2. Digestible and Metabolisable Energy

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Learning objectives

On completion of this topic you should be able to:

- Describe the concept of digestible energy
- Describe the concept of metabolisable energy (ME)
- Discuss the nutritional factors affecting DE and ME
- Apply the law of conservation of energy and account for all ingested feed energy.

Key terms and concepts

Feed digestibility; availability of energy; Gross Energy; Digestible Energy; Metabolisable Energy; Net Energy; efficiency of energy use for different body functions; factors affecting digestible energy intake; feeding systems for energy.

Introduction to the topic

The commonly used unit of energy is the megajoule (MJ) although the 'calorie' is also used. One calorie is the amount of energy required to raise the temperature of 1 ml of water 1 degree Celsius and 1 MJ equals 4128 calories or 4.182 kcal. All living cells require energy to maintain their integrity and to grow and produce secretions and so on. Only chemical energy can fulfil cellular needs and this is provided by the organic materials an animal ingests. (The energy in organic matter comes from solar energy trapped by photosynthesis in plants.) Energy cannot be created or destroyed – so the energy ingested can be accounted for by adding that excreted to that retained in tissues and that converted to heat. The energy stored chemically in organic materials (the Gross Energy, GE) is released as heat if the material is completely oxidised in cells or combusted in an oxygenated atmosphere.

The first law of thermodynamics states the principle of conservation of energy, i.e. that energy cannot be created or destroyed, but only changed from one form to another. Thus, chemical energy may be converted in cells into heat (or perhaps light or sound energy).

2.1 Feed digestibility and availability of energy

The fraction of the chemical energy in a feed ingredient that is useful to the animal's tissues is determined by the extent of digestion and absorption of the nutrients contained in the feed and the efficiency of conservation of the energy within the tissue cells. The way that energy is 'processed' by animals in the gut and in the tissues of animals is summarised in Figure 3–1.

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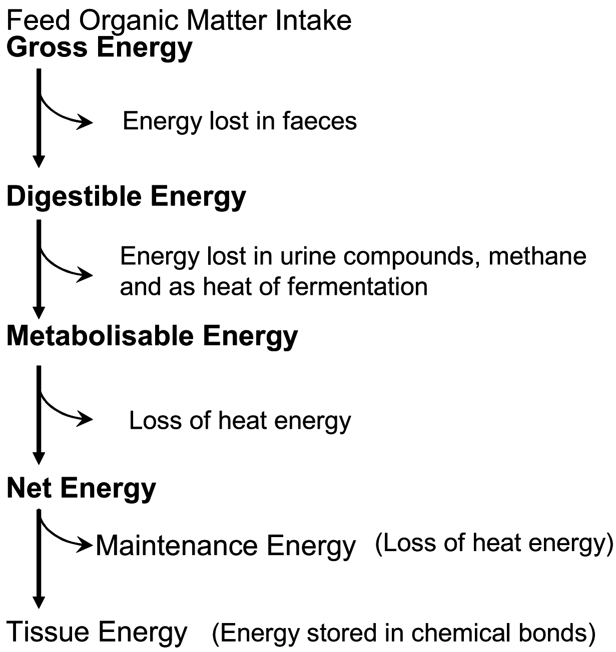
Figure 2.1 Partitioning the gross energy of feed into fractions of increasing usefulness to the animal. Source: Rowe and Nolan (2006).



It is important to understand these components and to realise that all of the gross energy is accounted for in the subsequent categories (energy conservation applies): energy is either conserved in chemical forms in the tissues or released as excreted products or as heat. Net Energy availability is often only about 50% of the GE intake.

Gross energy—(GE) is the total energy released through oxidation when a sample of feed is ignited in an atmosphere of pure oxygen. The resulting combustion produces energy in the form of heat. In analytical laboratories, this method of determining the gross energy content of a feed is done in an instrument known as a Calorimeter Bomb. The amount of heat released from any sample depends on its composition as shown in Table 2–1. In tables produced by the Qld DPI, the values for a sample of meatmeal used for feeding adult birds are given as 12.1 and 10.0 MJ/ kg for DE and ME content. The tabulated values reflect the gross energy values of the fat, protein and carbohydrate in meatmeal and the respective digestibilities of these components, and the further effect of an ash content of 32% in reducing the 'energy density' of the meatmeal.

Different feed groups and their gross energy values are summarised in Table 2-1.

Table 2.1 Gross energy of major chemical constituents of feed as determined by bomb calorimetry. Source: UNE animal science database.

Constituent	Gross energy (MJ/kg DM)
Carbohydrate	18
Protein	24
Fat	**39**

Digestible energy—(DE) is the difference between gross energy intake and the amount of energy excreted in the faeces.

Metabolisable energy—(ME) is the difference between the digestible energy and the loss of energy in the form of urine and methane gas released by rumen and hind–gut microbes. ME is approximately 81% of DE in ruminants, which means that approximately 19% of DE is lost as urine and methane energy.

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***Net energy*—**(NE) is the amount of energy available for use by the animal from ME after accounting for the heat that is generated during the processes of digestion and metabolism. This heat is, in effect, a consequence of the inefficiency of ME use. NE can be further divided into energy used for maintenance and for production. All of the energy used for maintenance is also released as heat.

Gross energy

When a feed sample is combusted in a Bomb Calorimeter, the heat energy released is referred to as the *gross energy of the feed* (GE). However, as we have seen already, the gross energy of a feed is not all digested and absorbed (i.e. not all of it is 'digestible'). Some feed energy passes through the gut and is lost in undegraded materials in faeces. The amount that is absorbed from the gut depends on the types of carbohydrates and lipids present and is much lower when there are high concentrations of indigestible fibre and lignin present. Straw, for example, has a lower digestibility than starch. This means that less energy is extracted by the animal from straw as it passes through the gut than from the same amount of starch.

Digestible energy

The *digestible energy intake* (DEI) of an animal is the gross energy intake in feed multiplied by the digestibility coefficient of the feed. The apparent digestibility coefficient (or more simply 'the digestibility of the feed material') is calculated as

$$\frac{\textbf{[amount of GE ingested minus the GE in the faeces]}}{\textbf{[GE in feed ingested]}}$$

Not all of the digestible energy (DE) is actually available for use within the animal. Some energy is released as methane by eructation (burping) and in flatus, having been produced by anaerobic gut microbes, and some is excreted in energy–rich compounds in the urine. In ruminants, the DE lost by these two routes may be up to 19 % of the GE. The remaining energy (about 81 % of DE) is referred to as the metabolisable energy (ME). This is the energy available to cells in the body for metabolism—for *maintenance* (enabling cells to stay alive and to function effectively), and for deposition of protein and fat and other materials in products such as meat or milk (referred to as *production*). The ME content of a feed is usually tabulated as ME/kg 'as fed', or ME/kg DM (often abbreviated to M/D). A point of practical significance is that the ME value of feeds may be higher when expressed on a 'dry matter' basis in contrast to an 'as fed' basis (and this difference can greatly affect the cost effectiveness of some ingredients compared with others).

The chemical composition of feeds can be determined by wet chemistry or predicted from Near Infrared Spectrometry (NIR, see Topic 10 for more detail) using calibrations obtained by wet chemistry. Digestibility can be determined in vivo (see next section) or predicted by *in vitro* or *in situ* techniques or by NIR.

2.2 Apparent digestibility and digestible energy intake

The single most important characteristic of a feed for understanding its nutritional value is its digestibility. Would it be better to give your dairy cow 5 kilograms of wheat or 5 kilograms of sawdust? Both release about the same amount of heat energy if combusted, i.e. they have the same gross energy but sawdust has vastly lower DE and ME values. The digestibility of a feed is largely determined by its intrinsic chemical and physical properties. The amount of starch and sugar (which a highly digestible) present relative to the less digestible structural carbohydrates (fibre) and lignin and cell-wall materials are also important determinants of digestibility. In practice, digestibility is estimated in a number of ways.

In vivo. Estimates of digestibility made *in vivo* (i.e. 'in the living animal') are derived by measuring the amount of feed ingested and the amount of faeces excreted by animals housed in specially designed crates in which the faeces and urine excreted can be separated. Estimates of the digestibility of dry matter, or any other component of the dry matter, e.g. protein, energy or an individual mineral, can be made in a similar way. Digestible DM intake is

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given by feed DM intake multiplied by feed DM digestibility. Digestible energy intake can be similarly calculated if the gross energy of feed and faeces DM are known. Such experiments give a ‘real’ estimate of the digestibility of the feed sample under the conditions existing when the evaluation was made, but are time–consuming and expensive to carry out. Thus other simpler procedures are often used.

In vitro (meaning, literally, ‘in glass’). The processes of digestion are simulated in test tubes in the laboratory. Synthetic digestive enzymes or rumen fluid, with living microbes to secrete digestive enzymes, can be used.

***In situ* digestibility** (ruminant). Feed samples (ground to simulate chewed material) are placed in a porous bag (40 mm pores) that enables rumen fluid and microbes to enter the bag from outside, but prevents feed particles inside from being lost unless they are first digested to soluble compounds. The rate and extent of feed disappearance is estimated over time. This method is very dependent on how finely the feed is milled before being placed in the sac.

Both the *in vitro* and *in situ* (sometimes called *in sacco*) techniques give quite good predictions of *in vivo* digestibility, and are convenient and relatively inexpensive to perform.

Digestibility is also sometimes predicted from measurements of the chemical composition of feeds. NSW DPI has used the following equation to predict dry method digestibility of roughages, *viz.*

Digestibility of DM = 83.6 – 0.82ADF% + 2.62N%

Metabolisable energy

Metabolisable energy represents the energy available for tissues which use it for firstly for maintenance purposes and then any remaining energy can be used to synthesise new polymers to go towards body gain or product production.

For ruminants, ME is often predicted from DE as follows:

ME intake = 0.81 x DE intake

The 19% loss of DE implied by this equation is an approximation of the energy losses, mainly via methane, urinary compounds and heat production by microorganisms in the rumen. Percentage methane losses from non–ruminants are relatively low, and differences between DE and ME are therefore much smaller.

For ruminant feeds, ME content is usually about 81% of DE content - the other 19 % of GE is lost as heat and methane.

Feed dry matter digestibility in ruminants

In the case of ruminants, feeds of intrinsically low digestibility will be even less well digested by microbes in the rumen if there are deficiencies of nitrogen or other minerals that restrict the ability of the microbes to grow and ferment feed constituents efficiently. Thus, the efficiency of digestion of low–quality feed may be increased by supplementing ruminants with urea or sulphur when the diet is low in protein (other minerals are usually adequate for rumen microbes). This is the basis for supplementing cattle with urea–molasses blocks when they are grazing on dry standing roughage. The cattle have the potential to digest more of the feed, but the lack of protein building monomers for the microbial cells limits the microbial rate of growth which in turn reduces the rate of digestion of feed and lowers digestibility in the rumen.

- Low digestibility in the rumen means feeds must be retained for prolonged periods in the rumen to enable them to be *reduced in size* (comminuted) sufficiently, by rumination and microbial digestion, to pass out of the rumen. Slow rumen emptying causes the rumen to become distended and this causes the animal to reduce its feed intake.

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- Low digestibility and low intake leads to low digestible DM intake and low ME intake. This is often made worse by nutrient (N and S), deficiency in the rumen, and imbalance in the ratio of protein to energy (P:E ratio) in the materials available for absorption from the gut.

- Fine grinding increases the surface area available for microbial attachment and digestion and may increase feed intake. But it also decreases feed retention time in the rumen which tends to decrease digestibility in the rumen. As a consequence, there may be increased fermentation in the large intestine.

- Rate of passage of digesta through the rumen (referred to as dilution rate) increases when animals are in cold environments and decreases in heat stressed animals. Lower retention times of digesta (and microbes), i.e. higher dilution rates, tend to increase the efficiency of microbial growth in the rumen which improves microbial supply to the host.

Acids and alkalis have been used to treat hay, straw and other agricultural by– products to increase their digestibility. (These chemicals are more effective than the enzymes of microbes in breaking the chemical bonds in complex carbohydrates such as cellulose and releasing their constituent sugars, but some are corrosive and dangerous to use.) If using treated materials, it is important to recognise that the increased potential digestibility may only be achieved if the rumen microbes are given even more building monomers to allow them to take advantage of the extra available energy in the chemically treated feed materials, i.e. microbes require a balanced supply of nutrients.

2.3 Feeding systems for energy

A number of feeding systems are based on the use of DE or ME to describe the requirements of the animal and the amount of useable energy that various feeds can provide. Requirements are usually determined by calculating the animal's energy needs for survival (maintenance) then adding additional requirements for growth and product synthesis.

The energy in feeds that is available to meet an animal's requirements depends on digestibility. Table 2–2 summarises the ME content and the concentration of fibre in various sources of feed grain and roughage for ruminants.

Table 2.2 Metabolisable energy and acid detergent fibre (ADF) content of ruminant feeds Source: Feed Evaluation Service, NSW Agriculture.

Feed	ME (MJ/kg DM)	ADF (%)	Description
Wheat grain	13	3.9	Concentrate
Barley grain	12.2	8.8	Concentrate
Oat grain	12.0	19.9	Concentrate
Grazing oats	10.4	26.0	Forage/roughage
Lucerne	9.1	36.6	Forage/roughage
Oaten hay	8.0	39.6	Roughage
Wheat straw	6.0	54.1	Roughage

It is clear from the information in Table 2–2 that the ME content of the diet decreases with increasing amounts of indigestible fibre (ADF, acid detergent fibre) in the form of roughage. Among the grains, oats provides a high level of ME even though it has considerable fibre in the hull. This is because oat grain contains around 7 times more oil (approximately 7%) than wheat or barley. If all dietary factors are well balanced, and provided there is a normal and efficient pattern of rumen fermentation, then the amount of energy that the animal can ingest and its growth rate are closely related to the DE or ME concentration of the diet. Although this is a good general rule, it should be applied with great caution because there are four major areas where the relationship between ME concentration in the diet and performance of the animal can break down. These are listed below:

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(a) a deficiency of nutrients for rumen microbes (normally this means a deficiency of nitrogen or sulphur on low quality feeds);

(b) too much lipid for microbial activity and for efficient fibre degradation;

(c) too much readily fermentable carbohydrate in the form of sugars or starch leading to acidic conditions in the rumen, poor feed utilisation and a low intake; or

(d) an imbalance in nutrients absorbed by the animal and/or toxic factors in the feed which can reduce feed intake irrespective of the ME concentration of the diet.

ME values found in tables of feed constituents have normally been determined in animals given 'well– balanced' diets — they may overestimate the ME available to animals if the feeds are given in diets that are imbalanced.

2.4 Factors affecting digestible energy intake

Based on the simple principle that the digestive tract has a finite capacity to hold and process feed, it is logical to conclude that animals should be able to ingest greater quantities of those feeds that are more digestible and more quickly digested in the rumen. The more fermentable or digestible feeds are more quickly broken down into small particles and cleared from the digestive tract and this makes space for new feed to be added. There are however some important exceptions to this basic principle and these have already been outlined above.

Nutrients for rumen microbes

Table 2–3 shows the response in terms of dry matter intake and live–weight gain when cattle with access to tropical grass hay were given different supplements. The first supplement considered was urea. Simply by providing additional N for the rumen microbes, the intake of grass was increased by around 50%, from 2.26 kg/d to 3.01 kg/d. In this example it was not the digestibility of the basic feed that limited feed intake but rather the amount of N available to the rumen microbes that ferment the roughage that was the primary factor limiting the amount of feed the animals could eat.

Table 2.3 Dry matter intake and live–weight change in cattle (initially 170 kg live– weight) fed a tropical grass hay when supplemented with urea or urea plus an escape protein supplement (cottonseed meal).
Source: unpublished data from D. Hennessy, NSW Agriculture.

	Dry Matter Intake (kg/day)	Live-weight Change (kg)
Native tropical grass hay	2.25	-0.41
Hay + urea	3.01	-0.32
Hay + cottonseed meal	3.72	0.11
Hay + cottonseed meal + urea	4.43	0.22

Too much lipid slows rumen fermentation and limits intake

When the level of lipid in the diet exceeds around 5%, the lipid reduces the ability of rumen microbes to degrade fibre. This negative effect on fibre degradation, in turn, further reduces the amount of roughage that the animal can ingest, and so has a negative effect on feed intake.

Problems associated with high levels of fat inclusion in the diet have only been of practical significance in recent years, since oil and fat have become unwanted by–products in diets in many Western countries where obesity and heart disease have become major problems. The reduced demand for fat in the human diet means it can be fed to animals as a by–product.

High levels of dietary fat can become important in certain diets for dairy cattle where lard is used to increase the DE density of the ration.

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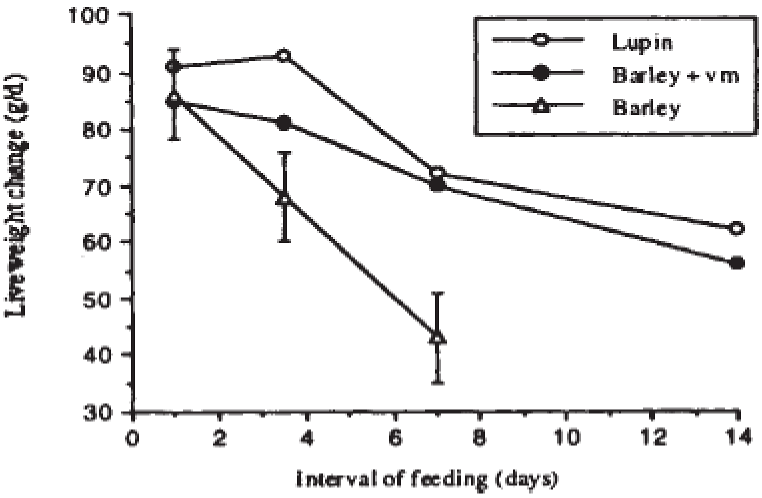
Acidosis associated with grain feeding

Cereal grains are included in diets to increase the DE content of the diet. However, there are potential problems when grain is a high proportion of the diet of ruminants. The rapid fermentation of starch leads to a decrease in pH and this, in turn, reduces the digestion of fibre and leads to a reduced feed intake. With severe acidosis, lactic acid is produced and if absorbed, also has a direct toxic effect on the animal that reduces feed intake independent of the effect of the lower rumen pH on fibre digestion. This adverse effect of cereal grain on the feed intake can cause a dramatic reduction in the total amount of DE available to the animal. In many situations a change in diet designed to increase DE intake, through supplementation with grain, can actually decrease the DE available to the animal.

Figure 2.2 shows the adverse effects on live–weight gain of increasing the amount of grain fed at any one time. With infrequent feeding of grain supplements under grazing conditions, the amount of grain presented to animals on each occasion quickly reaches the stage were it is likely to lead to acid build–up through the rapid fermentation of large quantities of readily fermentable carbohydrate. This example shows responses of sheep to supplements of lupin and barley grain. Both grains contain similar DE contents and when fed in small amounts each day, both produce similar levels of live–weight gain. However, when fed at weekly intervals, the value of barley as a supplement is significantly lower than that of lupins. This is due to the adverse effects of acid build–up in the rumen and hind gut. If these effects of acidosis are prevented, using virginiamycin, animal performance on barley is similar to that on lupins.

Figure 2.2 The effect of feeding barley or lupin grain daily, twice weekly, weekly or fortnightly at levels equivalent to 200 g/d to animals with free access to hay containing 1.5% urea. The barley was fed with or without virginiamycin (Vm). The bars represent the standard error of the difference between treatments. Source: Godfrey *et al*. (1993).



An imbalance in the nutrients absorbed by the animal can limit intake and production

If nutrients are not absorbed from the gut in the optimum ratios required for growth or production, then intake can be reduced. This effect on intake is different from the intake limitations caused by low digestibility of feed in the rumen, i.e. animal factors rather than rumen factors are responsible.

Table 2–3 shows data for the supplementary feeding of cattle given tropical grass and supplemented with urea and/or cottonseed meal. DM intake was higher when animals were fed a supplement of cottonseed meal and urea than when fed urea on its own. Cottonseed meal provides protein directly to the animal, adding extra protein to that available from the rumen microbes, i.e. ‘escape protein’. The increased intake of DM in response to the additional protein

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from cottonseed meal suggests that the animals' tissue requirements for protein were not fully met just by microbial protein. When the additional protein was available, the imbalance of amino acids relative to available energy was corrected, and then DE intake was further increased in order to achieve a new balance with the extra protein relative to energy available to the tissues. For the high producing dairy cow, with her very high demand for protein at peak lactation, there is good evidence that feed intake is increased in response to supplements that supply 'escape' protein.

In summary, the amino acid to energy ratio in the absorbed nutrients determines whether the animal can grow or produce at a level close to its genetic potential. Even though energy and protein are usually of most practical importance, it must be remembered that a single mineral or vitamin could be the first limiting nutrient. A deficiency of phosphorus supply, for example, could create the situation where efforts by the nutritionist to adjust energy and protein would not improve growth or production.

Readings

The following readings are available on CD:

1. Krehbiel, C.R., Ferrell, C.L. and Freetly, H.C., 1998 'Effects of frequency of supplementation on dry matter intake and net portal and hepatic influx of nutrients in mature ewes that consume low-quality roughage', *Journal of Animal Science,* vol. 76, pp. 2464-2473.
2. Soto-Navarro, S., Krehbiel, C.R., Duff, G. and Galyean, M., et al. 2000, 'Influence of feed intake fluctuation and frequency on nutrient digestion, digesta kinetics and ruminal fermentation profiles in limit-fed steers', *Journal of Animal Science,* vol. 78, pp. 2215-2222.

Activities

Available on WebCT

Multi-Choice Questions

Submit answers via WebCT

Self Assessment Questions

1. What is meant by the 'gross energy content' of a feed and how can it be estimated?
2. What is meant by 'metabolisable energy' and how does ME content of a feed differ from its digestible energy content?
3. What are two important roles of metabolisable energy in growing animals?
4. Since energy used for maintenance, like all forms of energy, cannot be destroyed, were does this energy end up?

Useful Web Links

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Assignment Questions

Choose ONE question from ONE of the topics as your assignment. Short answer questions appear on WebCT. Submit your answer via WebCt

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Summary

Summary Slides are available on CD
The digestible energy intake from a feed is the gross energy less the energy lost to the animal through faeces. The amount of energy lost via faeces is variable and can be influenced by chemical and physical factors of the feed and also by the feeding regime, i.e. the digestibility of the feed is affected. For example, a reduction in the pH of the rumen environment below 5.2 (by giving ruminants high concentrate rations without adaptation) will increase the feed energy lost through the faeces and therefore reduce digestible energy intake. Feeding management is important not only for animal health, but also ultimately, for animal performance.

References

Godfrey, S.I., Rowe, J.B., Speijers, E.J. and Toon, W., 1993, 'Lupins, barley, or barley plus Virginiamycin as supplements for sheep at different feeding intervals', *Australian Journal of Experimental Agriculture,* vol. 33, pp. 135–140.

Hennessy, D., unpublished data. 'Dry matter intake and live-weight change in cattle'. NSW Department of Primary Industries.

NSW Department of Primary Industries. 'Feed Evaluation Service', NSW Agriculture, Armidale.

University of New England, Animal Science Nutritional Database.

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