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Applied Ruminant Nutrition for Dairy Cows

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Animal production response to feed is a function of the amount of feed an animal consumes and the proportion of that feed which is utilized by the animal. Animal nutrition is the art of balancing feed intake and digestibility, relative to the animal's requirements. This leaflet will concentrate on the digestive process and factors which affect feed intake in grazing cattle. The mineral requirements are dealt with in KwaZulu-Natal Dairy leaflet 5.3, while the energy and protein requirements as well as expected dry matter intakes are dealt with in KwaZulu-Natal Dairy leaflet 5.13.

DIGESTION

Digestion is the process by which the complex substances found in food are broken down into simpler substances. The animal is able to absorb these through the wall of the gut and use them in its metabolism. The breakdown process comprises a series of chemical reactions with a number of intermediate products. Each stage of the process is brought about by the action of an enzyme, which is a special substance produced by the digestive system for this purpose. There are enzymes which break down protein (proteolytic enzymes), fat (lipolytic enzymes) and carbohydrate (amylitic enzymes). One carbohydrate which cannot be digested is cellulose, as there is no enzyme to accomplish this. Ruminants consume vast amounts of cellulose, and in order to break down this substance and make use of it, they rely on bacteria which reside in the rumen.

THE RUMINANT DIGESTIVE SYSTEM

Cattle and sheep have a compound stomach divided into four compartments, which are closely linked together and function as a single unit. The entire stomach system in adult cattle has a capacity of 150 to 200 litres. The stomach system consists of the rumen, making up 80 % of the total volume, the reticulum (5 %), the omasum (6 to 8 %) and the abomasum (7 to 8 %). Cattle can be likened to a walking fermentation vat containing 20 to 40 billion bacteria and up to a million protozoa per millilitre of ruminal fluid.

The bacteria in the rumen break down the organic matter in the feed, through fermentation, into ammonia or relatively simple compounds called volatile fatty acids, in this way supplying both their own nutrient requirements and those of the host. Some of these simple compounds are absorbed through the reticulo-rumen wall into the blood stream, while others are incorporated into the bodies of the micro-organisms. The micro-organisms are digested by the animal in the abomasum as they are swept along with the feed moving through the digestive tract. About 70 % of the digestible organic matter entering the rumen is broken down by the micro-organisms before the feed passes to the omasum.

The volatile fatty acids (VFA) produced by the bacterial fermentation in the rumen are used by the cow to provide 50 to 70 % of her daily energy requirements and to form nearly 50 % of the butterfat produced by the mammary gland. Acetic, propionic and butyric acids constitute nearly 90 % of the ruminal VFAs and each is produced by a particular strain of bacterium that require a specific acidity (pH) range in the rumen for maximal growth.

The feed must be broken down into small particles before it can progress from the reticulum into the omasum and abomasum where true digestion occurs. Any feed particles which are not small enough (less than 2 mm) to pass through the reticulum are regurgitated for extra chewing (chewing the cud). Chewing the cud (6 to 8 hours daily) not only helps reduce feed particle size, but also incorporates saliva into the feed. This saliva contains salivary salts which act as a natural buffer to maintain the rumen pH at normal levels (pH 6 to 7) and reduce acidosis. Cows on a typical dairy ration can produce 80 to 100 litres of saliva per day.

Cattle on low roughage/high concentrate rations, or finely milled rations, chew less and consequently produce less saliva. This reduced saliva production can result in excessive acidity (acidosis) in the rumen which reduces the rumen pH from a norm of between 6,0 and 7,0 to between 5,2 and 5,5. The reduced pH can:

- cause reduced feed intake
- reduce the population of bacteria producing acetic acid, which is used to produce milkfat by the cow, thus reducing the butterfat levels in the milk
- damage to the rumen wall, a common condition with animals on feedlot rations.

The damage to the rumen wall can lead to liver abscesses because bacteria normally limited to the rumen enter the bloodstream and eventually infect the liver.

The problems caused by the reduced buffering which is associated with feeding high levels of concentrate can be alleviated by supplemental buffers such as bicarbonate of soda or magnesium oxide. These commercial products simulate the buffering effect of the saliva. Splitting the daily concentrate portion of the diet into more, but smaller, feeds to reduce the pH drop in the rumen, has been shown to alleviate low butterfat (BF) problems, *i.e.* less than 3,3% BF for Holstein-Friesland cows. Research has also shown that splitting the concentrates into more than two feeds per day is usually beneficial only when the concentrate proportion of the diet exceeds 60% or an amount equivalent to approximately 2% of body weight.

The feed usually remains in the rumen-reticulum complex for up to 60 hours, in the omasum for 8 hours and in the abomasum, where true digestion occurs, for 3 hours. After leaving the abomasum, the feed enters the 40 metre long small intestine from which the nutrients are absorbed into the bloodstream. The last part of the alimentary tract is the large intestine, which is 11 metres long, where the water is removed from the feed immediately prior to excretion from the animal's body. In the case of grazing cattle, the faeces are still very fluid when they are voided, whereas with sheep, the faeces are normally dry due to the efficient manner in which water is removed by the colon.

The reticulo-rumen acts as a fermentation vat which functions on a "continuous production" principle and not a "batch" system. It therefore requires a constant supply of feed material to keep it functioning. This is achieved in the natural state by the long periods spent grazing, both day and night. When cattle are placed on processed feeds, *e.g.* complete diet or total mixed rations, the time spent eating may be considerably reduced to about 3 to 4 hours, instead of the normal 8 to 9 hours spent grazing. It is considered preferable to split this shorter period of feeding into several feeding periods, so that the reticulo-rumen is frequently replenished with new feed material.

PROTEIN DIGESTION

Proteins are chemical compounds of great complexity and high molecular mass containing about 16 % nitrogen (N). Nitrogen is the chief element which distinguishes proteins from carbohydrates and fats. Since there is a fairly constant proportion of about 16 % nitrogen in protein, nitrogen is used to estimate the protein content of feeds by determining the nitrogen content of the feed and then multiplying this value by 6,25 (100/16 = 6,25). The estimate of protein obtained from nitrogen determinations is called crude protein (CP).

The building blocks of protein are 20 naturally occurring amino-acids which are linked together by di-peptide bonds in a manner similar to beads strung on a necklace. The ruminant cannot synthesize these amino-acids in its body, but the micro-organisms in the reticulo-rumen can. This protein is known as microbial protein.

Amino-acids are the essential building blocks of all living tissues. Proteins are not absorbed as such, but enter the bloodstream as amino-acids which are released during digestion in the duodenum. To produce milk protein, the correct casein precursor amino-acids must be supplied to the udder.

In the ruminant, amino-acids are provided from two radically different sources. The first is the feed offered to the animal. Some of the protein in the feed will escape fermentation in the rumen and will arrive in the duodenum with its constituent amino-acids intact. This is called undegraded (UDP) or bypass protein and the constituent amino-acids can then be absorbed through the gut wall into the bloodstream.

The second source of amino-acids is from protein contained in the microbes' bodies. This microbial protein is derived from the nitrogenous feed material which is fermented in the rumen (called rumen degradable protein or RDP) by the same micro-organisms which transform the carbohydrate fraction of the feed into volatile fatty acids. The end products of the fermentation process are simple nitrogenous compounds, mostly ammonia, but also various other protein break-down products such as peptides and amides. Ammonia is also produced from any non-protein nitrogen in the foodstuff. The micro-organisms then proceed to use these simple materials as building blocks for their own body protein. These micro-organisms are constantly being swept down the gut with the rest of the digesta. The animal then digests these microbes in the duodenum and, during the digestion process, absorbs the amino-acids released from the microbes' body protein in the same way that it absorbs the amino-acids from the protein which has has bypassed ruminal fermentation. The amount of protein which bypasses rumen fermentation varies between approximately 20 %, (in grazing) and approximately 40 to 60 % (for processed feeds, depending on the amount of heating, grinding, *etc*. employed in processing).

The unique ability of the ruminant to convert protein to ammonia, and subsequently into microbial protein is one of the most important aspects of ruminant nutrition, in that it allows the ruminant to convert non-protein nitrogen sources, such as urea, into ammonia through ruminal fermentation, and subsequently into microbial protein. This means that the ruminant can synthesize amino-acids from elemental nitrogen.

The rumen, however, has a limited capacity to convert ammonia to microbial protein. The maximum limit of conversion is considered to be 30 to 32 g N per kilogram digestible organic matter consumed by the animal. If more non-protein, or degradable nitrogen, is supplied than the microbes are able to convert into microbial protein, excessive ammonia may accumulate in the rumen. The excess ammonia produced has no nutritive value and is absorbed into the bloodstream across the rumen walls. The ammonia in the blood is converted to urea in the liver and excreted in the urine. It is possible to exceed the animals ability to convert ammonia into urea in the liver, resulting in ammonia toxicity (urea poisoning). If non-protein nitrogen alone is provided as the only protein source in the diet of the cow, her milk yield will be restricted to a very low level of approximately 9 litres per day over the lactation. Therefore if a higher production level is required, the amino-acids absorbed in the mid-gut must be derived from undegradable or bypass protein. The higher the production level, the greater the requirement for bypass protein.

Measures of expressing protein content

The present simple system of expressing the protein content of feeds, according to crude protein content (the CP system) does not take into account the degradability of protein. This system is therefore slowly giving way to other systems which take the role of undegradable protein into account. At present there are several major research efforts, in Europe and the United States of America, to develop and to perfect a new system of evaluating protein for ruminants. The modern trend is not to express the nitrogen content of feed as crude protein, but as the nitrogen from which it was derived.

This new system was recommended by the British Agricultural Research Council in 1980 and by the National Research Council (USA) in 1985. It takes into account the fact that the use of protein by the ruminant is dependant on the energy intake of the animal. This is because the ability of the microflora of the reticulo-rumen to synthesize microbial protein is directly dependant on the amount of energy supplied in the diet. The physical composition of the diet will also affect the natural degradability of the same protein source, such as by altering the rate of passage of the digesta through the reticulo-rumen.

Perhaps the best argument for adopting this new approach to determining the protein requirements of ruminants, is that ruminal digestion is an essential component of feed utilization in ruminants. The functioning of the rumen is dependant on a healthy microbial population which requires both energy and rumen degradable protein to survive. If insufficient degradable protein is available to the ruminal micro-organisms, the rate of fermentation in the rumen will be reduced, leading to a reduction in feed intake and consequently a decreased energy supply to the animal for production.

In conclusion, the advantage of the new system is that it describes animal protein requirements in terms of RDP (degradable) and UDP (bypass) protein. This allows for the formulation of rations with not only the correct quantity, but also the correct type of protein. Correctly formulated rations will lead to the most efficient possible use of protein by the animal in that a proper balance of RDP and UDP is required for optimal fibre digestion in the rumen. A surplus of RDP is wasteful in that the cow only benefits if ammonia is converted to microbial protein. Excess ammonia has to be excreted from the bloodstream, at an energy cost of 22.8 kilo Joules per gram of N. The cost of excreting surplus RDP in the diet has been calculated to cost British dairy farmers between 1.3 to 2.6 litres fat-corrected milk (FCM) per cow per day on a typical grazing system. Surplus ammonia in the bloodstream has also been shown to adversely affect reproduction. Dry matter intakes have also been shown to be depressed by high non-protein nitrogen (NPN) levels in the herbage.

NATURE AND MEASUREMENT OF ENERGY

Carbohydrates (comprising sugars, starches, cellulose, hemi-cellulose and lignin) are the major source from which the grazing animal derives its energy, although fats and, to a lesser extent, protein also provide energy which the animal uses in its metabolism.

The energy component of the diet, unlike protein and minerals, is not a nutrient as such. When complex organic materials are broken down in the metabolic processes, energy is released (this is the reverse process to that which occurs in plants during photosynthesis). This release of energy depends on the ability of the digestive system to break down the complex organic molecules into simple chemical structures.

Excessive levels of readily fermentable carbohydrates (such as starch) in the diet have been shown to cause large changes in rumen pH. High-starch rations, which exceed the fermentive capacity of the micro-organisms in the rumen can result in glucose accumulating in the rumen. This leads to the rapid growth of lactic acid-producing bacteria which can produce high levels of lactic acid. When more lactic acid is produced than can be used by the ruminal micro-organisms, the ruminal acidity increases and many of the normal ruminal protozoa and bacteria are inhibited or killed (lactic acidosis) leading to reduced levels of acetic acid which is needed for normal milk and butterfat production. Starch levels should not exceed 35 % of the diet. It is important to maintain a balance between digestible fibre, long roughage (to ensure cud chewing) and starch in the diet. Symptoms of a carbohydrate imbalance are depressed butterfat levels, low or fluctuating feed intakes, large changes in body condition in early lactation cows, excessive amounts of grain in the dung and low peak milk yield or poor persistency of milk production. Problems associated with starch and a lack of fibre are usually encountered only when the proportion of concentrates in the diet exceeds 60% or approximately 2% of live-mass.

FATS AND OILS

Fat levels in the diet should not exceed 8% of the dry matter, otherwise fibre digestion is impaired, resulting in lower butterfat production. Supplemental dietary fat may be beneficial to the high-producing cow in two ways. First, by increasing the energy density of the diet when feed capacity limits energy intake and production. Second, by substituting for starch in high-cereal diets, thereby increasing forage-to-concentrate ratios, normalizing rumen fermentation and correcting milkfat percentage.

Research has determined that highly saturated, long-chain fatty acids boost both milk yields and fat content, whereas unsaturated fatty acids contained in groundnut, soyabean, sunflower, maize and linseed oils tend to enhance yields but depress milkfat content. It is recommended that, when high levels of fat are to be fed, a fat protected from ruminal degradation, to avoid degradation problems in the rumen be fed. Milk production responses of between 2,2 and 5,8 kg FCM, with an average of 4,6 kg FCM, have been recorded per kilogram protected fat fed.

Increased levels of fat or oil in the diet have been shown often to depress the protein content of milk by approximately 0,28 % per kg fat fed. Increased levels of dietary fat will change the energy:protein ratio of the diet, and thus necessitate higher protein levels in the diet. It has been suggested that the CP content of the diet, in the form of undegradable protein, be increased by 1 % for every 3 % increase in dietary fat in excess of 4 % in the total diet.

When the ruminant is fed supplemental fats and oils there is an increase in the dietary requirement for calcium and magnesium which are required for optimal fibre utilization. It is therefore recommended that in the dietary dry matter, ration fibre levels be increased, and that the dietary calcium and magnesium levels also be increased to 0,9% Ca and 0,3% Mg to improve oil utilization.

FIBRE

One nutrient source unique to ruminants is fibre. Fibre is not a distinct chemical substance as such, but a general term given to a variety of different carbohydrate-type materials, especially cellulose, hemi-cellulose and lignin, which together form the cell walls of all plants. In general, the higher the fibre content of the overall diet, the lower is its digestibility.

The presence of long fibre in the diets of ruminants has a number of advantages. Fibre in diets can provide a more continuous flow of fermentable carbohydrate to the ruminal micro-organisms, and thus can improve the overall utilization of the diet. Both the slow and the fast fermenting carbohydrates therefore can act in a complementary fashion to produce an optimal substrate for the ruminal microbes. Acetic acid is the main fermentation product from the fermentation of long fibre. Acetic acid is an intermediate metabolite of milkfat, with nearly half of the milkfat being directly produced from acetic acid. Fibre is therefore an essential component of the diet if the maximum butterfat content of the milk is to be obtained. As a rule of thumb, if butterfat production is to be maintained, the fibre content of the total dry matter of diets should consist of not less than 16 % crude fibre (CF); 21 % acid detergent fibre (ADF) or 28 % neutral detergent fibre (NDF). Expressed in another way, the roughage component of the diet should not be less than 35 to 40 % of the total dry matter. To maintain its roughage character, a roughage should never be milled shorter than 10 mm in length. Milling roughages through 40, 20, 5 and 1 mm screens has been shown to reduce chewing activity by 20, 30, 50 and 75 % respectively. The provision of sufficient long fibre in the diet to permit at least 30 minutes of cud chewing time per day for each kilogram of dry matter intake is important. The proper selection of feeds to maintain rumen pH above 5,8 is also important. Research has shown that a proper balance of the fibre:starch ratio will increase dry matter intake and milk production. This can also be observed in practice on dairy farms throughout North America, Japan and Western Europe when proper attention has been given to the digestible fibre requirements for dairy rations.

DIGESTIBILIY

The digestibility of a feed is the proportion which is digested as it passes through the animal. The digestibility of feeds is determined by feeding the relevant feed to animals and measuring both intake and the faecal output. The difference between intake and faecal excretion is the digested fraction. The digestibility is expressed as the digested fraction divided by the intake as a percentage, *i.e.*:

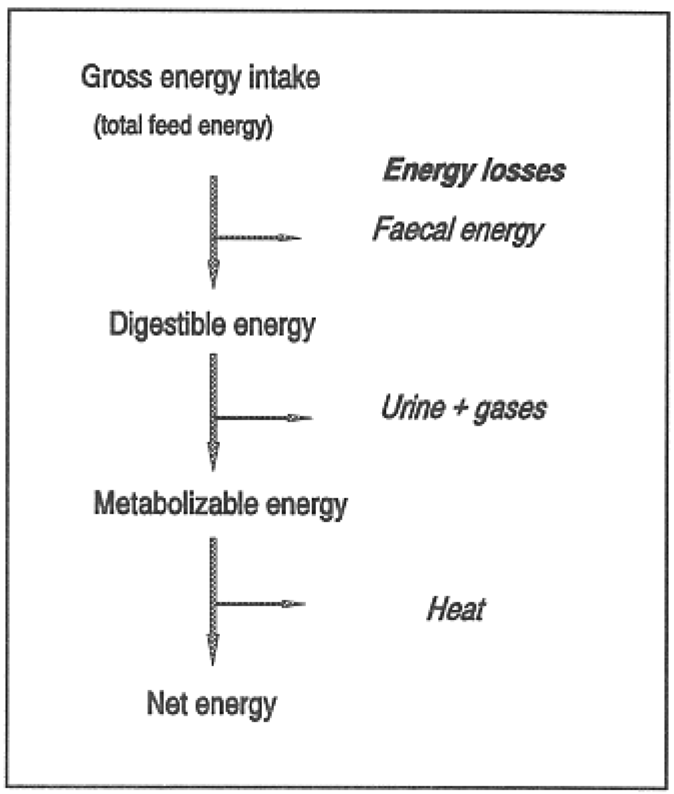
$$\text{Digestibility (\%)} = \frac{\text{feed intake} - \text{faecal output}}{\text{feed intake}} \times 100$$

Measures of digestility

There are various measures of digestibility, namely digestible energy (DE), digestible organic matter (DOM) and digestible dry matter (DDM), which are all measured directly. Total digestible nutrients (TDN) is an indirect measure which gives values very close to DOM in ruminants. These measurements give slightly different answers and therefore the appropriate set of animal requirements must be used for each measure.

Unfortunately not all of the digested energy is available for animal metabolic function and production. Energy is excreted in the urine as well as in the gases produced during the fermentation process in the rumen. These gases, which are lost by belching, are highly combustible, that means that they contain energy. When the energy losses from the animal body *via* the faeces, urine and combustible gases are accounted for, the energy remaining in the animal body is available for the body's metabolic processes. This measure of energy is known as metabolizable energy (ME). Metabolizable energy is thus the energy extracted from the feed and which is necessary to keep the animal alive (known as maintenance requirement), and for production. These energy losses in the animal are illustrated in Figure 1.

Figure 1. Partitioning of feed energy within the animal



Metabolizable energy does not account for the energy lost via heat production in the animal. When this heat loss, which is the source of energy for the metabolic processes, is accounted for, the remaining energy is called net energy (NE). Owing to the technical difficulties in measuring net energy, metabolizable energy has been accepted in many countries, including South Africa as the standard for measuring the energy value of feeds.

The efficiency of the dairy cow's digestive system is shown by the fact that it takes only 5,8 MJ of energy from the feed to produce one MJ of energy in the milk. This is the most efficient energy conversion of energy consumed to energy contained in the animal product by any animal species, including fish (6.9 MJ feed energy per MJ of product energy) and poultry (12.1 MJ feed energy per MJ supplied in eggs).

WATER

Water is essential for digestion and body function. An inadequate water supply can depress milk yields. Ensure that water is cool and is available in sufficient volumes to satisfy the cow. A dairy cows appetite for water can be satisfied long before it has reached its capacity for water, so if the water is slow to come through to the trough, the cow may be quite contented, but its milk yield can be down by 25%. These aspects are dealt with in detail in KwaZulu-Natal Dairy Leaflet 1.3.

HERBAGE INTAKE

Grazing management has been said to be "an art of successful compromise", *i.e.* a compromise between dry matter (DM) production and herbage quality. It has also been stated that many of the problems of nutritional management would disappear if cows were able to eat to capacity and to graze intensively simultaneously. It has been found that for every 5 to 10 kg extra pasture allowed between 15 and 50 kg DM/cow/day, one kg of extra DM intake is achieved and the quality of the herbage selected by the animal improves dramatically. Each additional kilogram of dry matter a cow consumes can produce an additional 1,0 to 2,5 kg of milk.

The relatively low intake of herbage by dairy cows grazing pasture is considered to be the major factor limiting milk production from pasture on temperate grassland. The peak potential intake for high yielding dairy cows can be over 3,25 % of livemass on a variety of diets. However, daily intakes of herbage are normally well below 3,0 % of livemass indicating that factors are operating which prevent the grazing dairy cow from consuming her potential intake. As the amount eaten daily depends on a range of animal, feed and environmental factors, the prediction of intake and the development of systems of grazing with predictable outcomes are very difficult.

Grazing behaviour studies have shown not only that cattle spend 8 to 9 hours each day grazing, but also that one of the four grazing periods takes place around midnight, even on dark nights. Cattle usually do two-thirds of their grazing during the daylight hours and one-third at night. In hot weather this pattern will change, with more grazing occurring at night.

Research results have shown that when daytime maximum temperatures are 20° C, about 60 % of all grazing is done between morning and afternoon milkings. At temperatures of 28° C about 35 % of all grazing is done during the day, and at temperatures of 30° C, less than 25 % of all grazing can be expected during the day. Cows do not graze at all when the temperature exceeds 35° C.

Pasture yield also influences grazing times. The time spent grazing has been found to increase as the yield of the pasture on offer increases. This trend continues up to 2,5 t DM/ha on tropical pastures. Above this level, the time cows spend grazing is reduced. It was found that below 2,5 t DM/ha, on tropical pastures, a deficiency of pasture could limit milk yield per cow. Observations have shown that when pasture yield is low, cows do not work harder to try to get their fill of pasture. In fact they reduce the effort put into grazing, with a consequent drop in milk production.

Observations have shown that cows graze for considerably less time when grazing temperate pastures as compared with tropical pastures. Research has shown that post-grazing residue yields should not be lower than 1,3 to 1,5 t DM/ha for lactating cows to maximize their dry matter intakes on temperate pastures, compared to the 2,5 t DM/ha for tropical pastures.

Pasture intake has been shown to increase with increases in pasture allowance per cow, the amount of pasture on offer (kg DM/ha) and digestibility. The relationship between intake and allowance is curvilinear, following a pattern of diminishing returns. For each additional kg of herbage offered above 10 kg DM/day, a Jersey cow will consume a maximum of 0,27 kg DM of the herbage. In addition, daily pasture intake increases by 1,11 kg DM/cow for every additional ton DM/ha of pasture on offer. Pasture intake also increases by 0,06 kg DM/cow for each unit increase in digestibility. It has been concluded that "to feed cows well, a farmer must offer each cow at least four times more than she is expected to eat", which results in abundant residual pasture which must be removed later, *e.g.* by topping or conservation. In rotational grazing systems, intakes of herbage are reduced when the daily herbage allowance falls to less than 70 g DM/kg liveweight, *e.g.* 35 kg per 500 kg cow, or when stubble height falls below 8 to 10 cm.

Present knowledge on grazing management is based almost exclusively on temperate pastures. Tropical pastures, however, may require different grazing management practices. The perception of a perfect pasture is based on many years of experience with temperate pastures where the ideal pasture is dense and short. Investigations with tropical pastures have revealed that taller pastures contain a higher yield of leaf than shorter pastures and that cows were quite happy to select amongst the stems and seedheads. Milk yields increased with increasing leaf yield and high leaf yields were only measured in tall pastures, often with large amounts of seedheads present.

The bottom line for maximum animal production is never to restrict feed intake in any way, *e.g.* no night grazing or restricted access to water, especially in hot weather.

CONCLUSION

The dairy cow is one of the most complex farm animals because she can be growing, lactating and pregnant all at one time. In addition, she also requires energy and protein for maintenance. Therefore the utilization of dietary energy and protein depends upon the interaction amongst these various physiological demands, which can vary from time to time. The system is a dynamic one in which body reserves are also mobilized, or deposited, at various stages of lactation. Consideration of feed inputs and milk output alone is an oversimplification of the biology of the cow.

Nutritional research over the past 25 years has made it possible to formulate the more basic principles of nutrition applicable to dairy cows. The earlier-established principles of an input-output relationship between feed energy and milk energy, operating on a day-to-day basis, has been questioned. The input-output philosophy ignores the fact that responses in milk yield to an increment or decrement of feed are not fully registered immediately. There is a lag, such that only 60 to 70 % of the response occurs in the first seven days following the change in input; by fourteen days this response has reached about 90 %. Yet feed allowances are usually adjusted weekly and time lags in response are ignored. Each cow has its own response curve, unique to a specific lactation, as a result of previous and current management.

Milk yield per day has held the stage for too long as the sole, or major, measure of output from the dairy cow. Actual milk production is not only the result of immediate feeding and management, but is also influenced by long-term conditions. Factors other than concentrate feeding must also be taken into account when considering yield responses. For example, heifer rearing forms part of the lifetime output. Thus, the limitations of the day to day approach are being recognised. It has gradually become appreciated that each lactation should be considered not only as a complete unit rather than an aggregate of individual and independent days, but also that one lactation influences the next. That is, we should plan life-time performance, and plan the feeding strategy accordingly.

FURTHER READING

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