4

What is in feeds?

This chapter

Explains the important constituents of feed for dairy cows and how ration ingredients are sampled and analysed for chemical analyses.

The main points in this chapter:

- dry matter (DM) is the feed remaining after all the water has been removed – all other components of feed are expressed as a proportion of dry matter
- digestibility (expressed in %) is the proportion of a feed which is not excreted as manure, and is used to describe feed quality
- Metabolisable Energy (ME) is the energy available from feed used by the cow for maintenance, activity, milk production, pregnancy and weight gain
- Total Digestible Nutrients (TDN) is sometimes used to describe energy available in feeds
- Crude Protein (CP) includes both true protein (made up of amino acids) and Non-Protein Nitrogen (NPN) which rumen microbes can convert into protein
- Neutral Detergent Fibre (NDF) is the preferred measure of dietary fibre – it includes indigestible and digestible fibre
- Crude Fibre (CF) is used to describe dietary fibre in certain countries, because of its inclusion in TDN calculations
- it is important to obtain a representative sample of any feed to be analysed, ensuring minimum deterioration between sampling and its arrival at the testing laboratory.

4.1 Dry matter

Dry matter (DM) is that portion of the feed remaining after all the water has been removed. The dry matter part of a feed contains the nutrients: energy, protein, fibre, vitamins and minerals. Dry matter is measured by weighing samples of feed before and

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after they have been dried at 100°C for 24 hours. The proportion of dry matter in a feed is usually expressed as a percentage of the wet feed. Different feeds contain different proportions of dry matter and water (Figure 4.1, Table 4.1).

The chemical composition of tropical feeds is sometimes expressed in terms of percentage of fresh feed, in which case, that value should be divided by the DM content, expressed as a proportion (not a percentage). For example, if the protein content of fresh grass is 2% (of its fresh weight) and its DM content is 20%, then its protein content is 2 ÷ 0.2 or 10% on a DM basis.

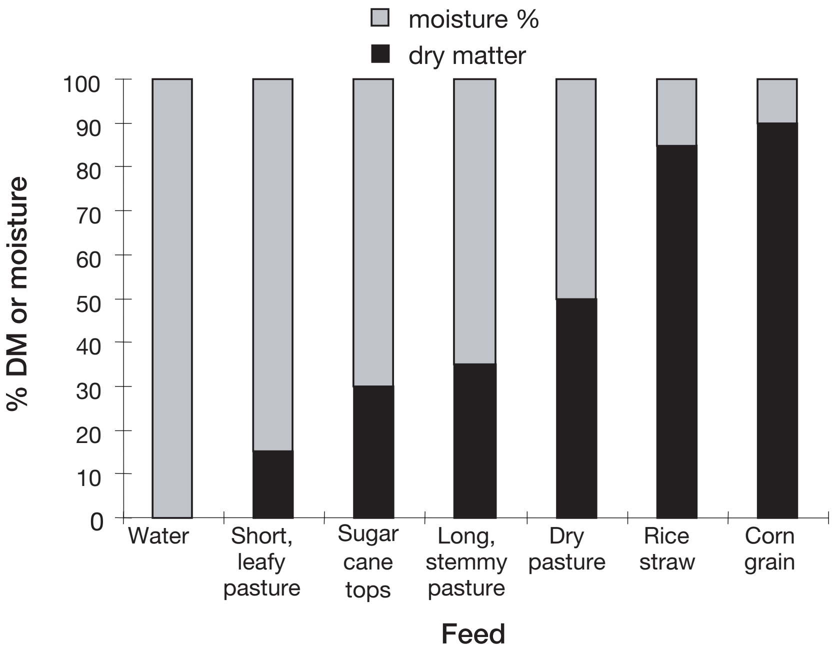

Figure 4.1 Dry matter and moisture content of some typical tropical feeds.

Table 4.1 The approximate dry matter and moisture content of some typical tropical feeds

Dry matter (%)	Moisture (%)	Feed
0	100	Water
10	90	Banana stems
20	80	Young pasture
30	70	Corn silage
40	60	Mature pasture
50	50	
60	40	
70	30	
80	20	Urea treated rice straw
90	10	Corn grain
100	0	

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4.2 Energy

The energy in feed is a measure of that feed's ability to help the cow function and be productive. All feeds have a gross energy value (Figure 4.2). Some of the gross energy is lost in the faeces. The energy that is absorbed by the cow is termed digestible energy. From the digestible energy, further energy losses occur in the production of urine, as well as digestive heat and gas. All the remaining energy is known as Metabolisable Energy (ME).

Megajoules are used to measure energy content, although the term megacalories is still sometimes used. The higher the value in megajoules, the better the quality of the feed. In certain South-East Asian countries, energy is often described in terms of Total Digestible Nutrients (TDN).

The Metabolisable Energy (ME) is the energy available for use by the cow: it is the energy used for maintenance of body systems, activity, milk production, pregnancy and weight gain.

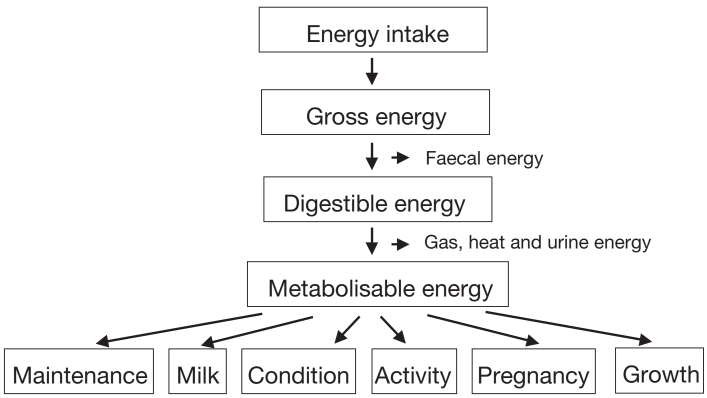

Figure 4.2 The flow and partitioning of dietary energy through the cow.

4.2.1 How energy is measured

Three measures of energy are digestibility, Metabolisable Energy and Total Digestible Nutrients.

Digestibility

Digestibility relates to the portion of food which is not excreted in the faeces and so is available for use by the cow. Digestibility is not a direct measure of energy, but it does indicate overall feed quality. The greater the digestibility, the greater the benefit of that food to the cow because the cows are able to digest and use more of the feed. Thus, the higher the digestibility, the higher the Metabolisable Energy.

Digestibility is commonly measured as a percentage. A grass with a digestibility of 50%, for example, means that only half of the feed eaten will actually be of use to the animal. The other half will be excreted in the faeces. The digestibility of various feed constituents can be determined, with Organic Matter Digestibility (OMD) sometimes being used to describe feed quality. OMD is a measurement of the percentage of digestible organic matter per total dry weight.

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Metabolisable Energy

Cows cannot use all the energy released by digestion. Some of the energy is belched out of the rumen as methane and carbon dioxide, some is passed out in the urine while some is lost as heat created during rumen fermentation (Figure 4.2). The energy in a feed that a cow can use for its metabolic activities (ie maintenance, activity, pregnancy, milk production, gain in body condition) is called Metabolisable Energy. The Metabolisable Energy content of a feed can be calculated directly from its digestibility.

The Metabolisable Energy content of a feed (also called its energy density) is measured as megajoules of Metabolisable Energy per kilogram of dry matter (MJ ME/kg DM), although some United States texts express energy in megacalories per kilogram of dry matter (Mcal ME/kg DM). Intake of Metabolisable Energy is expressed in megajoules per day (MJ/d).

The higher the energy content of a feed, the more energy is available to the animal. If a feed contains 10 MJ/kg DM, then each kilogram of dry matter of that feed contains 10 megajoules of Metabolisable Energy available for use by the cow. A feed containing 12 MJ/kg DM then has a higher energy content than a feed containing 10 MJ/kg DM.

For most roughage feeds, it is possible to convert digestibility to Metabolisable Energy as follows:

$$\text{ME} = 0.17\ \text{DDM\%} - 2.0$$

For corn silage, because of its higher organic matter content, the conversion equation should be:

$$\text{ME} = 0.16\ \text{DDM\%} - 0.8$$

where DDM% is dry matter digestibility (%) and ME is Metabolisable Energy (MJ/kg DM).

Total Digestible Nutrients

An alternative method to describe feed energy is Total Digestible Nutrients (TDN). This is an older energy system but it is used in the United States and some countries whose nutritionists studied in the United States. It is not used formally in Australia and other countries whose nutritionists studied in England. It is a less accurate measurement of energy than Metabolisable Energy because it does not take into account energy losses via methane (from rumen digestion) and urine. The two systems are interchangeable through the use of conversion equations (National Research Council 2000). Total Digestible Nutrients content is expressed as a percentage, with Total Digestible Nutrients intake expressed in kg/d.

The amount of Total Digestible Nutrients is calculated from the proportions of digestible crude protein, crude fibre, nitrogen free extract and ether extract (or crude fat). Nitrogen free extract is the difference between the total dry matter and the sum of ash, crude protein, crude fibre and ether extract. As it is difficult to measure the digestibility of all these feed nutrients, Total Digestible Nutrients must be calculated from prediction equations of the total content of each of these feed nutrients. This requires separate equations for various feed types. Some generalised equations are available, and the following provides a reasonable prediction of Total Digestible Nutrients from the concentration of individual feed nutrients:

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TDN = 5.31 + 0.412 CP% + 0.249 CF% + 1.444 EE% + 0.937 NFE% **Equation 1**

where CP% is percentage crude protein, CF% is percentage crude fibre, EE% is percentage ether extract, and NFE% is percentage nitrogen free extract.

The following equations allow a conversion from Metabolisable Energy to Total Digestible Nutrients, and from Total Digestible Nutrients to Metabolisable Energy:

$$TDN = 5.4\ ME + 10.2$$

$$ME = 0.185\ TDN - 1.89.$$

Throughout this manual, references to the energy density of feeds will be given in these two measures, as Metabolisable Energy (as MJ/kg DM) and Total Digestible Nutrients (as %). References to the energy requirements or intakes of cows will also be presented in these two measures, either as Metabolisable Energy (MJ/day) or Total Digestible Nutrients (kg/d).

To facilitate the calculation of energy values of forages and concentrates, I have developed an EXCEL spreadsheet that calculates Total Digestible Nutrients and Metabolisable Energy contents of feeds directly from their chemical analyses using Equation 1 above. This program, 'the TDN workbook', is freely available from the author, Dr John Moran, at john.moran@dpi.vic.gov.au.

Table 4.2 presents the relationship between digestibility, Metabolisable Energy and Total Digestible Nutrients, while Table 4.3 presents the interconversion between the two.

Table 4.2 Relationship between dry matter digestibility, Metabolisable Energy and Total Digestible Nutrients

Dry matter digestibility (%)	Metabolisable Energy (MJ/kg DM)	Total Digestible Nutrients (%)
40	4.8	36
45	5.6	41
50	6.5	45
55	7.3	50
60	8.2	54
65	9.0	59
70	9.9	64
75	10.7	68
80	11.6	73
1 unit	0.17 unit	0.9 unit

Table 4.3 Interconversion between Metabolisable Energy and Total Digestible Nutrients

Metabolisable Energy (MJ/kg DM)	Total Digestible Nutrients (%)	Total Digestible Nutrients (%)	Metabolisable Energy (MJ/kg DM)
4	32	30	3.7
5	37	40	5.5
6	43	45	6.4
7	48	50	7.4
8	53	55	8.3
9	59	60	9.2
10	64	65	10.1
11	70	70	11.1
12	75	80	12.9
1 unit	5.4 units	1 unit	0.185 unit

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4.2.2 Types of energy

Energy can come from various parts of the feed. Carbohydrates, fats and oils, and even protein can provide energy.

Carbohydrates

Plant tissue dry matter is about 75% carbohydrates. Carbohydrates are the main source of energy for livestock. Sugar molecules of various types are the building blocks of carbohydrates. The sugars are chemically bound together in different numbers and in a variety of ways to form the three types of carbohydrate: soluble, storage and structural.

Soluble carbohydrates are the simple or individual sugars found in the cells of growing plants. They are digested and used almost instantly by the microbes in the rumen. Soluble carbohydrates are digested 100 times faster than storage carbohydrates. Soluble carbohydrates are found more in leaf than in stem.

Storage carbohydrates are made up of sugar subunits which are chemically bound together and are found inside plant cells. Starch is an example of a storage carbohydrate. Storage carbohydrates are digested about five times faster than structural carbohydrates. Storage carbohydrates are found in grains, leaf and stem and in the bulbous roots of fodder crops.

Structural carbohydrates are fibrous components of plant cell walls. They provide the structural support that plants need to grow upright. Pectin, hemicellulose, and cellulose are all structural carbohydrates. Large amounts of structural carbohydrate are found in mature pasture and straw. Lignin and silica are often associated with structural carbohydrates in plants. They give structural support to plants but are indigestible and are not actually carbohydrates. They can bind to the structural carbohydrates and make them less digestible.

Fats and oils

Only 2% to 3% of forages are fat or oil. Fats and oils include vegetable oils, tallow (animal fat) and processed fats. No more than 5% of a cow's total intake of dietary dry matter should be fats. Fats can decrease the palatability of the diet and coat the fibre, interfering with its digestion by rumen microbes.

Protein

The rumen microbes can use a surplus of protein in the rumen for energy. This is, however, an inefficient use of protein.

4.2.3 Energy and milk production

Diets for three cows, producing 13 L, 17 L or 20 L is shown in Table 4.4. The second column shows the amount of energy each cow needs to eat each day to produce that amount of milk.

The dairy farmer has two feeds available to give to the cows:

- mature pasture, with an energy density of 8 MJ/kg DM of Metabolisable Energy and
- green, leafy grass, with an energy density of 10 MJ/kg DM of Metabolisable Energy.

To produce more milk, a cow must eat more dry matter. If lower quality (ie lower energy density) feed is provided (eg 8 MJ/kg DM), the cow must eat more of it.

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Therefore, to produce 20 L of milk on the mature pasture, a cow must eat 20 kg DM/d – a virtually impossible task.

Table 4.4 Cows fed diets of different energy density and producing at three levels of milk production: amounts of dry matter required daily

Milk yield (L/d)	Daily energy requirement (MJ ME)	Daily required intake (kg DM)	
		8 MJ/kg DM	10 MJ/kg DM
13	125	15.6	12.5
17	146	18.2	14.6
20	161	20.1	16.1

4.3 Protein

4.3.1 Types of protein

Crude protein

Dietary protein is commonly termed 'crude protein'. This can be misleading, because crude protein percentage (CP%) is not measured directly but is calculated from the amount of nitrogen (N%) in a feed:

$$CP\% = N\% \times 6.25$$

Some of the nitrogen is true protein, whereas there are other sources of nitrogen, called Non-Protein Nitrogen (NPN). The microbes in the rumen are able to convert this non-protein nitrogen into true protein if sufficient energy is available to them. Because of this, both sources of nitrogen can be used as protein source by the cow. The components of crude protein are shown in Figure 4.3.

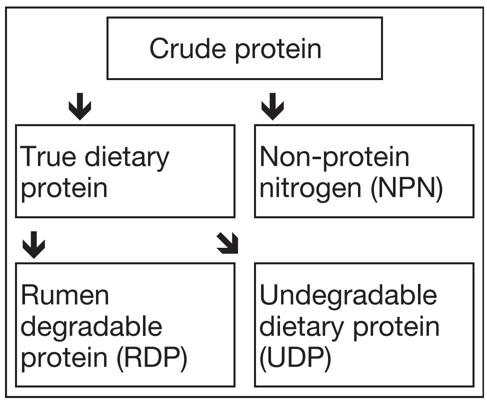

Figure 4.3 The components of crude protein.

Non-protein nitrogen

Non-Protein Nitrogen (NPN) is not actually protein, it is simple nitrogen. Rumen microbes use energy to convert non-protein nitrogen to microbial protein. In the forage-fed cows, however, the rumen microbes use non-protein nitrogen with only 80% efficiency (compared to true protein), which reduces the overall value of crude protein. Urea is a source of non-protein nitrogen.

Rumen degradable protein

Rumen Degradable Protein (RDP) is any protein in the diet that is broken down (digested) and used by the microbes in the rumen. If enough energy is available in the rumen, some rumen degradable protein will be used to produce microbial protein.

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Undegradable dietary protein

Undegradable Dietary Protein (UDP) is any protein in the diet that is not digested in the rumen. It is digested 'as eaten', further along the gut. That is why undegradable dietary protein is sometimes called 'bypass protein'.

The proportion of the protein in the diet which bypasses rumen digestion (ie becomes undegradable dietary protein) varies with several factors: first, how well the protein is protected from the rumen digestion; and second, feed intake.

Feeds can be protected from the rumen digestion through treatment with heat or chemicals. However, if the treatment is too severe, the protein can become 'overprotected' in that it passes through the entire gut and out the other end without being digested.

The undegradable dietary protein content of feeds then depends on how much is eaten in total, and how quickly the feed flows through the rumen. Greater intake and faster flow-through mean that more of the dietary protein becomes undegradable dietary protein because it simply 'escapes' through the rumen before microbial breakdown can occur.

4.3.2 Measuring rumen degradable protein and undegradable protein

Nutritionists may want to know how much of the crude protein in the feed is rumen degradable protein and how much is undegradable dietary protein. This analysis is called protein degradability. The degradability of protein in the diet depends on many factors including dry matter intake, how long feed stays in the rumen, the degree of processing, the total protein intake and the supply of dietary energy to the rumen microbes. Therefore, the proportions measured in a laboratory test for rumen degradable protein and undegradable dietary protein may not necessarily be the same as when that feed is eaten by a cow.

Nevertheless, a system describing the degradability of protein has been developed to help assess the undegradable dietary protein supply in feeds. This classification is shown in Table 4.5 and will be used in Chapter 10. A feed with lower rumen degradable protein, hence higher undegradable dietary protein, has more milk production potential.

Table 4.5 Categories used to assess ability of feeds to supply undegradable dietary protein
(Source: Target 10, 1999)

Category	Undegradable dietary protein (UDP)	Rumen degradable protein (RDP)
High	More than 69%	less than 31%
Good	69–50%	31–50%
Moderate	49–30%	51–70%
Poor	29–10%	71–90%

4.4 Fibre

For efficient digestion, the rumen contents must be coarse, with an open structure, and this is best met by the fibre in the diet. Fibre makes up the cell wall, or structural material, in a plant and is made of hemicellulose, cellulose and lignin. Some of the fibre is digestible, some is not.

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4.4.1 Types of fibre

There are three methods of describing the fibre in feeds.

Neutral Detergent Fibre
Neutral Detergent Fibre (NDF) is a measure of all the fibre (digestible plus indigestible parts) and indicates how bulky the feed is. Some of it is digested, and some is excreted. A high Neutral Detergent Fibre might mean lower intake because of the bulk. Conversely, lower Neutral Detergent Fibre values lead to higher intakes (see Table 12.1).

Acid Detergent Fibre
Acid Detergent Fibre (ADF) is the poorly-digested and indigestible parts of the fibre (ie the cellulose and lignin). If the Acid Detergent Fibre is low, the feed must be very digestible (ie of high quality).

Crude fibre
Crude Fibre (CF), although sometimes used to indicate fibre content, is now considered an unacceptable measure because it does not take into account the digestible fibre which is nutritionally useful to the animal, both a source of energy in the diet and as a substrate for some of the rumen bacteria. However, it is commonly analysed because it is required in the calculation of Total Digestible Nutrients.

4.4.2 Measuring fibre

Different approaches to measuring fibre are shown in Figure 4.4. Sometimes the fibre in the diet is expressed as kilograms of dry matter (kg DM), but more often, fibre is expressed as percentage of dry matter (% DM). For example, if a feed contains 25% NDF, one-quarter of its dry matter weight is fibre.

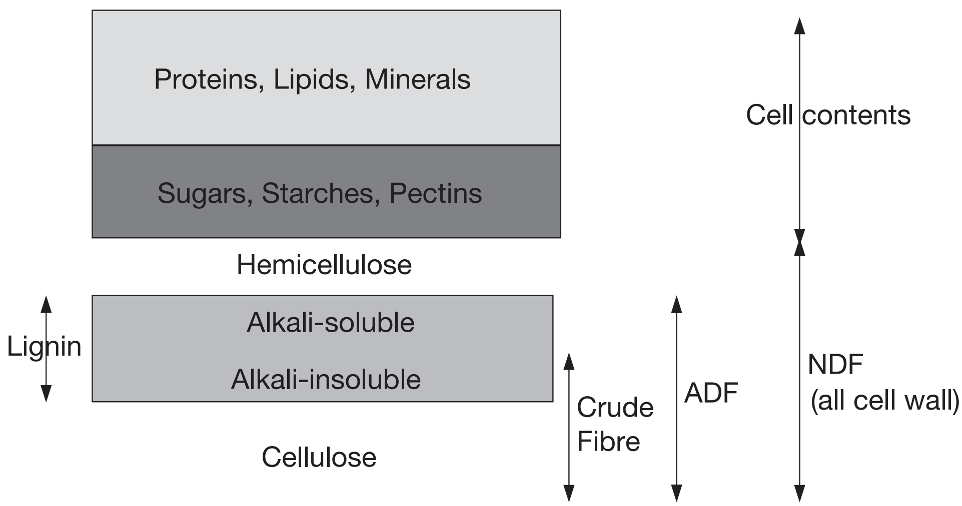

Figure 4.4 Forage analysis showing the difference in definitions of Crude Fibre, Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF).

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4.5 Vitamins and minerals

4.5.1 Vitamins

Vitamins are organic compounds that all animals require in very small amounts. At least 15 vitamins are essential for animals. Vitamins are needed for many metabolic processes in the body (eg for production of enzymes, bone formation, milk production, reproduction, disease resistance).

The vitamin needs of most ruminants are met under normal conditions by natural feeds, microbial activity in the rumen, and tissue synthesis. Vitamins A, D and E are usually present in adequate amounts in quality forage. Members of the B-vitamin group and Vitamins K and C are synthesised in the tissues and rumen.

Vitamins are either water soluble or fat soluble. The water-soluble vitamins of importance to cows are the B group of vitamins and Vitamin C. The important fat-soluble vitamins are A, D, E and K.

Vitamins are normally expressed in international units (IU). Vitamin deficiencies are rare in normal forage feeding situations.

4.5.2 Minerals

About 21 minerals are essential for animal health and growth. However, many of these can become toxic if the animal eats too much of them. Mineral deficiencies are less likely if forages constitute the major part of the diet.

High-producing herds fed diets high in cereal grain or maize silage may require added minerals.

The mineral content of feed is expressed in units of weight: gram (g) or milligram (mg). Further details on the important vitamins and minerals required by dairy cows are provided in Appendix 4.

4.6 Essential nutrients and sources summary

Essential nutrients, their sources in feed and the units by which they are measured are summarised in Table 4.6.

Table 4.6 Sources and units of measurement of nutrients essential in the diet of dairy cows

Nutrient	Source in feed	Unit of measurement
Energy	Carbohydrates Fats and oils Protein	Megajoules of Metabolisable Energy (MJ ME/kg DM) kg of Total Digestible Nutrients (kg TDN/kg DM)
Protein	Rumen degradable protein (RDP) Undegradable dietary protein (UDP) Non-protein nitrogen (NPN)	Crude protein percentage (CP%) % Degradability of protein
Fibre	Structural carbohydrates	% Neutral Detergent Fibre (% NDF) % Acid Detergent Fibre (% ADF) % Crude Fibre (% CF)
Vitamins	Present in feeds Some synthesised by microbes in the rumen	International units (IU)
Minerals	Present in feeds	Grams (g) or milligrams (mg)

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4.7 Sampling feeds for chemical analyses

It is important to obtain a representative sample of any feed to be chemically analysed. This is easy for homogenous feeds, such as cereal grains or finely ground by-products, but very difficult for heterogenous feeds such as freshly harvested Napier grass (*Pennisetum purpureum*) or pasture hay.

Moderate quality Napier grass harvested for dairy cows in West Java, Indonesia.

Fresh forages will deteriorate very quickly, so they should be taken to the laboratory as soon as possible after sampling. Storing them in a freezer will preserve their quality for weeks, as will storage in a refrigerator for a few days. Silage should be restored in airtight plastic bags, with all the air squeezed out prior to sealing. Wet by-products should also be kept air tight and chilled. Dried forages and concentrates will not deteriorate if kept dry and cool.

With silages, it is essential that the sample arrives at the laboratory in a similar state as in the silage stack. If left to dry out before leaving the farm, volatile compounds will be lost and these contain both energy and protein.

Ensure that any instructions from the laboratory are closely followed, detailing the date of sampling, full description of the feed to be tested and method of storage prior to transport to the laboratory.

4.7.1 Fresh forages

Walk through the paddock selecting whole plants or randomly sample a stack of freshly harvested grass, taking entire plants. Select say six plants and chop each one up into short lengths (no more than 5 cm long). If cows routinely leave a lot of grass stems, the bottom

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stems of the grass can be left out of the sample. It is much more difficult obtaining a representative sample of tall erect grasses (eg Napier grass) than prostrate creeping grasses (eg Ruzi grass, *Brachiaria ruziziensis*).

With fresh shrubs and trees, it is important to sample only the part of the forage that the animals consume, such as the leaves and thin stems.

Poor quality banana leaves harvested for dairy cows in West Java, Indonesia.

Poor quality alang alang grass (*Imperatica cylindrica*) harvested for dairy cows in Central Java, Indonesia.

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4.7.2 Dry feeds

Select a handful from at least six locations or different bags that make up a complete batch. Combine the samples into one and mix thoroughly to obtain a final quantity not exceeding 500 g.

With concentrates mixed on the farm, it is better to sample all the ingredients individually rather than a single mixed batch.

4.7.3 Silages and wet by-products

Ideally, silages should be sampled by forcing a metal corer into the stack when newly opened. These corers can be made of steel tubing 30 to 45 cm long, an internal diameter of 20 to 30 mm, with one end sharpened to allow it to be forced into the silage stack. Corers can be driven into forage stacks by using a hand drill or electric drill.

Alternatively since such devices are rarely available, silages can be sampled by taking many (at least 10) small handfuls over a few days and bulking them into a plastic bag which is kept sealed and frozen (or at least chilled) between samplings. This is easier with wet by-products such as cassava waste or brewer's grain because these are more homogenous than the forages made into silage.

4.7.4 Hays and straws

Hay and dried grasses are the most difficult to sample because the leaves are very brittle and will easily separate from the stems. Corers are really the only way to ensure a representative sample of bales of hay, by sampling 10 to 20 small bales.

Straws are easier because the leaves and grains have usually been removed prior to harvest. All forages should be cut to short lengths of no more than 5 cm.

Cassava trunks do not provide many nutrients when fed as a dry season roughage source to milking cows (Central Java, Indonesia).

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