/kgDM

production are to be achieved and a recent report from New York State, highlighting the incidence of production related diseases during the peri–parturient period, provided confirmatory evidence. Analysis of individual cow data from a number of herds identified seven important disease states, of which five had a median incidence day within 14 days of calving (Table 2). Retained foetal membranes and metritis were the highest risks during the peri–parturient period, whilst highest overall risks were for mastitis and ovarian cysts, albeit both had median incidence days later in lactation.

Table 2 Incidence of major production–related diseases in Holstein cows.

Disease	Median incidence day	Assessment of lactational risk %
Retained placenta	1	7.4
Milk fever	1	>5.0
Ketosis	8	>5.0
Metritis	11	7.6
Displaced abomasum	11	>5.0
Mastitis	59	9.7
Ovarian cysts	97	9.1

(from New York State survey)

Feed intake and lactational performance

From drying off until calving, primary management objectives consist of repletion of secretory and other metabolically active tissues, avoidance of peri–parturient problems (diseases) and establishment of the subsequent lactation. It is advisable to complete body tissue repletion prior to drying off, as anecdotal evidence suggests achievement of body condition gain in non–lactating cows is relatively difficult. This assumption does not however appear to have been adequately evaluated under rigorous experimental conditions and may be based on the belief that reduced feed intake at this time plus increasing foetal demands is likely to result in reduced partitioning of nutrients to body tissue repletion in favour of more demanding processes, which include tissue hypertrophy in preparation for the subsequent lactation. It is relatively clear that feed intake will be reduced once lactation ceases and unlikely to exceed 20 g DM/kg liveweight, of which at least half should be as reasonable quality forage. From drying off until approximately 7 days before expected calving, Burhans and Bell (1998) and others found appetite to be relatively constant and only seriously affected during the week prior to calving when intake reductions of >30% may be experienced. The most noticeable reductions occur on the day of calving and Grummer (1995) showed a strong relationship between DM intake achieved on the day prior to calving with that on day 21 after calving, stressing the importance of providing the peri–parturient cow an opportunity to maintain satisfactory levels of feed intake by providing palatable feeds that are both accessible and available in sufficient quantities.

In most cows, feed intake increases quite rapidly in the immediate post–calving period although peak intake is unlikely to be achieved until week 8 of lactation or later. During this time nutrient demands to support milk production will exceed nutrient intake and body tissue mobilisation will be inevitable. Whilst this is an acceptable phenomenon in all lactating mammals, avoidance of excessive tissue loss is desirable through stimulation of feed intake. Burhans and Bell (1998) showed a strong inverse relationship between plasma non–esterified fatty acid (NEFA) concentrations and dry matter intake from 18 days prior– until 18 days post–calving with a pronounced increase in NEFA levels at day 6 prior to calving coinciding with detectable reductions in feed intake. NEFA levels peaked at day 4 post–calving but were reduced to 50% of peak values by day 18. To control such processes and prevent the accumulation of ketone bodies, indicative of compromised liver metabolism and possibly giving rise to sub clinical or even clinical ketosis, promotion of feed intake after calving is essential. Abrupt changes to the ration should be avoided and current practice recommends inclusion of part of the lactation ration in the total ration for approximately 2 to 3 weeks prior to expected calving date. In particular where significant amounts of concentrates are to be fed in the lactation ration, this will stimulate microbial adaptation and rumen papillae development, both essential to the prevention of acidosis.

It is also important to maintain adequate dietary fibre levels to promote rumen contractions and rumination activity. The practice of feeding straw *ad libitum*, whilst recommended in the 'far–off' period (from drying off until week 3 prior to expected calving date), should be discontinued during the 'close–up' period (from week 3 prior to expected calving date) as this will increase the quantity of indigestible fibre in the rumen at a time when rumen space is limited. When Murphy (1999) included 0.2 kg straw/kg total ration for transition cows, feed intake was compromised in the close–up period and whilst grass silage intake post–calving was marginally increased, milk fat and protein contents were reduced during early lactation. Dewhurst *et al.* (1996, 2000) included 0.4 kg straw/kg total ration for transition cows but in contrast to Murphy (1999), grass silage intakes were reduced during early and into mid–lactation with associated reductions in milk yield of up to 2.0 kg/d along with small depressions in milk fat and protein content. McNamara *et al.* (2000) showed similar overall effects where, despite no reduction in grass silage intake, a milk yield reduction (2 kg/d) was associated with reduced milk fat content. It is concluded that as cows enter the close–up period, the quality of the forage component of the ration should be improved, removing a significant proportion of the straw in the far–off ration and replacing with grazed or ensiled feeds, although grass and grass silage should be avoided if high potassium levels are expected as this can adversely affect the cation:anion ratio of the ration and increase the possible incidence of peri–parturient hypocalcaemia (milk fever).

Changing the concentrate component of the close–up or early lactation ration has been considered with respect to stimulating early lactation feed intake. Keady *et al.* (2001) with average yielding cows reported improvements in DM intake at this time when feeding 5 kg/d starch–based concentrates and *ad libitum* grass silage compared with grass silage alone during the close–up period, but by week 4 of lactation, with all cows receiving the same lactation ration, no differences in feed intake were evident. However, during the first 12 weeks of lactation cows supplemented prior to calving had improved milk fat contents as well as improved body condition score at calving, but this resulted in increased loss of body condition. Subsequently, Keady *et al.* (2002) examined the effects of increased ME allowance prior to calving and forage:concentrate ratio of the ration on feed intake and milk yield in early lactation when all cows received the same ration. Increased ME allowance in the close–up period had a positive effect on body condition score at calving whilst calf weight was unaffected. Milk yield was unaffected by treatment but both increased ME allowance and concentrate feeding had small positive effects on milk fat content.

Recently, Reynolds *et al.* (2002) fed a total mixed ration from 5 weeks prior to calving containing 12% crude protein as the control along with a protein–supplemented ration (15% protein) achieved by the addition of ruminally protected soyabean meal, or a positive control supplying a similar amount of additional ME as rolled barley. Cows consuming the barley–supplemented ration had higher intakes during the dry period and improved body condition scores at calving whilst protein supplementation increased feed intake but with no associated improvements in body condition. Pre–calving effects on feed intake were maintained until week 5 of lactation, suggesting a metabolic response to the nutritional composition of the rations fed prior to calving with no discernable effects thereafter. During early lactation the protein–supplemented cows lost more body condition than control cows, an effect which was maintained to week 20 of lactation. In contrast, control cows regained some body condition by this time, whilst highest body condition score loss at week 20 was for cows receiving rolled barley prior to calving. However these cows had the highest total milk yield although protein supplemented cows had the highest overall levels of milk fat. Protein supplementation prior to calving increased plasma β–OH butyrate levels compared with the control, with slower improvements in IGF1 levels suggesting these cows experienced increased energy deficit as a consequence of increased protein supply. In this respect, the cows which received rolled barley prior to calving had the lowest overall IGF1 levels.

To review lactational responses obtained through feeding additional protein prior to calving, data from approximately 20 studies have been collated. Only one study showed a 10% improvement in feed intake over the control whilst 3 studies had a negative effect of more than 10%. With respect to milk production, one study showed a positive response of more than 10% whilst 4 studies showed a reduction of more than 10%. One study showed more than a 5% improvement in milk protein content with over half of the studies showing reductions in milk protein content, of which 3 studies recorded more than a 5% decline. It is concluded that protein supplementation prior to calving has little overall positive effect on lactational performance, although van Suan *et al.* (1993) showed some benefits in primaparous heifers, presumably due to an increased requirement for protein to complete growth of body tissues.

An alternative approach examined by Reynolds *et al.* (2002) was the inclusion of highly digestible fibre sources in transition and early lactation rations at the expense of starch, based on possible problems which may occur if high levels of starch are fed during this period of relatively unstable feed intakes, as well as limited evidence that feed intakes were higher when molassed sugar beet feed replaced rolled barley, at least until week 8 of lactation (Sutton *et al*. 1991). However, whilst higher fibre rations promote milk fat contents, they may adversely affect milk protein levels (Aston *et al.* 1995). In the study of Reynolds *et al.* (2002) multiparous cows received a ration of limited barley straw with grass and maize silage plus limited concentrates and either barley meal (B) or molassed sugar beet feed (SB) supplements from 5 weeks before expected calving. After calving, the cows were further allocated to lactation rations based on grass and maize silage with either a starch (S) or fibre (F) concentrate containing cracked wheat or molassed sugar beet feed/wheatfeed, providing four distinct treatments: pre/postcalving B/S, B/F, SB/S or SB/F). The lactation rations were introduced at 2 kg/d from 10 days prior to expected calving. Feeding barley or sugar beet feed prior to calving had no effect on overall feed intake (mean 11.7 kg/d) or pattern of feed intake with all cows showing a characteristic decline in intake from 2 weeks prior to calving. Body condition score was unaffected by treatment and no significant effects on plasma metabolite concentrations (NEFA, β–OH butyrate, insulin, glucose or IGF1) were noted. Post–calving intakes were increased by 1.3 kgDM/d for cows receiving the fibre based lactation ration and these cows had marginally higher body condition scores. However cows receiving the starch based lactation concentrate produced more milk (+ 2 kg/d) with higher milk fat and protein outputs but no overall effects on milk composition. In relation to the pre–calving treatments, barley supplemented cows had non–significantly higher milk yields during the first 5 weeks of lactation with marginally higher milk fat and protein outputs.

Data for the first 20 weeks of lactation showed the positive effects of fibre based lactation rations on feed intake were maintained with marginally improved body condition scores compared with starch fed cows, probably reflecting the increased milk yields (+ 2.1 kg/d) for starch–fed cows without commensurate improvements in feed intake. Overall outputs of fat and protein were higher for cows fed the starch based lactation ration with no effect on milk composition. Lactational responses to transition management were less evident over the long term, although those cows receiving barley at this time had higher body condition scores. Milk protein yields were unaffected whilst the improved milk fat output for cows receiving the pre–calving starch supplement are worthy of note.

One other strategy to improve total nutrient intake during early lactation is the dietary inclusion of fat supplements (Coppock and Wilks 1991). Many fat sources are available, with some treated to confer protection against rumen fermentation, thus minimising possible adverse effects on rumen fibre digestion due to increased free oil/fat levels. Given the need for additional energy after calving to reduce potential energy deficits, fat supplementation from calving may be worthy of consideration. Some added fat sources however cause feed inappetance and thus inclusion of added fat in close–up rations is often advocated. This may also adapt the liver to deal with increased circulating lipid levels after calving. Evidence by Skaar *et al.* (1989), Salfer *et al.* (1995) and Grum *et al.* (1996) with respect to pre–partum fat supplementation effects on subsequent lactational performance is, however, equivocal whilst the occurrence of increased circulating NEFA levels has led to the suggestion that this may predispose cows receiving fat supplements to fatty liver syndrome. In contrast, stimulation of hepatic NEFA metabolism prior to calving by the strategic use of fat supplements may be beneficial immediately after calving when NEFA load from mobilised body tissue is increased. On the other hand, feeding too much fat prior to calving may over–condition the cow, subsequently affecting the cow's ability to metabolise mobilised body tissue after calving along with related fertility and dystocia problems.

On the basis of this evidence it would appear advisable to include modest amounts of fat in the ration of transition cows if the intention is to feed fat supplements during early/mid lactation. This formed the basis of a study by Reynolds *et al.* (2002) in which cows prior to calving cows received a ruminally–protected fat supplement or the equivalent amount of ME (13 MJ/d) as ground wheat. Fat supplementation did not affect total DM intake during the close–up period but circulating NEFA levels were increased whilst β–OH butyrate levels were unaffected. After calving, feed intake increased more rapidly on the control ration, but the small improvement noted during weeks 2–5 of lactation (+ 0.l6 kg DM/d) was not sustained. All cows lost body condition post–calving but no effects due to pre–calving supplementation were established. However, during this period the cows that had received supplementary fat prior to calving produced an additional 2 kg milk/d with increased milk fat content and an additional milk fat output of more than 0.1 kg/d. Cows which received supplementary fat prior to calving had elevated NEFA levels during early lactation with marginally increased β–OH butyrate but reduced insulin levels.

By lactation week 20, pre–calving fat supplementation had no overall effect on feed DM intake but resulted in significantly increased milk yields, marginally increased milk fat contents, but reduced milk protein levels. This latter effect is often noted on fat supplemented diets and may be due to increased milk volume having an overall dilution effect as milk protein output is generally unaffected. One interesting observation however was increased IGF1 levels in cows which had received fat supplementation prior to calving which may have had positive effects on body protein metabolism, and imposed an additional drain on available protein supplies.

On the basis of this evidence however, and especially the post–calving effects noted in the control cows which were first introduced to supplementary fat in the lactation ration, there appears to be relatively little justification for feeding fat prior to calving with respect to adaptation of the rumen. In contrast, adaptation of hepatic metabolism may be worthy of consideration through strategic pre–calving fat supplementation, especially in those situations where the intention is to feed relatively high levels of fat during the lactation.

Metabolic changes during the peri–parturient period

In the light of these macroscopic effects it is pertinent to examine some of the more subtle changes which occur as the cow moves through pregnancy towards term and the initiation of lactation. In line with a 305 day lactation, most cows will be dried off when the foetus is at 220 days gestation. Bell *et al.* (1995) estimated the energy content of foetal and uterine contents at this time to be 125 MJ, increasing by term to 350 MJ, indicative of the exponential growth occurring during the latter stages of pregnancy. They also estimated a total foetal/uterine protein content of 3.6 kg at drying off, increasing to 10 kg by term. On this basis they estimated a daily ME requirement for foetal growth of 17 MJ/d, with Varga and Ordway (2001) drawing attention to the relatively low efficiency with which the foetus uses ME due to the high energy cost of placental metabolism. This led them to suggest a higher daily ME requirement for foetal growth of 21 MJ, and that on the basis of both values an ME cost of mid/late pregnancy equating to approximately 25% of maintenance energy costs can be assumed. With the revised maintenance ME requirements recently proposed for high genetic merit cows, this equates to a daily ME requirement of 95 MJ/d, which appears relatively easy to achieve if rations of moderate ME density (>10 MJ/kgDM) are fed. Bell *et al.* (1995) also derived a net protein requirement for satisfactory foetal growth of 450 g/d which suggests the need to consume an additional 3 kg/d of a ration containing 15% crude protein or a substantial increase in the protein content of the total ration. However maintenance protein requirements are quite modest at this time and Bell (1996) recommended a total ration crude protein content of 14%, mindful that some increase in dietary crude protein content may be advisable in the last few days of pregnancy in anticipation of reduced appetites. One issue often ignored however is the nutrient cost of mammary development/regeneration, with studies by Vandehaar *et al.* (1999) suggesting a daily requirement of 36 MJ. If such values are confirmed this would have quite serious implications with respect to the levels of feed intake needed to meet total nutrient requirements for transition cows, and whilst it may not necessarily result in the need for increased ration nutrient densities, it would inevitably increase the levels of feed intake required at this time.

One concern over the feeding of cows in late pregnancy relates to possible overfeeding which may result in oversized calves. Despite seemingly similar cows and management regimes, recent studies from this laboratory recorded a two–fold range in heifer calf birth weight. Such changes are clearly influenced by the different priorities placed by the cow on nutrient supply at this time given the large calf syndrome appears to be more complex than simply an oversupply of nutrients. Oversized calves can present calving problems which will be exacerbated in over–conditioned cows, whilst Quigley and Drewey (1998) pointed out that the problem may be worse in heifers and small framed animals. Reference has already been made to the low efficiency with which the foetus utilises nutrients whilst its preferential demand for glucose is recognised. Feeding increasing amounts of starch in the transition ration could be a suitable strategy for improving overall glucose supply to the cow, although studies reported by Reynolds *et al.* (2003a) showed relatively little evidence of any significant increases in glucose demand until just prior to calving. Using cows with multi–catheters to determine splanchnic metabolism, they reported no change in hepatic flux of glucose at 9 days compared with 18 days prior to calving. In contrast, by 11 days post calving, hepatic glucose flux had doubled and further increases were noted at 21 and 33 days after calving. Most interestingly, measurements in one cow showed a notable increase in hepatic glucose flux approximately 12 h prior to calving and was deemed to be in response to the onset of uterine contractions, with hepatic glucose production subsequently being directed towards the synthesis of milk lactose. For other metabolites, these studies failed to note any major changes 9 days prior to calving compared with day 19, but by day 11 post–calving increases in hepatic output of β–OH butyrate, urea, acetic acid and carbon dioxide, with corresponding increases in hepatic utilisation of NEFA, propionic acid, ammonia and oxygen had occurred. As lactation progressed, hepatic utilisation of NEFA declined in response to reduced portal supply of NEFA, glucose output was maintained as was β–OH butyrate output whilst ammonia removal increased but without any corresponding increase in urea output. Over the first 12 weeks of lactation, hepatic oxygen consumption increased by 115% compared with pre–calving levels, with a commensurate doubling of carbon dioxide output. From respiration calorimetric data obtained in similar cows, hepatic oxygen consumption was estimated to account for 25% of whole body oxygen consumption. Additional to this, oxygen consumption in the portal–drained viscera during early lactation increased to 110% of late pregnancy levels, and accounted for 24% of estimated whole body consumption.

Changes in gut and tissue mass during the peri–parturient period

In parallel with these observations, Reynolds *et al.* (2003b) determined changes in gut and tissue mass from approximately 3 weeks prior until 4 weeks post–calving. By day 31 of lactation, when feed DM intake was approaching 20 kg/d compared with 10 kg/d prior to calving and cows were producing 43 kg milk/d, total rumen contents had only increased by 17% with a commensurate increase in liquid outflow rate of 14%. Comparison of pre– and post–calving tissue mass (all empty weights) showed a 10% overall increase for the reticulo–rumen, with measurements taken at day 22 post–calving being 18.2% greater than pre–calving values. Similarly the intestines showed an overall increase in weight of 17.8% of which the greatest increase was noted in small intestinal tissue weight whilst liver weight increased by 27%. At the same time, mesenteric fat content at day 22 post–calving was only 72% of pre–calving levels, whilst rumen papillae mass, determined by weighing representative samples taken from several sites in the rumen was increased by over 40%.

Peri–parturient mineral metabolism

Transition from late pregnancy to the establishment of a successful lactation represents a series of major insults to the cow, and the sudden increased demand for minerals, principally to support lactation, can adversely affect the well–being of the cow and her lactational performance. Compromised mineral metabolism at this time can result in milk fever or 'peri–parturient hypocalcaemia'. Increased understanding of mineral metabolism suggests that compromised calcium metabolism during this period may lead to other important conditions, all of which can affect both the lactational performance and general well–being of the cow. Milk fever is well known and documented and whilst cows suffering from this condition usually show rapid recovery if treated with intravenous calcium soon after onset, lost appetite and impaired milk production will add to the overall costs of the condition, suggesting prevention of the condition is preferable to cure. Furthermore, Goff and Horst (1997) found cows which had suffered from milk fever to be more likely to have retained placenta and possibly uterine prolapse as well as displaced abosmasum.

Calcium is used continuously by the cow but it is the sudden demand for additional calcium at parturition which can rapidly result in low blood calcium levels and the onset of subclinical (>4 but <5 mg Ca/100ml blood) or clinical (<4 mg Ca/100ml) hypocalcaemia. Colostrum has a much higher calcium content than normal milk with Horst *et al.* (1997) estimating the total calcium secreted in colostrum to be equivalent to nine times total blood calcium pool in mature cows. To exacerbate the problem, this increased demand occurs when total feed intake is relatively low. Once dietary calcium intake fails to meet total demand, the cow can only meet this shortfall either through increased intestinal availability of calcium or mobilisation of calcium from skeletal tissues. The small intestine is the major site for calcium absorption but there is little evidence of increased calcium availability during periods of calcium insufficiency, whilst earlier studies by Lomba *et al.* (1978) suggesting that increased acidity of gut contents may promote calcium absorption, were not confirmed by Block and Takagi (1986) or Leclerc and Block (1989). As blood calcium levels fall there is evidence that the cow will respond by increasing the renal secretion of vitamin D through the action of parathyroid hormone (PTH) secretions which may stimulate calcium absorption from the intestines. More importantly, vitamin D together with PTH is involved in bone calcium mobilisation as well as increased re–absorption of calcium by the kidneys, suggesting that prophylactic dosing with vitamin D may be appropriate for those cows which are predisposed to milk fever. In practice this approach is only moderately successful and in breeds such as Jerseys, which have lower number of vitamin D receptors in the intestines, its use is not advisable. Interestingly, it is the lower number of intestinal receptors along with the higher levels of calcium in milk that appear to predispose Jerseys to milk fever.

Previous strategies to avoid milk fever have included feeding high calcium supplements prior to calving but this down–regulated PTH secretion, thus exacerbating rather than alleviating the problem by blocking the mobilisation of bone calcium. In such situations, cows became less responsive to compromised blood calcium levels, thus increasing the possible incidence of subclinical or clinical milk fever. An alternative approach was to feed low dietary calcium levels, on the basis that this would promote bone mobilisation. However this relies on putting the cow into a mild state of calcium deficiency and, given the huge demands for calcium once the modern Holstein has calved, this may be considered to be an approach too close to the edge for most situations.

More recently the concept of dietary cation:anion difference or balance (DCAD) has been proposed in which the cationic balance of the ration is lowered by strategic addition of anionic salts. This approach is claimed to increase calcium availability via gut absorption or bone mobilisation whilst ration acidification allows higher dietary inclusion rates of calcium without reducing the effectiveness of the parathyroid in relation to bone calcium mobilisation. The approach consists of balancing the ration with respect to two major cations (sodium, Na^+, and potassium K^+) and two major anions (chloride, Cl^-, and sulphate, SO_4^{--}) in order to provide late gestation/early pregnancy rations which have an overall negative balance when expressed on a milli–equivalent basis. This will cause blood pH to fall, reducing the incidence of metabolic alkalosis which reduces bone calcium mobilisation whilst improving homeostatic mechanisms designed to maintain blood calcium levels within acceptable physiological boundaries. In this respect high potassium diets are to be avoided as they will increase overall alkalinity of the ration and may adversely affect magnesium availability. In turn, low blood magnesium levels can affect PTH secretion, thus reducing the ability of the cow to maintain blood calcium levels. If the feeding of high potassium feeds, especially grazed or ensiled grass, cannot be avoided then supplementation of the ration with magnesium chloride is recommended, possibly through the drinking water, to maintain blood magnesium levels whilst increasing the anion:cation ratio of the total ration.

Within the UK, balancing dairy cow rations for major cations and anions is now commonplace, with notable reductions in the incidence of milk fever, and many farms reporting zero occurrence. Compromised mineral metabolism in early lactation may also increase the incidence of other health issues, where reduced blood calcium levels have been associated with reduced muscle function. There is growing evidence that impaired muscle contractions due to reduced blood calcium levels may be involved in displaced abomasums, retained foetal membranes and possibly increased incidence of dystocia.

Other peri–parturient issues

Recognising the importance of the transition period, a number of dietary strategies have been developed and some are being marketed as dietary supplements. Dosing cows with propylene glycol to stimulate glucose production has been a recognised strategy for many years but despite the biological basis of this approach, the efficacy of many products has not been established. A study in this laboratory with primaparous heifers noted substantial responses in feed intake and milk yield in early lactation when a single drench was given within 12 h of calving yet a subsequent study with multiparous cows showed less dramatic effects and the cost of the drench could not be justified. Others have recommended longer periods of treatment, including daily dosing from 40 days prior to expected calving, but variability of response suggests this practice may not be effective in terms of product and labour costs. In contrast, Pickett *et al*. (2001) and Stokes and Goff (2001) showed beneficial effects from drenching cows with propylene glycol for 3 days commencing on the day of calving, with Pickett *et al*. (2001) reporting a 20% reduction in circulating NEFA and β–OH butyrate levels compared with the control. When additional fat was supplied by oral drenching, blood NEFA levels were similar to control cows with marginally lower β–OH butyrate levels. In contrast, addition of propylene glycol to the fat drench resulted in markedly lower NEFA and β–OH butyrate levels compared with control or fat–only supplemented cows.

More recently, choline has been proposed as a dietary supplement to improve hepatic fat metabolism. Piepenbrink and Overton (2000) provided cows with 100 g/d ruminally protected choline and reported a substantial reduction in fat accumulation in liver slices and a 20% reduction in the esterification of labelled palmitate. They also reported an increased conversion of propionate to glucose, using liver slices suggesting that strategic use of choline supplements may improve the capacity of the liver to metabolise circulating NEFA. More recently, Richards *et al.* (2002) fed a ruminally protected supplement of choline, niacin and other B vitamins to transition cows and reported significant improvements in milk yield although feed intakes were not recorded. Blood samples at 4 and 9 weeks post–calving indicated lower plasma NEFA but increased β–OH butyrate levels although these differences were not statistically significant. In a further study, Middlemass *et al.* (2002) included 50 or 100 g/d of the same product in the ration of post–partum cows and reported a 1.7 kg/d increase in milk yield with a non significant increase in feed intake. Treated cows had marginally lower milk fat contents but milk protein content was increased, albeit these effects were not statistically significant. Consequently total milk protein yield was increased by 13% whilst milk fat output was unaffected. No changes in body condition score were noted whilst blood urea contents were significantly increased in supplemented cows. A further option to improve the hepatic capacity to metabolise increased NEFA load and prevent fatty liver syndrome has been the use of methionine and lysine rich supplements, although the data are more equivocal than those appertaining to choline. Piepenbrink *et al.* (2001) fed two levels of a methionine analogue to dairy cows and at the first level noted a 2 kg/d milk yield response accompanied by lower milk fat and protein contents with an overall milk solids response of 0.27 kg/d, principally as milk lactose. Finally, vitamin E or selenium supplements have been suggested as a possible strategy for reducing peri–parturient incidence of retained foetal membranes, metritis and cystic ovaries. When Baldi *et al.* (2000) fed vitamin E supplement from 14 days prior to expected calving until 7 days post–partum, the number of days to conception and the number of services required for the subsequent conception were reduced whilst Erskine *et al.* (1997) reported improved immunity when vitamin E was given. Similarly, Weiss *et al.* (1997) showed a reduced incidence of mastitis with high doses of vitamin E whilst Lacetera *et al.* (1997) showed a 10% improvement in milk yield over the first 8 weeks of lactation.

Optimisation of breed: consideration of milk compositional issues

Whilst the dominance of the Holstein cow continues, driven by high milk yield potential and a large genetic pool, many countries with relatively sophisticated dairying systems are questioning their universal suitability and expressing interest in other breeds. Several reasons can be advanced, mainly attributable to perceived or real inabilities of the modern Holstein to cope with all situations. Genetically–improved Holsteins do not perform well on high forage diets compared with some other breeds, whilst the continuing decline in fertility is of major concern. Despite stated intentions to breed cows with improved fertility, many farmers remain unconvinced, given the relatively low heritability of this trait. Increased lameness and excessive body condition score loss in early lactation are further concerns. Given the current fragility of the modern Holstein, efforts in Northern Ireland, where grazed or ensiled grass form a major part of dairy rations, are evaluating Norwegian red cattle on the basis of claimed improvements in temperament, fertility and hoof strength. In Southern Ireland, Montbelliere and Normandy cattle are being evaluated as better forage utilisers, along with New Zealand Holsteins, although this latter choice is rather surprising when less than two decades ago the UK was dominated by British Friesians, considered superior with respect to the production of milk from forage. As yet Ayrshires, Guernseys and Shorthorns are not enjoying the same renaissance, but there is considerable interest in Jerseys. Both American and Danish Jerseys are markedly different from the original 'island' cow, and Jerseys in general tend to be favoured for their higher production of milk solids and the opportunity to produce niche milk products as well as desirable production traits that include better forage utilisation, improved fertility, better hoof health and fewer calving difficulties; their only major drawbacks are increased predisposition to milk fever and generally lower milk yields. However some Jerseys are now capable of routinely producing over 7500 kg milk/lactation.

A spreadsheet model was recently developed (Beever, unpublished observations) to challenge the concept of producing high milk yields (Holsteins) in relation to the biological efficiency of producing milk of higher solids content. As summarised in Table 3, these data are based on a notional herd of 100 multiparous Holsteins with an average 7800 kg lactation milk yield and fat and protein contents of 39 and 32 g/kg respectively. This provides an annual combined yield of milk fat and protein of 55.4 tonnes and whilst approximately half of UK milk is still sold for liquid composition, respective contents of fat and protein remain important determinants of overall milk price. Assuming modest yielding Jerseys (5400 kg/lactation) but with appreciably higher milk fat and protein contents, an annual production of an equivalent amount of fat and protein would require an additional 10 cows (n = 110).

Based on annual milk yields and average lactose content, Holsteins produced over 37 tonnes lactose, almost 9 tonnes more than the amount produced by Jerseys and a commodity which attracts low prices yet is an essential component of milk. Knowing the calorific value of lactose, its partial efficiency of synthesis (0.54; Chwalibog 1991) and assuming a dietary ME content of 11.5 MJ/kgDM, Jerseys required 75.9 tonnes of feed compared with 99.5 tonnes for the Holsteins, a saving of almost 24 tonnes/annum. In addition, there are likely to be differences in total ME required to maintain the contrasting herds. Using the data of Kebreab *et al.* (2003) and the same ration ME density, total feed costs of 245.7 tonnes were computed for Holsteins compared with 199.5 tonnes for Jerseys, even after the additional 10 cows had been accounted for. Thus to produce the same amount of milk fat and protein from Jerseys equates to a net feed saving of 69.7 tonnes/annum due to lower maintenance ME requirements and lactose yields. However additional costs for management costs of maintaining extra animals must be recognised, but assuming an annual cost per head of £80 and an overall feed price of £100/tonne resulted in an improved gross margin for Jerseys compared with Holsteins of £6044/annum. Furthermore, 100 Holsteins produced an annual water output of 687 tonnes with annual milk sales of 780 000 litres, compared with only 512 tonnes for Jerseys producing 595 000 litres milk. This difference of 176 tonnes/annum, or 0.48 tonnes/day must represent an important saving when the cost of water, reduced cooling needs, reduced transportation and reduced processing and waste disposal are taken into account.

With respect to choice of breed for efficient milk production, brief mention should be made of current interests in cross breeding. Many reasons may be advanced, including the benefits of hybrid vigour, smaller cows, improved milk composition or production traits including reduced lameness or improved fertility. Whilst not popular in the UK, considerable interest exists in some parts of Australia, especially crossing Holsteins with Jerseys. This could be seen as a strategy to improve overall milk composition, but in reality is being pursued to overcome calving difficulties, especially large calves from small cows and prevalent in first calving heifers. The origins of this problem may be multifactorial and in part due to the type of Holstein bulls currently available in Australia. It may also be due to the partitioning of nutrients during pregnancy between milk, tissue synthesis or foetal growth. The phenomenon of foetal programming in humans is well recognised but has not been examined in detail in dairy cows or other farm animal species. On the other hand, it may be due to inadequate preparation of the first bred heifer, where periods of under–nutrition together with breeding the heifer prior to achievement of satisfactory body weight and size, both relatively common in some parts of Australia, can seriously affect the stature of the cow at first calving, with longer term effects persisting. If proved to be the main cause of the problem, then improved management of the growing heifer would undoubtedly be the most appropriate course of action. Whilst cross breeding will undoubtedly bring the added advantage of hybrid vigour, the question remains as to the breeding strategy for the F1 hybrid. Geneticists would advise that to maintain this vigour it is necessary to outcross the F1 hybrid before crossing F2 back to one of the original breeds. It is largely irrelevant, with

Table 3 A comparative analysis of the biological efficiency of Holsteins and Jerseys producing equivalent amounts of milk fat and protein on a herd basis.

	Holsteins	Jerseys	Difference[1]
Annual milk yield (kg)	7800	5400	–2400
Milk fat/protein content (g/kg)	39/32	55/38	+16/+6
Herd size[2]	100	110	+10
Annual fat and protein yield (tonnes)	55.38	55.24	–0.06
Milk lactose yield (tonnes)[3]	37.44	28.58	–8.86
Feed use for lactose synthesis (tonnes)[4]	99.50	75.90	–23.60
Maintenance feed costs (tonnes)[5]	245.70	199.50	–46.20
Annual water sold (tonnes)	687.20	511.50	–175.70

[1]Jersey less Holstein
[2]Computed on basis of equal annual yield of milk fat and protein
[3]Milk lactose content of 48 g/kg assumed for both breeds
[4]Based on calorific value of lactose (16.5 MJ/kgDM), assumed efficiency of lactose synthesis (0.54) and dietary ME concentration of 11.5 MJ/kgDM
[5] Based on 0.6 MJ/kg metabolic body weight/d and dietary ME concentration of 11.5 MJ/kgDM

respect to commercial milk production, that such animals would never gain registered breed status but what is of more concern is how this added complexity in the business can be managed to ensure improved life time performance for all home produced heifer replacements.

Conclusions

This paper has examined some of the major issues facing the management of the modern dairy cow for efficient lifetime milk production. In line with several publications from the CEDAR laboratory it has highlighted the importance of meeting the energy requirements of the cow through the provision of appropriate rations, whilst recognising that body tissue mobilisation in early lactation is unavoidable but should be limited by whatever means available, in both magnitude and duration. The limited role for grass silage in rations for high yielding cows is considered whilst the potential of grazed grass also seems to be relatively low. The paper also examined the importance of the transition period with respect to the preparation of the cow for the next lactation, highlighting some of the major physiological and metabolic changes which occur at this time. Finally the paper provides an interesting way of considering the role of alternative breeds for milk production and concludes that further consideration should be given to some of the opportunities these may provide, whilst tending to dismiss the recent interest being shown in some parts of the world in cross breeding.

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