Nutritional management of the high yielding cow into the future

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Summary

This paper considers the nutritional management of high yielding cows by examining energy flux during early lactation and providing quantitative data on the extent and duration of body tissue mobilisation. Early studies failed to establish the commencement of energy repletion by lactation week 20 but in a later study, where higher ME intakes were achieved, body energy loss ceased at week 14. This did not, however, coincide with body weight change which fell from calving to week 5 before increasing thereafter, irrespective of genetic merit, albeit at different rates. Body condition score changes were a much closer reflection of measured body energy change.

The possible implications of impaired energy intake in early lactation on reproductive function are presented, where a reduction in conception rate to first service with high yielding cows was attributed to significant disruptions in the cyclity of the cows post calving, with persistent corpus lutea being an important factor, as well as cows that showed early cyclity, followed by a considerable period of anoestrus.

High yielding cows in early lactation appear to spend as much as 12 h per day either eating or ruminating, and an estimate of 14 minutes required to ingest and ruminate each kg of fresh food was obtained. Without significant changes in diet composition, especially total DM content, intakes of 30 kg DM/d appear close to the limit for most cows; higher levels could only be achieved by providing drier diets.

Finally the paper examines the concepts of metabolic load and capacity and, whilst recognising that Holsteins have high total energy fluxes, these are not excessive when body weight (and hence metabolic body weight) are taken into account. Furthermore, when compared against the feats of other animals (including humans) these fluxes are not major cause for concern, provided deficits between energy input and output are kept to a minimum in both extent and duration.

Keywords: dairy cows, genetic merit, energy metabolism, milk composition, reproduction, rations

Introduction

Only 10 years ago more than 90% of the dairy cows on United Kingdom (UK) farms were ‘Black and Whites’ and the predominant breed was Friesian. Since then the situation has changed remarkably, for whilst Black and White cows still prevail, Holsteins have become the major breed with only few herds able to claim purebred Friesian status. The importation of North American and Dutch semen has contributed significantly to these changes whilst herd sizes and annual lactation yields have both increased. Against a fixed National milk quota of 14×10^9 litres, the average herd size is rapidly approaching 100 cows and in the last 15 years the total number of dairy cows has fallen from 3.2 million to 2.3 million. This has undoubtedly led to higher yield expectations, with current estimates indicating an increase of almost 1000 litres/cow since 1992. However, whilst average yield still remains at between 6000 and 6500 litres when first calf heifers are included, many herds are averaging over 8000 litres/cow, some are approaching 10,000 litres/cow whilst individual cows yielding over 12,000 litres per lactation are not uncommon.

Awareness that these cows were markedly different from their Friesian predecessors was slow to be realised, but as farmers strove to manage Holsteins to achieve their potential a number of important management issues started to emerge. Research information on high genetic merit cows fed typical UK rations was scant and a preliminary report by Ryder (1994) left many questions unanswered. The UK dairy industry continues to place considerable emphasis on the use of home–grown forages for milk production, grazed and ensiled grass being the most popular sources. The quality of grass silage has improved considerably as new harvesting and ensiling technologies have been adopted, but over recent years interest in alternative forages including maize silage and whole crop wheat silage has increased. Many cows are now fed more than one forage type, especially during periods of peak milk production. At the same time farmers and nutritionists have recognised the importance of starch in dairy cow diets, and through the inclusion of maize silage, along with a plentiful supply of cheap wheat, it is quite common to see rations containing 20+% starch in the total dry matter (DM).

The major issue facing those who manage high yielding cows continues to be the control of nutrient use between milk synthesis and body tissue mobilisation. Many of these cows experience considerable loss of body tissue during early lactation but no benchmarks are available in relation to ideal rate or duration of body tissue mobilisation in order to avoid metabolic problems, compromised productivity and, in some cases, reduced longevity. Equally, both reproductive function and immuno–competence in cows experiencing extensive tissue mobilisation may be compromised but reliable data on the extent and the causes have not been available. It was the suggestion that cessation of bodyweight loss, which generally occurs in these cows by lactation week 5 to 6, was indicative of cows reaching their nadir of body energy content that led this laboratory to undertake a comprehensive research programme into the nutritional management of high yielding dairy cows. In this context high yielding animals have been considered to be those with annual lactations in excess of 10,000 litres. Of most concern was the failure, based on current feeding standards, to balance energy output as milk and as heat (assumed) with energy intake (also assumed) and assumed energy contribution from body tissue, suggesting either that systems for meeting the energy requirements of high yielding cows required substantial revision or that many of the assumptions were incorrect.

Materials and methods

Studies in which the lactation performance of high yielding cows has been examined and in some instances compared with average yielding cows will be presented and supported by studies designed to measure total energy flux (input, output and partition) using open circuit respiration calorimetry. In addition, results of comprehensive monitoring of the reproductive competence of these animals will be presented whilst some preliminary data relating to the behaviour of high yielding cows in relation to allocation of time for essential processes (eating, ruminating etc) will also be detailed. Finally consideration will be given to the work load experienced by such animals, before concluding with recommendations for the management of these and future high yielding dairy cows.

Preliminary studies to examine energy metabolism in high yielding dairy cows

In a study involving only 4 high yielding cows (Beever *et al.* 1998) full energy balances were determined between weeks 5 and 20 of lactation at 5 week intervals. Maximum milk yield was 51.7 kg/d (week 5), declining to 43.7 kg/d by week 20. However milk composition was impaired with subnormal fat levels at weeks 5 and 10 (mean 33.4 g/kg) and low protein throughout (mean 30.4 g/kg), with a lowest weekly mean value of 27.9 g/kg (week 5). Measured metabolizable energy (ME) intakes ranged between 250 and 282 MJ/d, the highest value being observed at week 15, but in all cases this was not sufficient to prevent substantial energy mobilisation. The main reason was the high rates of heat production (mean 160 MJ/d), which were substantially greater than the mean value of 106 MJ/d reported by Sutton *et al.* (1991) for British Friesian cows, although neither study provided data on cow body weight by which these estimates could be compared. Consequently, body energy loss amounted to 43 MJ/d at week 5, equivalent to not less than2 kg body tissue based on the estimates of tissue energy content provided by Alderman and Cottrill (1993). Reduced losses of 26, 19 and 34 MJ/d at weeks 10, 15 and 20 respectively indicated that body tissue mobilisation still exceeded 1 kg/d at lactation week 20. This suggests a possible loss of 4 GJ body tissue by week 20, and assuming most of this energy is derived from body fat, equates to a loss of body fat approximating to 100 kg.

In a study involving the serial slaughtering of cows between calving and week 29 of lactation, Gibbs *et al.* (1992) estimated a mean body fat level at calving for British Friesian/Holsteins of 90 kg. Similar data for Holsteins are not available but based on their larger size yet generally leaner body composition it is unlikely these animals will have substantially greater fat reserves at calving. On this basis it is concluded that the estimated mobilisation of body fat noted by Beever *et al.* (1998) for Holsteins represented a major proportion of total body fat reserves.

Due to limited numbers of cows, body weight changes and reproductive function were not determined, but the substantial reductions in milk fat and protein contents were clearly indicative of an inadequate intake of nutrients, particularly ME, especially in early lactation.

A systematic comparison of nutrient utilisation and lactational perfomance in high (HYC) and average yielding (AYC) cows

This study compromised 28 HYCs, with 8 randomly assigned to calorimetric studies to quantify energy flux, and the remainder compared with 20 AYCs in a full lactation study (Beever *et al.* 2000). All cows were selected from the CEDAR herd on the basis of previous lactation yields greater than 10000 kg (HYC), and greater than 7500 kg but not more than 10000 kg (AYC). The HYCs were fed a total mixed ration (TMR) comprising maize silage, grass silage, dried lucerne, chopped grass hay, potato starch and a concentrate blend

(31:6:14:4:5:40 DM basis) providing 480 gDM/kg fresh weight, and 217 g starch, 67 g sugars, 318 g NDF and 178 g crude protein per kgDM. The AYCs received a TMR based on similar ingredients but with lower ME and crude protein contents. HYCs were milked three times daily whilst AYCs were milked only twice daily. All cows were weighed and body condition scored weekly for the first 24 weeks of lactation.

The results (Table 1) indicate the DM intake of the HYC was the greater by approximately 2 kg/d, corresponding to mean intakes of 37.1 and 33.2 g/kg body weight for HYC and AYC respectively. Mean milk yield was approximately 10 kg/d higher for the HYCs, equivalent to an extra 1660 kg milk by the end of week 24. However milk produced by HYCs had lower fat and protein contents, with mean fat level being similar to that recorded earlier by Beever *et al.* (1998), whilst milk protein showed a modest improvement. In contrast the AYCs had satisfactory milk fat and protein contents such that when the two groups of cows were compared with respect to combined milk fat and protein production, the 30% greater milk yield of the HYC resulted in an improved solids (fat and protein) output only 19% greater.

Table 1 The lactational performance of high– and average–yielding cows between calving and week 24 of lactation.

Cow group	HYC	AYC	SED
DM intake (kg/d)	23.1	21.2	0.96
Milk yield (kg/d)			
Mean	42.4	32.5	1.39
Peak	49.1	37.8	1.66
Milk composition (g/kg)			
Fat	38.8	43.0	9.2
Protein	31.2	33.9	8.1
Liveweight (kg)			
Week 1	627	630	18.3
Week 6	615	632	16.7
Week 12	625	647	16.9
Body condition score			
Week 1	2.2	2.4	0.19
Week 6	1.9	2.1	0.15
Week 12	1.5	2.3	0.16

Both groups of cows had similar body weights immediately post–calving but HYCs showed a net loss of body weight by week 6 (0.2 kg/d) whilst AYCs at this time were similar to their post–calving weights. Thereafter, AYCs gained at 0.21 kg/d to week 12 and overall (to week 24) at 0.45 kg/d, whilst HYCs showed correspondingly lower gains of 0.14 and 0.28 kg/d respectively. At the same time, all cows lost body condition score (BCS), but both extent and duration were larger for HYCs than AYCs, the former not reaching their nadir until week 12 whilst AYCs were showing substantial repletion of BCS by that time.

The 8 HYCs selected for the energy metabolism study were fed the same ration and the results, as reported by Hattan *et al.* (2001) are summarised in Table 2. Overall DM intake averaged 24.3 kg/d and peaked between weeks 12 and 18, whilst milk yield was almost 52 kg/d at week 6 and declined thereafter at just over 1% per week. At week 6, milk fat and protein contents were characteristically reduced and did not achieve acceptable levels until week 24 for fat and week 30 for protein. Measured ME intake in week 6 was 279 MJ/d, comparable to the highest value noted by Beever *et al.* (1998), whilst by week 18 an increase of almost 20 MJ/d gave a mean intake approaching 300 MJ/d. Milk energy output on the other hand was highest in week 6, equivalent to 52% of total ME intake, declining progressively thereafter with lactation stage to 105 MJ/d by week 30. In contrast, heat energy was largely unaffected by stage of lactation (mean 160 MJ/d), with estimated energy deficits of 22 and 6 MJ/d noted at weeks 6 and 12 respectively. Thereafter, small positive tissue energy retentions were noted, indicating that body energy mobilisation ceased at approximately week 14 of lactation. Interestingly, this more or less coincided

Table 2 Energy metabolism in high yielding cows between calving and week 30 of lactation (units are MJ/d unless stated).

Week	6	12	18	24	30	SEM
DMI (kg/d)	24.1	25.3	25.2	23.7	23.3	0.7
Milk yield (kg/d)	51.7	47.7	43.9	39.6	35.4	1.30
Milk content (g/kg)						
Fat	33.3	33.1	33.9	36.1	36.2	13.00
Protein	28.2	29.6	30.4	30.7	32.3	7.00
ME intake	279	291	297	284	277	9.1
Milk energy	144	132	126	116	105	3.6
Heat energy	157	166	163	156	157	4.2
Retained energy	–22	–6.0	9.2	13	17	5.30

with the minimal BCS noted in the production study reported by Beever *et al.* (2000).

Extrapolating these data to the first 30 weeks of lactation provided estimates of the likely changes in total body energy content and, assuming most of this was related to body fat stores, estimates of changes in body fat content were also computed. By lactation week 10, cows had lost 2.15 GJ of body energy equivalent to 60 kg body fat. During lactation weeks 11–20, a small overall net body energy gain of 0.16 GJ equivalent to a gain of 4.5 kg body fat was estimated, indicating a period of relatively stable body energy reserves, whilst the largest repletion occurred during weeks 21–30 with body tissue showing a net gain of 0.98 GJ, equivalent to almost 28 kg body fat. Nevertheless, based on these calculations, it appears that even at week 30 these cows had not fully replaced the body fat reserves that existed at calving and were used in support of milk production during early lactation. Furthermore, on the basis of total milk energy secretion from calving to week 10 (9.6 GJ), a total energy cost of 15.4 GJ can be determined, of which approximately 14% had been derived from mobilised body tissue, assuming for the purpose of this calculation that all maintenance costs were derived from the feed.

Reproductive function in high and average yielding cows managed under the same system

The cows described in the previous study were extensively monitored from 3 weeks pre–calving through to lactation week 20 (minimum) and the results have been reported by Tayler *et al.* (2000). The data are summarised in Table 3 and provide a detailed characterisation of the reproductive cycle based on measurements made three times weekly of milk progesterone levels, as described by Lamming and Darwash (1998), along with actual fertility in terms of conception rates to first service and days from calving to conception. Overall, the AYC had considerably better reproductive function than HYC with only 25% showing any abnormality. Only 10% of all AYC failed to recommence cycling (DOV1 +PCL1), all of these attributable to persistent corpora lutea in the immediate post partum period (PCL1). A further 10% of cows failed to cycle for a second time (DOV2), having shown earlier cyclity, whilst 5% of the cows suffered from persistent corpora lutea later in the reproductive cycle (PCL2). Consequently, conception to first service was 50%, with an average of 87 days open, indicating a projected calving index of 362 days.

In contrast, only 43% of the HYC showed normal reproductive activity, significant problems being encountered with many cows. Collectively, 32% of the cows did not start to cycle when expected (DOV1 +PCL1) with approximately two thirds of these suffering from PCLs (PCL1 = 21% of all cows) and the remainder failing to cycle for other reasons. A further 14% of the cows failed to show subsequent cycling after a successful first cycle (DOV2) whilst 11% of the cows had PCLs between later reproductive cycles. Consequently, conception to first service was reduced to 39%, yet only a small overall increase in average days open was noted (94 days). Comparing the two groups of cows, it would appear that failure to recommence cyclity (DOV1) and persistent CLs in the immediate post partum period (PCL1) were the major contributory factors to the impaired reproductive function seen in HYCs.

Table 3 Reproductive function of high– and average–yielding cows (units are % unless stated).

	HYC	AYC
Cycle classification:		
Normal	43	75
DOV1	11	0
DOV2	14	10
PCL1	21	10
PCL2	11	5
First service conception	39	50
Calving to conception (d)	94	87

DOV1 Delayed ovulation in the post–partum phase
DOV2 Ceased to ovulate later in the cycle
PCL1(2) Persistent corpus luteum during immediate post partum period (between later reproductive cycles)

These data are currently being examined in relation to extensive analysis of blood metabolites and the energy fluxes observed in these cows with the intention of establishing to what extent a compromised nutritional state of HYCs may have contributed to these effects. Data of this nature are relatively scarce, although it is recognised by farmers that the reproductive function of high yielding cows is often compromised. In a recent study to examine possible relationships between genetic merit, level of milk production, blood parameters and reproductive function, Snijders *et al.* (2001) used two groups of cows of contrasting genetic merit. Whilst all cows were significantly lower yielding than those used in our study, and differences in milk yield between genetic merit classes were less pronounced (mean to 120 days; 28.6 v 31.8 kg/d), overall reproductive function in the cows of higher genetic merit was significantly compromised. For the lower yielding cows, conception to first service was 52% with an overall conception rate during a 13 week breeding cycle of 94%. These cows lost 0.23 BCS between calving and first service, had a backfat at first service of 0.37 cm and required 1.91 services per conception. In contrast, only 41% of the genetically superior cows conceived to first service with a total conception rate over 13 weeks of 77%. BCS loss to first service was greater (0.47) and fat depth at this time was reduced (0.26 cm), and 2.7 services were required per successful conception. Examination of blood parameters was however rather inconclusive, for whilst higher genetic merit cows had lower blood glucose and IGF1 levels, the magnitude of the differences was quite small and blood NEFA levels were unaffected. However data of Tayler *et al.* (2000) where differences in the lactational performance of the cows were greater indicated some interesting effects on IGF1 levels; these were significantly reduced in high yielding cows providing large quantities of milk.

Behaviour and time allocation in high yielding cows

In earlier studies it had been noted that during peak levels of production, HYCs may consume over 25 kg feed DM/d which, with a ration DM content of just less than 50%, resulted in a total fresh weight intake of 50+ kg. To this must be added 100–120 litres of water consumed daily, equivalent to a total intake of feed and water of 160+ kg/d. This amounts to the cow eating and drinking her own body weight every 4 days, in itself a phenomenal task the magnitude of which is made more evident when it is realised that this equates to 7 kg/h. These intakes of feed and water are by no means maximal and in more recent studies, DM intakes approaching 30 kg/d have been achieved, although currently no data on water consumption are available from that study.

To examine this matter further, Mogg (2000) closely monitored some HYCs in relation to specific activities undertaken during a normal day when the cows (mean body weight 639 kg) were yielding 48 kg milk/d at approximately week 8 of lactation and consuming 24.2 kgDM/d, The results (Table 4) indicate that the cows took 200 minutes to consume their total daily feed intake in 20 distinct bouts at an average rate per minute of 0.12 kg DM or 0.26 kg fresh weight. In addition they spent 500 minutes ruminating, indicating that prehension and oral degradation of feed occupied almost 50% of each day. The cows had 24 significant bouts of rumination, largely reflecting the number of meals consumed, with an overall rate of approximately 10 minutes/kg fresh weight consumed, to which must be added 4 minutes taken to consume each kg of fresh feed. Of total rumination time, the cows spent over one third lying with a further 260 minutes spent lying and idling. From these data it is possible to develop a more comprehensive budget on which to consider the likely limits in terms of feed intake as restricted by available time. With time spent eating and ruminating already accounted for and assuming the cows would be reluctant to forfeit any of their lying but idling (resting?) time, it can be assumed that 473 minutes still remain for possible 'useful' activity. However cows need to be milked (45 min/d), to drink (18 bouts at 2 min/bout = 36 min), to groom (30 min) and to defecate and urinate (25 min; all approximations) which reduces time available for extra feed prehension to 337 minutes. Referring to the earlier estimate of 14 minutes to consume and ruminate 1 kg of feed, a theoretical maximum intake of 35.7kg DM/d is estimated for a ration containing almost 50% DM of similar composition to that used by Hattan *et al.* (2001). In reality it is unlikely that such levels of intake would be achieved on such diets, suggesting that diets will need to have higher DM contents if intakes to match likely future levels of milk production are to be realised.

Table 4 Behaviour of high yielding cows during early lactation (units are minutes unless stated). (DM intake, 24.2kg/d; water intake, 108.8 litres/d; milk yield, 48 kg/d).

	Eating	Ruminating	Idling	Drinking
	199	506	735*	ND
Posture:				
Standing	199	325	473	ND
Lying	0	181	262	ND
No. of bouts	20	24	ND	18

ND; Not determined
* By difference, includes drinking

A comparison of the metabolic load of high yielding dairy cows with other animals

One consequence of higher yielding dairy cows has been the concerns expressed by some that metabolic rate is such in terms of both duration and magnitude that they are considered to be close to their limits of metabolic capacity and thus unlikely to be able to cope with the demands being placed upon them, either overtly or otherwise. Such theories were advanced to argue that the lactogenic hormone bovine somatotrophin should not be approved for use as lactation stimulant. Six years of its routine use in the United States has not seen any significant increases in culling through inability to cope with the systems of management being imposed, and yet the commercial product, Posilac™, is still not permitted for use in the EU for that and other reasons. Recently this area between metabolic load and capacity was reviewed by Knight *et al.* (1999) who conceded that whilst all lactating animals are likely to experience some degree of stress, this may be more pronounced in those dairy cows where the priority for lactation is paramount. These authors also argued that the degree of stress may progress beyond the mild stage to downregulation of important functions including reproduction, as evidenced by Tayler *et al.* (2001), and compromised immune function resulting in impaired health. Underlying such problems is likely to be an imbalance between nutrient input as feed and output of ‘products’ principally as milk and heat. In simple terms, it appears the failure of these animals to consume sufficient nutrients to support the level of production governed by the genetic make up of the animal is the principal problem from which a myriad of impaired performance related events emanate. However Knight *et al.* (1999) also pointed out that such occurrences are not solely confined to high genetic merit cows and can occur in animals of any genetic merit where a sizeable imbalance between nutrient intake and nutrient output exists.

Quantitative description of such events is difficult as they tend to occur gradually and the responses are often present long before they become clinical phenomena. In a recent publication on animal welfare considerations, Webster (1995) provided interesting comparisons of the yield of milk and milk solids in relation to metabolic size and showed cows yielding 31 kg/d and weighing 600 kg had outputs of milk energy and protein expressed on a metabolic size (0.745 MJ and 8.4 g/kg$^{0.75}$ respectively) similar to more modestly yielding Saanen goats, sows and bitches (means 0.728 MJ and 8.5 g), all animals having substantially higher yields than lactating women. Clearly many of today’s cows are capable of producing more than 31 kg milk/d with higher outputs of milk energy and protein but, when the data presented earlier in Table 2 are used to derive these values, it can be seen that whilst they are increased (1.15 MJ and 11.7 g/kg$^{0.75}$) they are not orders of magnitude greater than those proposed by Webster (1995). Webster, further, estimated that cows yielding 35 kg milk/d were likely to have daily ME intakes and heat productions of 1.86 and 1.02 MJ/kg$^{0.75}$ which equate with 225 and 123 MJ/day. Such values are closer to those recorded earlier by Sutton *et al.* (1991) for British Friesians whilst corresponding mean daily values from the study of Hattan *et al.* (2001) were 2.15 and 1.20 MJ/kg$^{0.75}$. Clearly these are significantly higher than those provided by Webster (1995), by approximately 16%, but once again not orders of magnitude greater.

Closer examination of the data provided in Table 2 and by Hattan *et al.* (2001) revealed that, as expected, the highest ME intakes in relation to metabolic body weight occurred in weeks 12 and 18 (2.22 MJ/kg$^{0.75}$), whilst by week 30 ME intake had declined to 2.03 MJ/kg$^{0.75}$/d. In contrast, highest heat production was observed at week 12 (1.26 MJ/kg$^{0.75}$/d), declining thereafter to 1.15 MJ/kg$^{0.75}$/d by week 30. At the same time, milk energy output was highest in week 6 (1.11 MJ/kg$^{0.75}$d), and from week 12 declined in a reasonably linear fashion to an output of 0.77 MJ/kg$^{0.75}$/d by week 30. This is close to the value of 0.74 MJ/kg$^{0.75}$/d reported by Webster, yet these cows were still producing more than 35 kg milk/d. Reconciliation of these effects lies in the fact that the cows had substantially higher body weights than those referred to by Webster (1995). If metabolic body size is to be used as an indicator of the metabolic capacity of dairy cows, then it is important that these weight differences are fully recognised in any comparisons of metabolic load. In simple terms, Holstein cows are heavier than Friesians, although whether or not the universal acceptance of one exponent in determining metabolic size applies to both breeds is difficult to judge. From a number of standpoints it seems reasonable to conclude that Holsteins and Friesians at similar lactational stages are unlikely to have similar body compositions, but how this relates to metabolic capacity is not easily determined.

One final point with respect to the levels of heat production noted by Hattan *et al.* 2001) is that whilst the mean value of 1.2 MJ/kg$^{0.75}$/d was relatively high, it appears to be rather modest when compared with that of endurance cyclists (1.51 MJ/kg$^{0.75}$/d) and even the songbird feeding its young (1.58 MJ/kg$^{0.75}$/d).

Strategies for the successful management of high yielding cows

Both research information and practical evidence with high yielding Holsteins indicate that if they are to become successful, efficient and profitable producers of milk a number of management issues need to be addressed. It should be added that as such cows have been successfully managed in several countries for a number of years, including in North America and Israel, considerable information can be gained from these experiences. However, failure to recognise specific local constraints (e.g. feedstuff availability) could rapidly turn any advantages that Holsteins bring into unmitigated disasters.

Whilst Holsteins have the same skin colour as Friesians, this is where the similarities end. Holsteins are invariably heavier, leaner and have the capacity to produce more milk. The modest yields often seen in Friesian heifers are rarely replicated in Holsteins. To plan for successful management of Holsteins, it is first necessary to establish expected lifetime yields. In the UK there are probably few cows that yield more than 30,000 litres in their lifetime (30 tonnes) yet with the high costs of replacements, a target of 50 tonnes should be the aim of all producers. Once this target is set, it will focus attention on the important issue of heifer rearing, and whilst calving at 24 months remains popular, it will be necessary to supply well grown heifers of approximately 600 kg body weight with a BCS of 3 at calving. Against an average heifer birth weight of 45 kg, this amounts to an average daily gain of 0.76 kg, an achievable target provided regular attention is given to their development. Once lactating, the aim must be to provide sufficient nutrients to match their demands as closely as possible. In this respect, energy intake is most important and whilst some body tissue loss during early lactation is acceptable, there is an overriding need to control both its rate and extent. Indeed, body tissue loss at this time is common in most lactating mammals, but if not controlled in cows it will lead to numerous problems. Those relating to impaired fertility and compromised milk composition have been referred to earlier.

To optimise feed intakes, rations based on palatable ingredients must be provided. ME densities in the total ration approaching 12 MJ/kgDM are essential and adoption of this benchmark will exclude some common feedstuffs. Whilst not essential, TMR feeding is advisable, and there is mounting evidence that a minimum DM content of 50% is essential. This certainly puts into doubt the continued inclusion of low DM grass silage (<25% DM) in the ration, and even when grass silage of 30+% DM is included, intakes are always less than those recorded when maize silage replaces part of the grass silage component (Phipps *et al.* 1995). There is an increasing preference for diets of open physical consistency, as these will undoubtedly stimulate total feed intake compared with more dense rations, especially those based on wet grass silage.

Given that suitable energy intakes can be achieved, it is a relatively simple task to balance the supplies of ruminally degradable protein (to maximise microbial protein synthesis) and undegradable dietary protein (to optimise metabolizable protein supply), whatever rationing scheme is adopted. With respect to other nutrients, there is growing evidence of the value of starch in the ration, based on the availability of relatively cheap sources (e.g. wheat) as well as the established stimulatory effect on milk protein content. Our recent studies in this series (unpublished) have demonstrated the benefits of diets containing 27% starch, and more recently levels of over 30% have been successfully fed. In such situations, however, it is advisable to feed a mixture of both rapidly (e.g. wheat) and slowly (e.g. maize) degrading starches, preferably in a TMR to avoid major fluctuations in rumen pH which could lead to sub–acute rumen acidosis. Finally, fat supplements are a useful way of increasing the energy density of the ration, but whilst some market brands have been shown to reduce milk protein content, inclusion of crushed whole oilseed rape (60 g/DM; approx. 1.3 kg/day/head) did not show such effects (Reynolds *et al.* 1998). With an estimated protein content of 240 g/kgDM and ME content of 23 MJ/kgDM, whole oilseed rape has attractions, provided it can be suitably processed to optimise its digestion.

In conclusion, high yielding cows need high energy intake to operate to their potential and this is the largest issue facing their nutritional management. Forages can still form a significant part of the diet but maize silage is preferred to grass silage, and even whole crop wheat silage or good quality chopped hay appear better options than low DM grass silage. Concentrates can be based on home blends, but many by–product feeds will not be suitable. The cow needs suitable accommodation and time to complete the daily tasks she faces, in particular eating and ruminating which may take over 50% of the day, and systems which minimise competition between cows for feeding space are essential, whilst the requisite number of cubicles must always be provided (1:1). Furthermore, as cows have become bigger, it is staggering to note the number of dairy units where cubicle size has not changed over the time that Holsteins have replaced Friesians. Cows need comfortable accommodation if they are to meet their lying (resting) and (part of) their rumination needs. Indeed, were it not for the likelihood of increased incidence of environmental mastitis, there would be more farmers returning to systems based on straw bedded yards. Finally, as high yielding cows may consume over 100 litres water/day, with a significant proportion of this consumed directly after milking, it is essential that clean water troughs of suitable capacity and adequate supply (litres/min) are provided in all units, with even the idea of a water trough placed in the collecting yard being worthy of consideration.

References

Alderman, G. and Cottrill, B.R. (1993). *Energy and Protein Requirements of Ruminants*. CAB International, Wallingford, Oxon.

Beever, D.E., Cammell, S.B., Sutton, J.D., Rowe, N. and Perrott, G.E. (1998). Energy metabolism in high yielding cows. *Proceedings of the British Society of Animal Science*, p. 13.

Beever, D.E., Hattan, A.J., Cammell, S.B., Humphries, D.J. and Jones, A.K. (2000). Lactational performance and energy utilisation in high yielding cows. *Proceedings of the British Society of Animal Science*, p. 10.

Gibbs, M.J., Ivings, W.E., Dhanoa, M.S. and Sutton, J.D. (1992). Changes in body components of autumn–calving Holstein–Friesian cows over the first 29 weeks of lactation. *Animal Production* 55, 339–60.

Hattan, A.J., Beever, D.E., Cammell, S.B. and Sutton, J.D. (2001). Energy metabolism in high yielding dairy cows during early lactation. *Proceedings of the 15th EAAP Energy Symposium*, Copenhagen, September 2000 (in press).

Knight, C.H., Beever, D.E. and Sorensen, A. (1999). Metabolic loads to be expected from different genotypes under different systems. In: *Metabolic Stress in Dairy Cows*, pp. 27–35 (eds. J.D. Oldham, G. Simm, A.F. Groen, B.L. Nielsen, J.E.Pryce and T.L.J. Lawrence), British Society of Animal Science, Occasional Meeting No. 24.

Lamming, G.E. and Darwash, A.O. (1998). The use of milk progesterone profiles to characterise components of subfertility in milked dairy cows. *Animal Reproduction Science* 52, 175–90.

Mogg, V. (2000). Time and behaviour budget for high yielding dairy cows and heifers. BSc Dissertation, The University of Reading.

Phipps, R.H., Sutton, J.D. and Jones, B.A. (1995). Forage mixtures for dairy cows: the effect on dry–matter intake and milk production of incorporating either fermented or urea–treated whole crop wheat, brewers' grains, fodder beet or maize silage into diets based on grass silage. *Animal Science* 61, 491–6.

Reynolds, C.K., Phipps, R.H., Jones, A.K. and Beever, D. E. (1998). Milk production response of lactating dairy cows to dietary fat from three sources. *Proceedings of the British Society of Animal Science*, p. 223.

Ryder, S. (1994). Secret of the high yielders sought. *Farmers Weekly* 121, 39.

Snijders, S. E. M., Dillon, P.G., O'Farrell, K.J., Diskin, M., O'Callaghan, D.O., Rath, M. and Boland, M. (2001). Relationship between genetic merit, milk production, body condition, blood parameters and reproductive performance of dairy cows. In: *Fertility in the High–producing Dairy Cow*, p. 94 (ed. M.G.Diskin), British Society of Animal Science, Occasional Meeting, Galway, September 1999 (in press).

Sutton, J.D., Cammell, S.B., Beever, D.E., Haines, M.J., Spooner, M.C. and Harland, J.I. (1991). The effect of energy and protein sources on energy and nitrogen balances in Friesian cows in early lactation. In: *Energy Metabolism in Farm Animals, Proceedings of the 12th EAAP Energy Symposium*, pp. 288–91 (eds. C. Wenk and M. Boessinger), Kartause Ittingen, Switzerland. EAAP Publication No. 58.

Tayler, V.J., Hattan, A.J., Bleach, E.C.L., Beever, D.E. and Wathes, D.C. (2001). Reproductive function in average and high yielding dairy cows. In: *Fertility in the High–producing Dairy Cow*, p. 92 (ed. M.G.Diskin), British Society of Animal Science, Occasional Meeting, Galway, September 1999 (in press).

Webster, A.J.F. (1995). Welfare considerations in future selection and management strategies. In: *Breeding and Feeding the High Genetic Merit Dairy Cow*, pp. 87–93 (eds. T.L.J. Lawrence, F.J. Gordon and A. Carson), British Society of Animal Science Occasional Publication No. 19.