14

Diet and milk production

This chapter:

Explains how milk is produced in the udder from the end-products of digestion, how the level of feeding and composition of the diet affects milk volume and composition and how cows partition some of these nutrients into body condition.

The main points in this chapter:

- because of their limited rumen capacity, cows in early lactation require feed with low fibre levels
- high levels of feeding in early lactation will not make up for poor condition at calving. It is important to feed cows well in early lactation, approaching peak lactation and peak intake
- cows close to calving and in early lactation need high quality diets with adequate supplies of energy, protein, fibre and minerals. It is important to avoid abrupt changes to the diet
- diet has considerable influence on the fat and protein content of milk, but relatively little effect on its lactose content
- cows should be in body condition score 4.5 to 5.5 when they calve
- cows put on condition more efficiently in late lactation when they are still milking, rather than when they are dry
- the persistency of milk production throughout lactation, expressed as the monthly percentage decline from peak yield, is a good guide to the feeding management. The target should be 7% to 8% per month.

The ability of cows to produce milk depends largely on:

- water and feed eaten; intakes of dry matter, energy, protein and fibre. The feed must first be digested (broken down to its constituent parts) for the products of digestion to be absorbed into the blood from the digestive tract

- how they use (or partition) these products of digestion for maintenance, activity, pregnancy, milk production or body condition.

This chapter discusses how cows partition nutrients between maintenance, milk production and body condition. Feed intake (the amount and type of feed and the resultant products of digestion) and their use or partitioning of these products to metabolic activities all influence the volume and composition of milk produced.

14.1 Fate of the products of digestion

There are a range of products from the digestion of feeds consumed. These include ammonia, carbon dioxide, methane, Volatile Fatty Acids (VFAs), fats, undigested fibre, rumen microbes and undegradable protein. Some products of digestion are wasted (carbon dioxide, methane, undigested fibre), with most being used by cows. The three major volatile fatty acids produced from rumen digestion are acetic acid (or acetate), propionic acid (or propionate) and butyric acid (or butyrate).

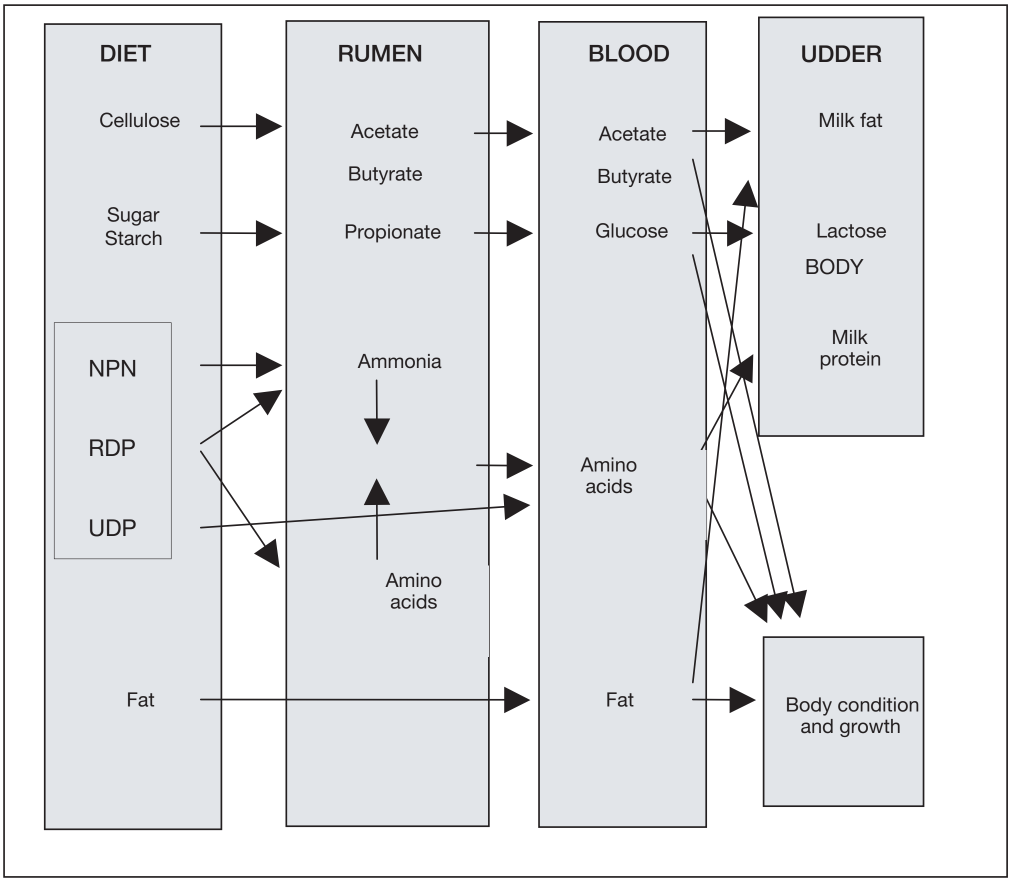

Figure 14.1 Flow of the major nutrients from the diet, through the rumen, to blood, and to the udder or to body condition and growth. Non-protein nitrogen (NPN); Rumen Degradable Protein (RDP); Undegradable Dietary Protein (UDP).

Fats (from acetate, butyrate and fats in the diet), glucose (from propionate), and amino acids (from microbes and undegradable dietary protein), circulate in the blood streams of the cow, becoming available for their role in metabolic processes (Figure 14.1).

14.2 Milk production in the udder

14.2.1 What is milk?

Milk is produced in the mammary gland by the udder tissue. About 500 L of blood pass through the udder to produce 1 L of milk. Blood delivers water, glucose, fats and amino acids to the udder. Cells in the udder tissue use these substrates to form and secrete milk which is made up of:

- water, from water in the blood
- lactose (milk sugar), produced from the glucose (from propionate) in the blood
- milk fat, produced from the fats (from acetate, fats in the diet, and released body fat) in the blood
- milk protein (mostly casein), built from the amino acids (from microbes and Undegradable Dietary Protein, UDP) in the blood (using glucose as an energy source to do the building).

The level of fat and protein in milk varies with many factors such as the breed of cow, stage of lactation, body condition and the diet.

14.2.2 Lactose production in the udder

The udder makes lactose from glucose arriving in the blood. The lactose secreted into the udder attracts water with it, at roughly constant proportions. The lactose content of milk hardly varies, at about 4.8% (Figure 14.2). Therefore, the quantity of glucose arriving at the udder determines how much lactose is produced, hence what volume of milk is produced. This can be depicted as follows:

More blood glucose → More lactose (kg) → More milk (L) → Constant lactose test

Figure 14.2 Relationship between quantity of glucose reaching the udder and volume of milk produced.

14.2.3 Fat production in the udder

The secretory cells in the udder make milk fat from the fats carried in the blood. These blood fats come from acetate and butyrate (mainly from fibre in the diet), from the fat from body condition, or from fats in the diet.

Fat percentage (or test) varies greatly, depending on:

- The type of energy in the diet. Fat test is higher in diets high in fibre, when the blood carries more acetate. Fat test is lower in diets high in starch, because the blood contains more glucose (from the propionate), which is used for lactose production. On a high starch diet, not only is less milk fat produced, but the extra lactose produced increases the milk volume, diluting the fat even more.

- The stage of lactation. Fat test is likely to be lower in early lactation when milk volume is at its highest
- Body condition of the cow. Fat test is higher in cows losing body condition, which is used for milk fat production. Body condition loss in early lactation (if cows have condition to utilise) may help maintain milk fat concentration as yield increases.
- Energy intake. Fat test tends to be lower if cows are well fed. When energy intakes are high, rumen fermentation rates are also high, the rumen is more acidic (lower pH), and the starch-digesting microbes which produce propionate will work better than the fibre-digesting microbes which produce acetate. With more propionate (which is converted to glucose), there will be more lactose produced and, therefore, a greater volume of milk. With less acetate, there will be less fat.

14.2.4 Protein production in the udder

The udder makes milk protein from the amino acids and glucose carried in the blood. Amino acids are the building blocks, and the glucose provides the energy to do the building.

Sometimes, although the supply of amino acids to the udder is plentiful, there is not enough glucose energy available to build them into milk protein. In this case, some of the amino acids are converted to glucose, and used to provide energy. This is not an efficient use of feed because it wastes the protein-producing potential of the amino acids.

Conversely, if glucose is plentiful but amino acids are in short supply, the building of milk protein will be limited. The surplus glucose may produce some lactose, but most will be stored. Cows will then put on body condition rather than produce more milk. This also is not an efficient use of feed.

Milk protein and lactose production (and hence milk volume) are related because:

- glucose in the blood is needed to produce both lactose and milk protein
- the quantity of amino acids and the amount of glucose in the blood, ready for protein and lactose production, tend to be related to each other due to diet.

A well-balanced diet high in energy often produces more rumen microbes, which are broken down to Undegradable Dietary Protein and amino acids; and a high energy diet also produces more propionate, which converts to glucose. However, a diet higher in fibre often produces fewer microbes and more acetate, which converts to fats. Amino acids can be broken down to glucose if there is a shortage of glucose. The reverse cannot occur.

Usually when milk protein production is high, lactose production is also high. Because lactose is high, milk volume is also high. So, as more kilograms of protein are produced, the number of litres increases, keeping the protein test fairly constant. Therefore, the diet does not greatly affect the protein test and certainly not as much as the diet affects the fat test.

14.2.5 Summarising nutritional effects on milk composition

Table 14.1 presents a summary of some of the effects of feeding management on milk composition. The measures of feeding management are relative to those on a well-balanced diet.

Table 14.1 Effects of feeding management on milk composition

Feeding management	Milk fat	Milk protein
Maximum intake	Increase	+ 0.2 to 0.3% units
Increase grain feeding frequency	+0.2 to 0.3% units	Small increase
Underfeed energy	Little effect	–0.1 to 0.4% units
High fibre	Small increase	–0.1 to 0.4% units
Low fibre	–1.0% units or more	+ 0.2 to 0.3% units
Low protein	No effect	Decrease if marginal
Excess fat	Variable	–0.1 to 0.2% units
Grinding/pelletising of concentrate	–0.1 to 0.2% units	Little effect
Heat stress	Variable	–0.1 to 0.3% units
Restrict water	Increase	Increase
Improving body condition at calving	+0.1 to 0.3% units	Little effect

An innovative small holder dairy farm in Sumatra, Indonesia, with a wilting rack to routinely wilt fresh forages prior to feeding.

Mott grass, an improved variety of Napier grass, has a high leaf to stem ration, hence a high nutritive value (East Java, Indonesia).

14.2.6 How milk composition varies with level of concentrates fed

With intensification of small holder dairying in many peri-urban areas in South-East Asia, shortages in quality roughages have led to increasing amounts of concentrate feeding, often with dramatic effects on milk composition. Sanh (2001) conducted a series of feeding trials in North Vietnam using crossbred Friesian cows fed diets based on varying proportions of Napier grass, brewer's grain and formulated concentrates, based on local by-products such as rice bran, cassava meal, maize bran and groundnut cake. Forage:concentrate ratios varied from 70:30 to 30:70.

When the forage ratio decreased from the highest to lowest, the daily Metabolisable Energy intake increased by 5 to 6 MJ/cow per day at a constant feeding level and by 8 to 13 MJ/cow per day at *ad libitum* feeding. The cows responded with higher daily milk yields with increasing concentrate. In addition, contents of Milk Protein (MP) increased and of Milk Fat (MF) decreased with increasing percentage of concentrates (%C), of which milk fat was more affected than milk protein. The significant regressions were:

Milk fat: MF = 3.90 + 0.006 %C
Milk protein: MP = 3.58 – 0.003 %C

At 30%, 50% and 70% concentrate, fat tests were then 4.1%, 4.2% and 4.3%, respectively, whereas protein tests were 3.5%, 3.4% and 3.4%.

These relationships would vary with base diets as they influence the concentrations of the nutrients presented in Figure 14.1.

14.3 Milk production and body condition

Cow body condition (or the amount of fat that a cow has stored on her body), particularly at calving, has a large effect on milk production and fertility. The cow either stores body fat or mobilises it, depending on the level and type of feed and the stage of lactation. Figure 14.2 depicts the changes during lactation of the partitioning of feed nutrients between the udder and body reserves.

Two hormones, which circulate in the cow's blood, cause body fat to be used or stored:

1 Insulin regulates the storage of body fat from the fats and glucose in the blood. Insulin is produced by the pancreas and is in higher concentrations in the blood when cows are being fed well and glucose is plentiful in the blood.
2 Growth hormone regulates the release of body fat to produce milk fat. Growth hormone is produced by the pituitary gland and is in the blood in higher concentrations in early lactation or when cows are not fed well.

14.3.1 Body condition in early lactation

The ideal body condition score at calving is between 4.5 and 5.5 (see Chapter 18). If cows are fat enough at calving, it is common for one condition score to be taken off the body and used for milk production in the first two months of lactation. This is an important source of energy at a time when cows are trying to achieve peak milk production and their appetites have yet to reach 100% (see Figure 7.1 in Chapter 7).

The amount of energy released when cows lose body condition varies with their live weight. One condition score lost in early lactation can produce up to 220 L of milk, about 10 kg of fat, and about 6.5 kg of protein, over the whole lactation (Robins *et al*. 2003).

If cows are low in body condition at calving and are underfed in early lactation, their peak milk production will be depressed and they will partition less feed to milk and more towards body condition over the whole lactation.

Each improvement in body condition at calving can increase milk yields by up to 1.3 L/d for the first 10 to 15 weeks of lactation with that milk having up to 0.5% higher units of milk fat.

Cows in higher condition at calving also have better fertility. For example, each additional condition score at calving can reduce the time between calving and first heat by 5 to 6 days. Other production benefits to improved body condition are discussed in Chapter 18.

Rapid loss in body condition during early lactation can adversely affect cow performance, through metabolic problems and delayed conception. Substances called 'ketone bodies' are produced as body fat is used. If body condition is being used rapidly, the high level of ketone bodies causes the metabolic disorder called acetonaemia (or ketosis) (see Section 13.2.3 in Chapter 13). Milk production drops suddenly, cows become lethargic and may not even be able to stand. Ketosis is caused by low intakes of energy relative to the requirement for milk production. Increasing the cow's energy intake can prevent ketosis.

14.3.2 Body condition in late lactation and the dry period

Milk production falls in late lactation because:

- cow are using (partitioning) more of their intake to build body condition rather than to produce milk
- their intake ability has decreased
- often, they are being offered less feed or lower quality feed.

Cows with high genetic production potential tend to continue partitioning nutrients to milk rather than to body condition during late lactation. They must then be fed very well at this time to put on body condition ready for their next calving. Consideration could also be given to cease milking very thin cows (dry them off) early, before the recommended 60 days before calving. This will reduce immediate milk returns, but this will be offset by better milk yields and fertility during the next lactation.

The dry period may be the only opportunity for cows to put on condition. However, cows use feed energy more efficiently to put on body condition while still milking compared to when dry. Therefore, it is better to plan feeding management to replace body condition during late lactation, rather than the during the dry period.

14.3.3 Summary of milk production and body condition

- cows should calve between condition scores 4.5 and 5.5 to ensure they have enough body fat to use in early lactation while feed intake lags behind milk production.

Tropical dairy farming : feeding management for small holder dairy farmers in the humid tropics
By John Moran, 312 pp., Landlinks Press, 2005

- adequate body reserves enable high production peaks to be achieved, which contributes to high milk production for the whole lactation.
- cows need to be well fed throughout the lactation to replace lost body condition.
- cows are more efficient at putting on body condition while still milking.

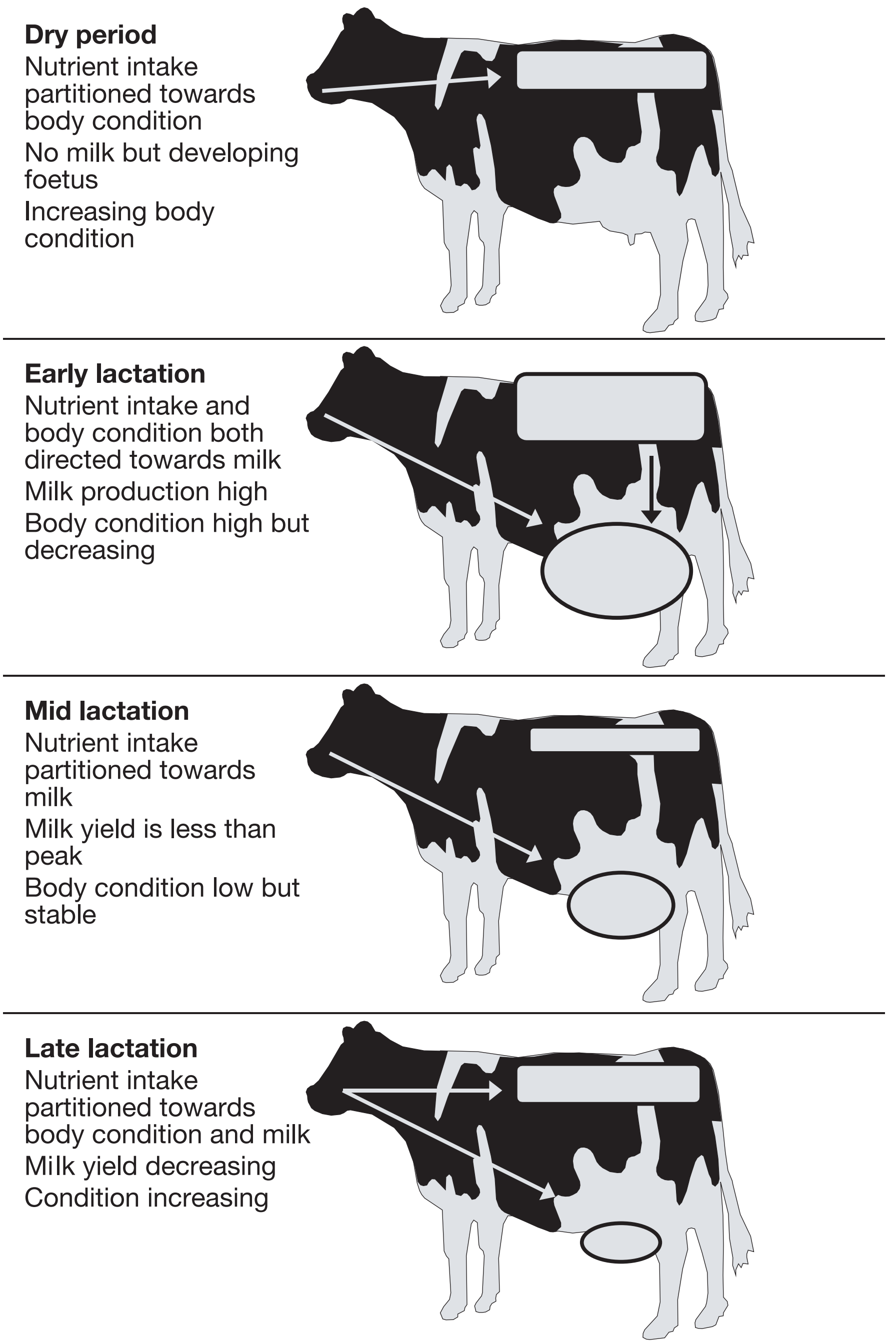

Figure 14.3 Changes in partitioning of feed nutrients over the lactation cycle. (Source: Tyndall, pers comm)

14.4 Persistency of milk production throughout lactation

The various stages of the lactation cycle have been described in Chapter 7. The two major factors determining total lactation yield are peak lactation and the rate of decline from this peak. In temperate dairy systems, total milk yield for a 300-day lactation can be estimated by multiplying peak yield by 200.

Hence, a cow that peaks in milk production at 20 L/d should produce 4000 L/lactation, while a peak of 30 L/d equates to a 6000 L full lactation milk yield. This is based on a rate of decline of 7% to 8% per month from peak yield; that is, every month the cow produces, on average, 7% to 8% of peak yield less than in the previous month. This level of persistency is the target for well-managed, pasture-based herds in temperate regions. Actual values can vary from 3% to 4% per month in fully fed, lot-fed cows to 12% or more per month in very poorly fed cows (eg during a severe dry season following a good wet season in the tropics).

The rate of decline from peak, or persistency, depends on:

- peak milk yield
- nutrient intake following peak yield due to changes in both feed quality and the amount offered
- body condition at calving
- other factors such as disease status and climatic stress.

Generally, the higher the milk yield at peak, the lower its persistency in percentage terms. Underfeeding of cows immediately post-calving reduces peak yield but also has adverse effects on persistency and fertility. Dairy cows have been bred to utilise body reserves for additional milk production, but high rates of live weight loss will delay the onset of oestrus (see Chapter 15). Compared to temperate forages, the lower energy and protein and higher water and fibre contents of tropical forages reduce appetite for forages, thus requiring higher intakes of high quality concentrates to compensate. Underfeeding of high genetic merit cows in early lactation is one of the biggest nutritionally induced problems facing many small holder farmers in the humid tropics.

This problem is induced because cow quality has been overemphasised in many South-East Asian dairy industries without the necessary improvements in feeding systems to utilise this genetic potential. If imported high genetic quality cows are not well fed, milk production is compromised, but of more importance, they will not cycle until many months post-calving.

Thin cows have less body reserves, therefore cannot partition as much to milk yield, thus reducing peak yield and persistency. Unhealthy and heat-stressed cows have reduced appetites, hence poorer persistency of lactation.

14.4.1 Theoretical models of lactation persistency

Data for milk yield over 300-day lactations in cows with various peak milk yields and lactation persistencies are presented in Table 14.2 and Figure 14.3. Such data provide the basis of herd management guidelines for temperate dairy systems with 12-month calving intervals. Depending on herd fertility, hence target lactation lengths, similar guidelines could be developed for 15- or 18-month calving intervals.

Table 14.2 and Figure 14.3 only present data for cows with peak yields of 15, 20 and 25 L milk/day. Small holder dairy farms in the humid tropics with good feeding and herd management should be able to achieve 15 L/d peak yield, and for those with high genetic merit cows, 20 or 25 L/d is realistic. Lactation persistencies of less than 8% per month may be achievable in tropical dairy feedlots but more realistic persistencies are the 10% to 12% per month presented.

Table 14.2 Effect of peak milk yield and persistency on 300 d lactation yields

Peak yield (L/d)	Persistency (%/mth)	Monthly milk decline (L/d)	Full lactation yield (L)	Average daily milk yield over entire lactation (L/d)
15	8	1.2	2980	9.9
	10	1.5	2650	8.9
	12	1.8	2330	7.8
20	8	1.6	3970	13.2
	10	2.0	3540	11.8
	12	2.4	3110	10.4
25	8	2.0	4960	16.6
	10	2.5	4420	14.8
	12	3.0	3885	13.0

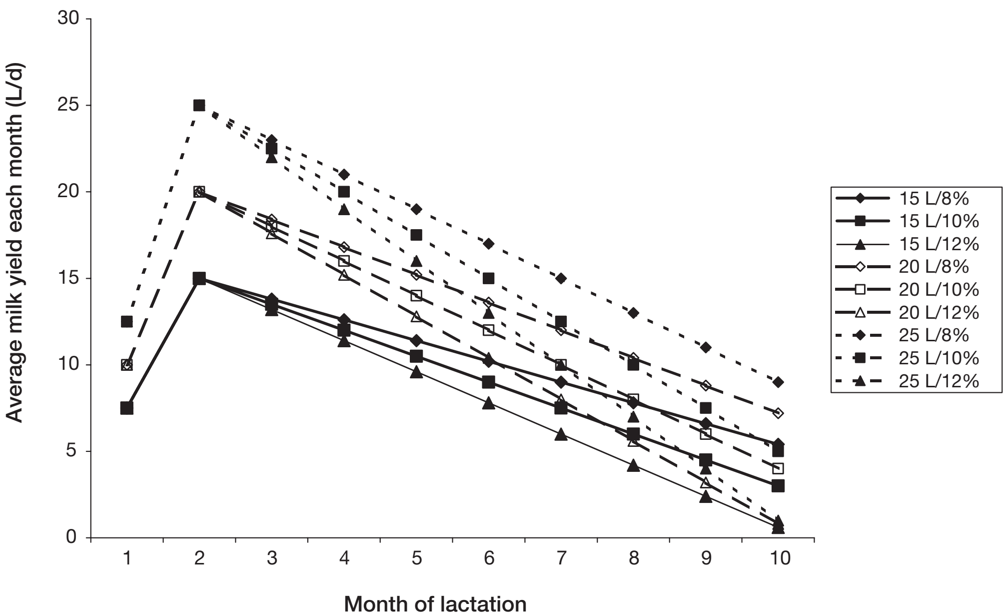

Figure 14.4 Milk yields each month for cows varying in peak yield and persistency. Legend shows peak yield (L/d) and persistency (% decline/mth).

Virtually every small holder farmer records daily milk yield of his cows, so they know peak yield and can easily determine the monthly rate of decline from the peak in litres per day (L/d), hence the percentage decline. This then provides a simple monitoring tool to assess their level of feeding management.

Unless feeding management can be improved, it may be better in the long run to import cows of lower genetic merit. For example, importers may request '5000 L cows' (ie cows that peak at 5000 L under good feeding management, with a persistency of 8%/mth). If, through poor feeding, their persistency is reduced to 12% per month, 300-d lactation yields are only 3900 L and they do not cycle for many months after calving, '4000 L cows' may be a better investment. From Table 14.2, such cows would produce similar milk yields if they could be fed to 8% per month milk persistency and they are more likely to cycle earlier (see Chapter 19).

14.4.2 Effects of diet on lactation persistency

A study in North Vietnam, with mature Friesian × Vietnamese Local Yellow cows weighing 400 kg post-calving, assessed the influence of diet on persistency during early and mid lactation (Sanh 2001). Cows were allocated one of three diets over early lactation (weeks 9–16) (see below) and then again during mid lactation (weeks 17–24) (Table 14.3).

Table 14.3 Effect of feed intake (H is high, M is medium and L is low) on milk production and lactation persistency during early and mid lactation

dry matter intake (DMI); * Persistency is the average rate of decline in milk yield over each 8 week period, expressed as % decline/month. Early lactation (weeks 9–16); mid (weeks 17–24). (Source: Sanh 2001)

Level of intake	H/H		M/M		L/L	
Stage of lactation	Early	Mid	Early	Mid	Early	Mid
Total DMI (kg/cow/day)	11.1	10.6	10.2	9.7	9.3	8.6
Milk yield (L/cow/day)	11.1	9.7	10.8	9.0	10.1	7.4
Persistency (% decline/month)*	2.9	7.4	5.1	10.2	10.6	14.3
Persistency (% decline/month)	5.1		7.6		12.4	
Live weight change (kg/cow per day)	+0.28		+0.18		–0.03	
Days from calving to 1st oestrus	92		94		102	

The diets consisted of the same quantity of freshly harvested Napier grass (4.5–4.7 kg DM/cow per day) with differing amounts of brewers grain and formulated concentrate (50% rice bran, 20% cassava meal, 15% maize bran, 15% groundnut cake). The Napier grass was harvested every 50 to 60 days and contained 19% DM, 11% CP and 9.3 MJ/kg DM of ME. The brewer's grain contained 22% DM, 33% CP and 12.4 MJ/kg DM of ME, and the formulated concentrate 89% DM, 15% CP and 11.5 MJ/kg DM of ME.

During the two stages of lactation, the diets were fed at three levels of intake, high (H), medium (M) and low (L), to supply 110%, 100% and 90%, respectively of National Research Council (1989) requirements. Diets were formulated, based on live weight and daily milk yield, at the beginning of each experimental period. The proportion of Napier grass varied from 40% to 55% on a dry matter basis, and all could be considered good quality lactation diets providing 10.5 to 11.0 MJ/kg DM of ME and 16 to 17% CP.

Two additional treatments are not included in Table 14.3. During early/mid lactation, other cows were fed the H/L and L/H treatments. During mid lactation, the L/H fed and H/L fed cows averaged 8.7 L and 8.5 L of milk/cow day with lactation persistencies of 3.9% and 15.7% decline per month, respectively. There were no effects of any of the feeding levels on milk fat or protein levels. Increased feeding regime increased live weight gain during the 16-week study, while it also had a slight effect on days to first oestrus.

Sanh (2001) considered that these crossbred cows would peak at about 12 L/cow per day under the M feeding regime while he recorded lactation persistencies during early/mid lactation varying from 5% to 8% to 12% decline/month, depending on intake. The highest dry matter intakes (on the H diet) were only 2.7 kg/100 kg LWT. Furthermore, the relatively rapid decline in persistency between early and mid lactation, together with their weight gain during early lactation, on the H and M diets, suggests:

- the genetic merit of these particular cows was not high in that they were not partitioning energy towards milk production during early lactation, or
- presentation of the diet limited nutrient intake, possibly through low dry matter contents, which were only 24 to 27%. Wilting the grass prior to feeding would encourage the cows to consume more.