La-Net

AGE 405

LIVESTOCK NUTRITION EDUCATION

Course code: AGE 405

Course title: Livestock Nutrition Education

Course credit load: 2 Units

Series 1: Foundations of Livestock Nutrition

- **Part 1.1: Introduction to Animal Nutrition**
    - Sub Part 1.1.1: Meaning and importance of nutrition
    - Sub Part 1.1.2: Classes of nutrients
    - Sub Part 1.1.3: Nutrition and animal production
- **Part 1.2: Digestive Systems of Farm Animals**
    - Sub Part 1.2.1: Monogastric digestion
    - Sub Part 1.2.2: Ruminant digestion
    - Sub Part 1.2.3: Comparative digestive efficiency
- **Part 1.3: Digestive Processes and Nutrient Absorption**
    - Sub Part 1.3.1: Mechanical and chemical digestion
    - Sub Part 1.3.2: Microbial digestion
    - Sub Part 1.3.3: Absorption and utilisation
- **Part 1.4: Principles Guiding Feeding Practice**
    - Sub Part 1.4.1: Nutrient requirements and life stage
    - Sub Part 1.4.2: Feed efficiency and economics
    - Sub Part 1.4.3: Scientific approach to feeding decisions

Introduction

Nutrition is the single largest cost and one of the most powerful levers affecting productivity in livestock and companion animal production, since even genetically superior animals cannot express their full growth, reproductive, or production potential without an adequate, balanced diet. AGE 405 introduces the principles of livestock nutrition, building toward the detailed nutrient function, feedstuff, ration formulation, and forage topics covered in the remaining four Series.

This opening Series covers the meaning and importance of nutrition, the classes of nutrients, and the link between nutrition and animal production; the digestive systems of monogastric and ruminant farm animals; the mechanical, chemical, and microbial processes of digestion and absorption; and the principles guiding sound feeding practice and decision making. This foundation supports all later Series of AGE 405.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** explain the meaning and importance of nutrition, the classes of nutrients, and the link between nutrition and animal production (Linked to Part 1.1),
- **SLO 1.2** distinguish monogastric and ruminant digestive systems and compare their digestive efficiency (Linked to Part 1.2),
- **SLO 1.3** describe mechanical, chemical, and microbial digestion and nutrient absorption (Linked to Part 1.3), and
- **SLO 1.4** explain the principles guiding sound feeding practice and decision making (Linked to Part 1.4).

1.1 Introduction to Animal Nutrition

1.1.1 Meaning and importance of nutrition

Animal nutrition is the science of how animals obtain and use nutrients from feed to support maintenance, growth, reproduction, and production (milk, eggs, meat, wool, or work); it encompasses the study of nutrient requirements, feedstuff composition, digestion, absorption, and metabolism, providing the scientific foundation for the practical feeding decisions examined throughout this course.

Good nutrition directly determines an animal capacity to grow, reproduce, resist disease, and produce efficiently, while poor nutrition (deficiency, excess, or imbalance, examined in depth in Series 2) depresses performance and increases disease susceptibility, a connection to the multi-factorial livestock health view introduced in related courses; since feed typically represents 60 to 70 percent of total livestock production costs, nutrition decisions also carry major direct economic significance for any livestock enterprise.

Fill in the blank: Feed typically represents ________ to 70 percent of total livestock production costs, giving nutrition decisions major direct economic significance for livestock enterprises.

1.1.2 Classes of nutrients

Nutrients are grouped into six major classes: water (essential for virtually every body function, often the most limiting nutrient in practice despite being frequently overlooked); carbohydrates (the primary energy source in most livestock diets, derived mainly from plant feedstuffs); proteins (supplying amino acids for tissue growth, repair, and production such as milk and egg protein); fats/lipids (a concentrated energy source, and a source of essential fatty acids and fat-soluble vitamin absorption support); vitamins (organic compounds required in small amounts for normal metabolic function); and minerals (inorganic elements required for skeletal structure, enzyme function, and other physiological roles).

Each nutrient class is examined in detail regarding its sources, functions, and deficiency symptoms in Series 2; this six-class framework provides the organising structure for understanding feedstuff composition (Series 3) and ration formulation (Series 4) throughout the remainder of this course.

Fill in the blank: Nutrients are grouped into six major classes: water, carbohydrates, proteins, fats/lipids, vitamins, and ________ .

1.1.3 Nutrition and animal production

Nutrition directly drives the major production outcomes livestock enterprises depend on: growth rate and feed conversion efficiency (meat production), milk yield and composition (dairy production), egg production rate and quality (poultry layer production), and reproductive performance (fertility, litter/offspring size and survival), with nutrient supply at each relevant life stage (growth, pregnancy, lactation) needing to match the specific physiological demand of that stage.

Beyond direct production outcomes, adequate nutrition supports immune function and disease resistance (connecting to the livestock health principles introduced in related courses), making nutrition management an integral part of overall animal management rather than an isolated technical concern separate from health, housing, and other production considerations covered elsewhere in agricultural education.

Fill in the blank: Nutrient supply at each relevant life stage, such as growth, pregnancy, or lactation, needs to match the specific physiological ________ of that stage for optimal production outcomes.

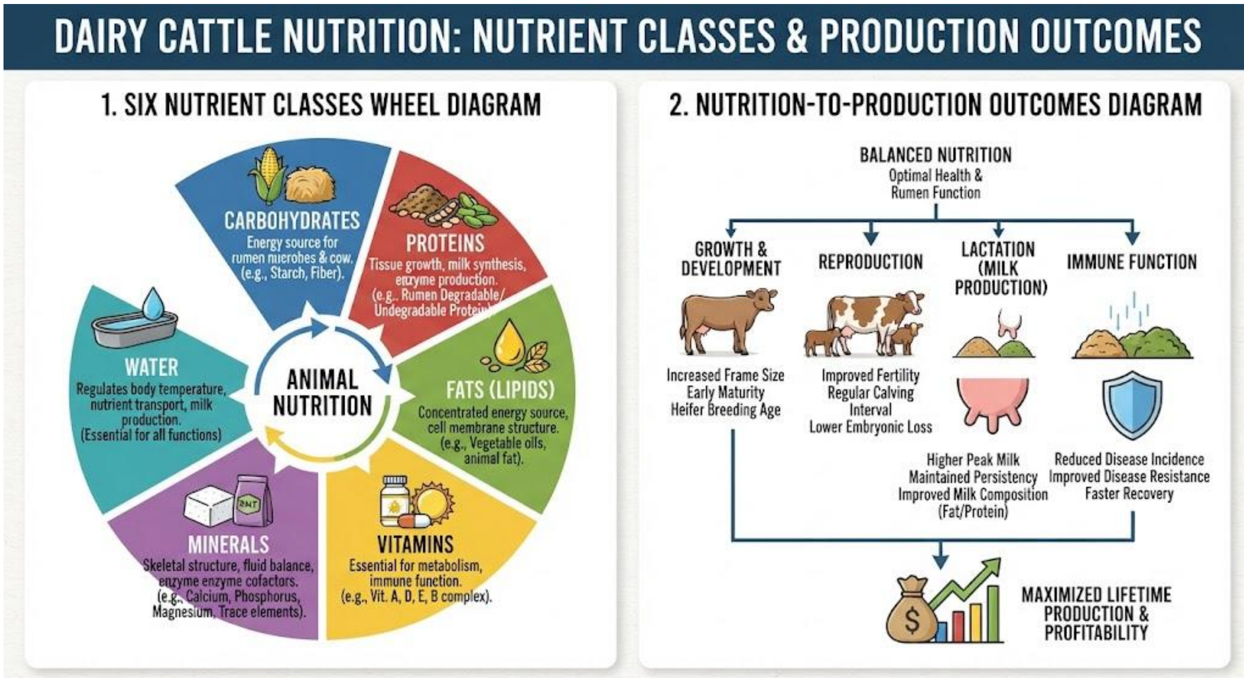


Figure 1.1: Introduction to animal nutrition

Pilot questions 1.1

1. Define animal nutrition.
2. State the approximate share of livestock production costs represented by feed.
3. Name the six major classes of nutrients.
4. Name four production outcomes directly driven by nutrition.
5. Explain why nutrient supply must match an animal physiological life stage.

1.2 Digestive Systems of Farm Animals

1.2.1 Monogastric digestion

Monogastric animals (having a single-chambered stomach, including pigs, poultry, and, among companion animals, dogs and cats) digest feed primarily through their own enzymatic secretions (from the stomach, pancreas, and small intestine) rather than relying heavily on microbial fermentation, making them generally less able to digest high-fibre feedstuffs efficiently compared to ruminants (Part 1.2.2).

Poultry possess a distinctive digestive adaptation, the gizzard (a muscular organ grinding feed, sometimes aided by ingested grit), positioned between the crop (a storage organ) and the true glandular stomach (proventriculus); this sequence (crop, proventriculus, gizzard, small intestine) distinguishes avian digestion from the mammalian monogastric pattern of pigs while still sharing the fundamentally enzymatic, low-fibre-tolerant digestive strategy.

Fill in the blank: Poultry possess a distinctive digestive organ, the ________ , a muscular organ that grinds feed, sometimes aided by ingested grit.

1.2.2 Ruminant digestion

Ruminants (cattle, sheep, and goats) possess a four-chambered stomach (rumen, reticulum, omasum, and abomasum) in which the rumen, the largest chamber, houses a vast population of microorganisms (bacteria, protozoa, fungi) that ferment feed, particularly fibre, that monogastric enzymes alone cannot break down, producing volatile fatty acids absorbed and used as a major energy source by the host animal.

This rumen microbial fermentation also allows ruminants to synthesise microbial protein from non-protein nitrogen sources (such as urea, used in some ration formulations, Series 4) and certain B-vitamins, reducing ruminant dependence on dietary sources of these nutrients compared to monogastric animals, a major nutritional advantage underlying the ruminant ability to thrive on forage-based diets unsuitable as a primary feed for monogastric species.

Fill in the blank: Ruminants possess a four-chambered stomach consisting of the rumen, reticulum, omasum, and ________ .

1.2.3 Comparative digestive efficiency

Ruminants digest fibre (cellulose, hemicellulose) far more efficiently than monogastric animals, due to rumen microbial fermentation (Part 1.2.2), making ruminants well suited to forage-based diets (Series 5) and able to convert otherwise low-value fibrous feedstuffs (crop residues, by-products) into useful animal products; monogastric animals, in contrast, require more energy-and nutrient-dense diets (grains, protein concentrates, Series 3) given their more limited fibre digestion capacity.

This fundamental digestive difference shapes ration formulation strategy across species (Series 4): ruminant rations can incorporate substantial forage proportions, while monogastric (pig and poultry) rations rely much more heavily on concentrate feeds; understanding this comparative digestive efficiency is essential background for the feedstuff classification and ration formulation topics covered later in this course.

Fill in the blank: ________ animals digest fibre far more efficiently than monogastric animals due to microbial fermentation, making them well suited to forage-based diets.

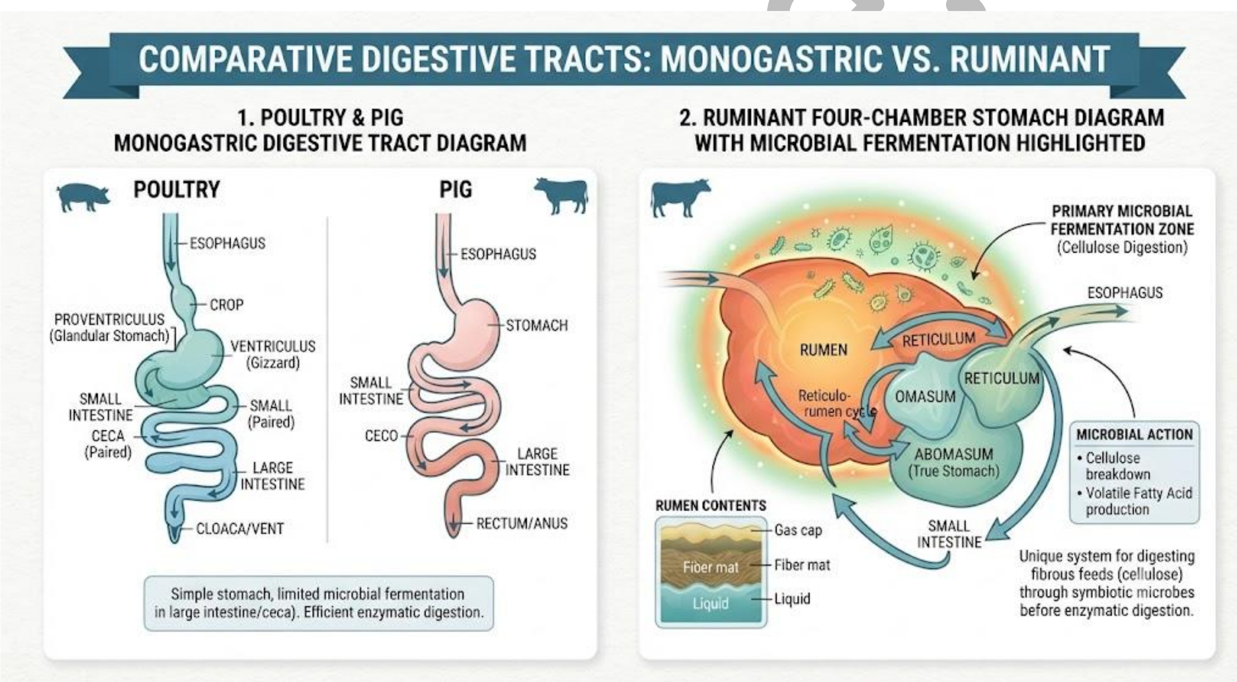


Figure 1.2: Monogastric and ruminant digestive systems

Pilot questions 1.2

1. Define monogastric digestion and name two monogastric livestock species.
2. Describe the function of the gizzard in poultry digestion.
3. Name the four chambers of the ruminant stomach.
4. Explain the role of rumen microbial fermentation.
5. Explain why ruminants are better suited to forage-based diets than monogastric animals.

1.3 Digestive Processes and Nutrient Absorption

1.3.1 Mechanical and chemical digestion

Mechanical digestion (chewing/mastication, and, in ruminants, rumination, the regurgitation and re-chewing of partially digested feed, cud chewing) physically breaks feed into smaller particles, increasing the surface area available for subsequent chemical digestion; gizzard grinding in poultry (Part 1.2.1) serves an analogous mechanical function in the absence of teeth.

Chemical digestion (enzymatic breakdown of carbohydrates, proteins, and fats into simpler absorbable units, occurring through digestive enzymes secreted by the salivary glands, stomach, pancreas, and small intestine) converts complex feed components into the simple sugars, amino acids, and fatty acids that can actually be absorbed across the intestinal wall (Part 1.3.3), with both mechanical and chemical digestion working together throughout the digestive tract.

Fill in the blank: Rumination, the regurgitation and re-chewing of partially digested feed (cud chewing), is a form of ________ digestion specific to ruminant animals.

1.3.2 Microbial digestion

Microbial digestion (fermentation of feed components by bacteria, protozoa, and fungi) occurs prominently in the ruminant rumen (Part 1.2.2) but also, to varying and generally lesser degrees, in the hindgut (caecum and large intestine) of monogastric animals, particularly horses and, to a more limited degree relevant to this course, pigs and poultry, allowing some additional fibre digestion beyond pure enzymatic capacity even in non-ruminant species.

Microbial digestion produces volatile fatty acids (an energy source, particularly significant in ruminants, Part 1.2.2) and, depending on location relative to the small intestine, microbial protein and vitamins that may or may not be efficiently absorbed by the host animal; ruminant rumen fermentation occurs before the small intestine, allowing efficient absorption of microbial products, while hindgut fermentation in monogastric animals occurs after the primary small intestine absorption site, limiting the nutritional benefit captured from that microbial activity.

Fill in the blank: Hindgut fermentation in monogastric animals occurs after the primary small intestine absorption site, ________ the nutritional benefit captured compared to ruminant rumen fermentation, which occurs before the small intestine.

1.3.3 Absorption and utilisation

Absorption (the movement of digested nutrients across the intestinal wall into the bloodstream or lymphatic system) occurs predominantly in the small intestine, where the extensive surface area created by villi and microvilli (finger-like projections of the intestinal lining) maximises contact between digested nutrients and the absorptive surface; absorbed nutrients are then transported via the bloodstream to the liver and other tissues for further metabolism and utilisation.

Utilisation (the metabolic use of absorbed nutrients for maintenance, growth, reproduction, or production) varies in efficiency depending on the specific nutrient, the animal physiological state, and the presence of other nutrients supporting or competing for the same metabolic pathways; this absorption-to-utilisation chain completes the digestive process, converting feed nutrients into the production outcomes discussed in Part 1.1.3.

Fill in the blank: Absorption occurs predominantly in the small intestine, where ________ and microvilli maximise the surface area available for nutrient absorption.

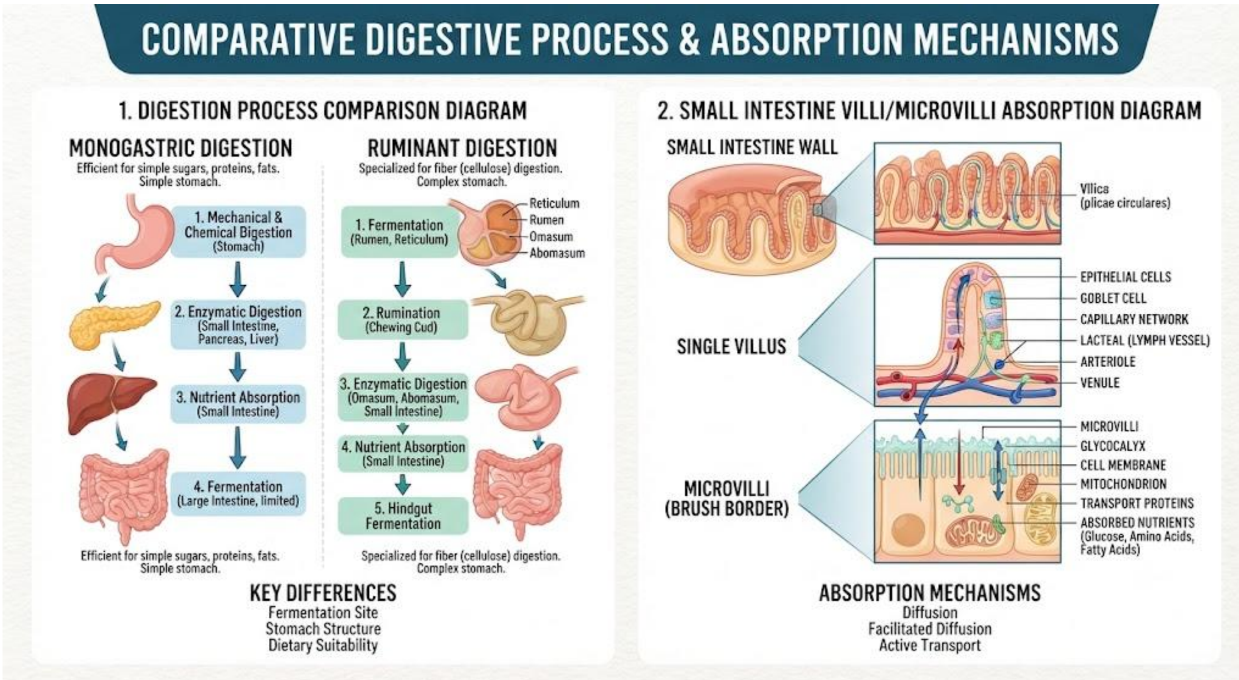


Figure 1.3: Digestive processes and nutrient absorption

Pilot questions 1.3

1. Distinguish between mechanical and chemical digestion.
2. Define rumination.
3. Explain where microbial digestion occurs in ruminants versus monogastric animals.
4. Explain why rumen fermentation captures more nutritional benefit than monogastric hindgut fermentation.
5. Explain the role of villi and microvilli in nutrient absorption.

1.4 Principles Guiding Feeding Practice

1.4.1 Nutrient requirements and life stage

Nutrient requirements (the minimum and optimal levels of each nutrient needed to support a given level of performance) vary by species, breed, body size, life stage (growth, pregnancy, lactation, maintenance), and production target, requiring feeding programmes (Series 4) tailored to these specific factors rather than a single generic diet applied uniformly regardless of animal status.

Requirements generally rise during periods of high physiological demand (rapid growth, late pregnancy, peak lactation) and fall during maintenance-only periods (mature, non-reproducing, non-lactating animals); matching feed nutrient density and quantity to these changing requirements across the production cycle is a core principle of sound feeding practice explored further in Series 4.

Fill in the blank: Nutrient requirements generally rise during periods of high physiological demand such as rapid growth, late pregnancy, and peak ________ .

1.4.2 Feed efficiency and economics

Feed efficiency (commonly expressed as feed conversion ratio, the amount of feed required to produce a unit of product such as weight gain, milk, or eggs) is a key performance and economic indicator, since feed represents the majority of production cost (Part 1.1.1); improving feed efficiency, whether through better feedstuff selection, ration balance, or animal genetics/health, directly improves enterprise profitability.

Feeding decisions should weigh both nutritional adequacy and cost-effectiveness, since the theoretically ideal ration is not economically practical if it relies on excessively costly ingredients; least-cost ration formulation (introduced in Series 4) formally balances nutritional requirements against ingredient cost, reflecting this practical economic dimension of feeding practice alongside the purely biological nutrient requirement considerations of Part 1.4.1.

Fill in the blank: Feed ________ , commonly expressed as feed conversion ratio, is the amount of feed required to produce a unit of product such as weight gain, milk, or eggs.

1.4.3 Scientific approach to feeding decisions

Sound feeding decisions rest on accurate knowledge of animal nutrient requirements (Part 1.4.1, informed by published nutrient requirement standards for different species and production levels) and accurate knowledge of feedstuff nutrient composition (Series 3, informed by feed analysis and published feed composition tables), combined through systematic ration formulation methods (Series 4) rather than informal guesswork or unexamined traditional practice alone.

A scientific approach also involves monitoring actual animal performance (growth rate, production level, body condition) against expected performance, using this feedback to identify and correct feeding programme deficiencies, an application of the data-informed management principle relevant across livestock production generally and specifically valuable for the practical ration formulation skills developed throughout this course.

Fill in the blank: A scientific approach to feeding involves monitoring actual animal ________ against expected performance, using this feedback to identify and correct feeding programme deficiencies.

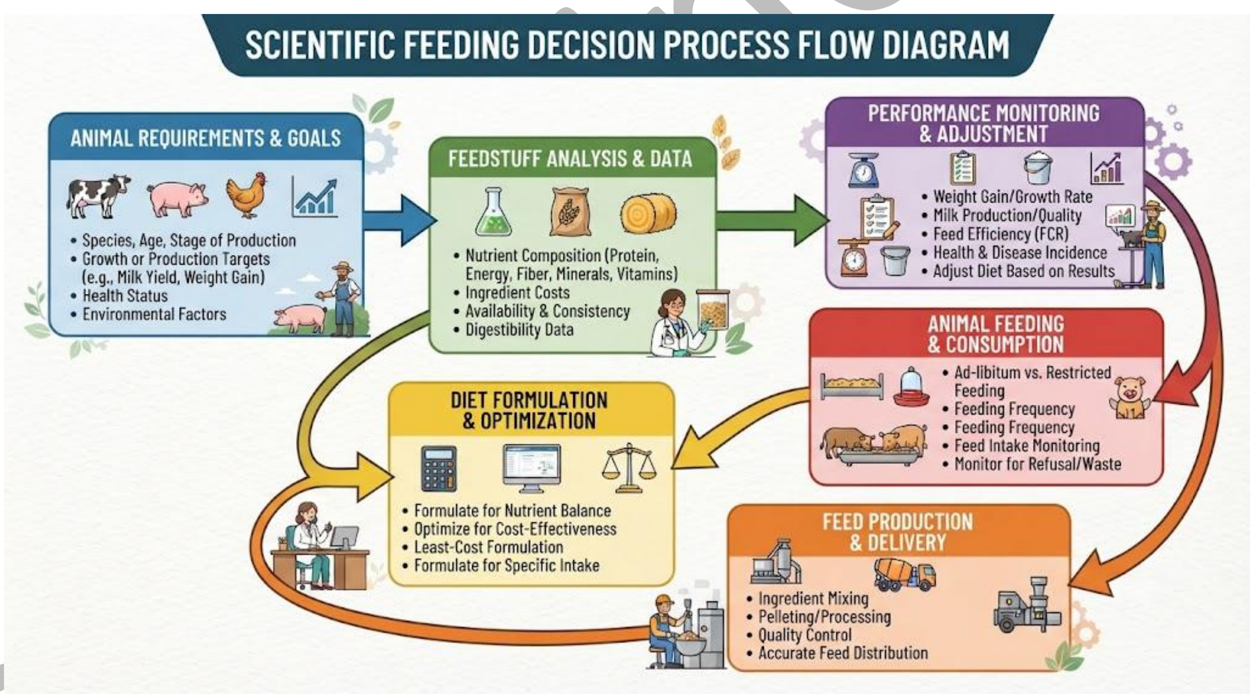


Figure 1.4: Principles guiding sound feeding practice

Pilot questions 1.4

1. Explain why nutrient requirements vary by life stage.
2. Define feed conversion ratio.

3. Explain why feeding decisions must weigh cost alongside nutritional adequacy.
4. Name two sources of information needed for sound ration formulation.
5. Explain why monitoring actual animal performance is important in feeding practice.

Series Summary

This Series examined **animal nutrition as the science of supplying nutrients required for maintenance, growth, reproduction, and production**, noting that feed typically accounts for **60–70% of livestock production costs**. The **six essential nutrient classes** are water, carbohydrates, proteins, fats, vitamins, and minerals, all of which influence growth, milk yield, egg production, reproduction, and overall health. The digestive systems of livestock differ by species: **monogastric animals** (e.g., pigs and poultry) have a simple stomach, with poultry also possessing a gizzard for grinding feed, while **ruminants** have a four-compartment stomach that enables microbial fermentation and superior digestion of fibrous feeds.

The Series also covered **digestive processes and feeding principles**. Digestion involves **mechanical processes** (chewing and rumination), **chemical digestion** by enzymes, and **microbial fermentation** in the rumen, while nutrient absorption occurs mainly through the villi and microvilli of the small intestine. Nutrient requirements vary with species, age, physiological state, and production purpose, making proper ration formulation essential. Feeding programmes should be guided by feed requirements, feedstuff composition, feed efficiency or feed conversion ratio (FCR), and continuous monitoring of animal performance. By completing this Series, students should achieve SLOs 1.1–1.4.

Glossary of Terms

- **Feed conversion ratio:** the amount of feed required to produce a unit of product such as weight gain, milk, or eggs.
- **Gizzard:** a muscular organ in poultry that grinds feed, sometimes aided by ingested grit.

- **Monogastric:** having a single-chambered stomach, relying primarily on enzymatic rather than microbial digestion.
- **Rumen:** the largest chamber of the ruminant stomach, housing microorganisms that ferment feed, particularly fibre.
- **Rumination:** the regurgitation and re-chewing of partially digested feed by ruminants, also called cud chewing.
- **Villi:** finger-like projections of the small intestine lining that increase surface area for nutrient absorption.
- **Volatile fatty acid:** an energy-yielding compound produced by microbial fermentation of feed, particularly significant in ruminants.

Concept Check Questions [Series 1]

Objective Questions

1. Feed typically represents 60 to ________ percent of total livestock production costs. (Linked to SLO 1.1)
2. Poultry possess a distinctive digestive organ, the ________ , that grinds feed. (Linked to SLO 1.2)
3. ________ , the regurgitation and re-chewing of partially digested feed, is specific to ruminants. (Linked to SLO 1.3)
4. Feed conversion ________ is the amount of feed required to produce a unit of product. (Linked to SLO 1.4)
5. Ruminants possess a four-chambered stomach: rumen, reticulum, omasum, and ________ . (Linked to SLO 1.2)

Short-Answer Questions

6. Name the six major classes of nutrients. (Linked to SLO 1.1)
7. Name two monogastric livestock species. (Linked to SLO 1.2)
8. Name the three types of digestion (mechanical, chemical, microbial) and where one occurs. (Linked to SLO 1.3)
9. Explain why nutrient requirements vary by life stage. (Linked to SLO 1.4)
10. Explain why ruminants digest fibre more efficiently than monogastric animals. (Linked to SLO 1.2)

Long-Answer Questions

11. Explain the meaning and importance of nutrition, nutrient classes, and the link to production. (Linked to SLO 1.1)
12. Distinguish monogastric and ruminant digestion and compare their digestive efficiency. (Linked to SLO 1.2)
13. Describe digestive processes, absorption, and principles guiding feeding practice. (Linked to SLOs 1.3, 1.4)

Answers to Concept Check Questions [Series 1]

Objective Questions

1. 70.
2. Gizzard.
3. Rumination.
4. Ratio.
5. Abomasum.

Short-Answer Questions

6. Water, carbohydrates, proteins, fats/lipids, vitamins, and minerals.
7. Pigs and poultry.
8. Mechanical (mouth/gizzard), chemical (enzymatic, stomach/small intestine), and microbial (fermentation, rumen/hindgut).
9. Requirements rise with physiological demand (growth, pregnancy, lactation) and fall during maintenance-only periods.
10. Rumen microbial fermentation breaks down fibre that monogastric enzymes alone cannot digest.

Long-Answer Questions

11. Nutrition is the science of how animals obtain and use nutrients, representing 60-70 percent of production cost. Six nutrient classes (water, carbohydrates, proteins, fats, vitamins, minerals) drive growth, milk, egg, and reproductive production outcomes.
12. Monogastric animals (pigs, poultry) rely on enzymatic digestion with limited fibre capacity. Ruminants (cattle, sheep, goats) use a four-chamber stomach with rumen microbial fermentation, giving superior fibre digestion and forage utilisation.
13. Mechanical, chemical, and microbial digestion break down feed; absorption occurs via villi/microvilli in the small intestine. Sound feeding practice matches nutrient requirements to life stage, balances feed efficiency and cost, and uses a scientific, performance-monitored approach.

Answers to Pilot Questions [Series 1]

Part 1.1

1. Animal nutrition is the science of how animals obtain and use nutrients to support maintenance, growth, reproduction, and production.
2. Approximately 60 to 70 percent.
3. Water, carbohydrates, proteins, fats/lipids, vitamins, and minerals.
4. Growth rate/feed conversion, milk yield, egg production, and reproductive performance.
5. Because requirements change with physiological demand, so feed must match growth, pregnancy, or lactation needs.

Part 1.2

1. Monogastric digestion relies on a single-chambered stomach and enzymatic digestion; pigs and poultry are examples.
2. The gizzard mechanically grinds feed, sometimes aided by ingested grit.
3. Rumen, reticulum, omasum, and abomasum.
4. Rumen microorganisms ferment fibre into volatile fatty acids absorbed as an energy source by the host.
5. Rumen microbial fermentation allows ruminants to break down fibre that monogastric enzymes alone cannot digest.

Part 1.3

1. Mechanical digestion physically breaks down feed; chemical digestion uses enzymes to break it into absorbable units.
2. Rumination is the regurgitation and re-chewing of partially digested feed (cud chewing).
3. In ruminants it occurs in the rumen before the small intestine; in monogastric animals it occurs in the hindgut after the small intestine.
4. Rumen fermentation occurs before the small intestine, allowing efficient absorption of microbial products, unlike hindgut fermentation.
5. Villi and microvilli increase the surface area of the small intestine, maximising nutrient absorption.

Part 1.4

1. Requirements rise with physiological demand (growth, pregnancy, lactation) and fall during maintenance-only periods.
2. Feed conversion ratio is the amount of feed required to produce a unit of product such as weight gain, milk, or eggs.
3. An ideal nutritional ration is impractical if it relies on excessively costly ingredients, so cost-effectiveness must be weighed too.
4. Published nutrient requirement standards and feedstuff composition data/tables.
5. It allows identification and correction of feeding programme deficiencies based on actual results rather than assumption.

References and Attributions

Textual References (Books and External Sources)

- National Research Council (NRC). (2001). Nutrient requirements of dairy cattle (7th ed.). National Academies Press.
- National Research Council (NRC). (2012). Nutrient requirements of swine (11th ed.). National Academies Press.
- McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., & Morgan, C. A. (2010). Animal nutrition (7th ed.). Pearson.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 1.1: Introduction to animal nutrition Attribution: AI generated. Suggested OER search string: "animal nutrition nutrient classes production outcomes livestock OER".
- Figure 1.2: Monogastric and ruminant digestive systems Attribution: AI generated. Suggested OER search string: "monogastric ruminant digestive system rumen gizzard livestock nutrition OER".
- Figure 1.3: Digestive processes and nutrient absorption Attribution: AI generated. Suggested OER search string: "mechanical chemical microbial digestion absorption villi small intestine livestock OER".
- Figure 1.4: Principles guiding sound feeding practice Attribution: AI generated. Suggested OER search string: "feeding practice nutrient requirements feed efficiency ration formulation livestock OER".

Series 2: Nutrient Functions and Deficiencies

- **Part 2.1: Water and Carbohydrates**
    - Sub Part 2.1.1: Functions and sources of water
    - Sub Part 2.1.2: Water deficiency and quality
    - Sub Part 2.1.3: Carbohydrate functions, sources, and deficiency
- **Part 2.2: Protein**
    - Sub Part 2.2.1: Protein functions and amino acids
    - Sub Part 2.2.2: Protein sources and quality
    - Sub Part 2.2.3: Protein deficiency and excess
- **Part 2.3: Fats and Vitamins**
    - Sub Part 2.3.1: Fat/lipid functions and sources
    - Sub Part 2.3.2: Fat-soluble vitamin functions and deficiency
    - Sub Part 2.3.3: Water-soluble vitamin functions and deficiency
- **Part 2.4: Minerals**
    - Sub Part 2.4.1: Macrominerals
    - Sub Part 2.4.2: Microminerals (trace elements)
    - Sub Part 2.4.3: Mineral supplementation strategy

Introduction

Building on the six nutrient classes introduced in Series 1, this Series examines each nutrient class in detail, covering specific functions in the animal body, dietary sources, and the deficiency (and, in some cases, excess) symptoms that arise when a nutrient is inadequately or excessively supplied. This detailed nutrient knowledge underpins the feedstuff characterisation (Series 3) and ration formulation (Series 4) skills developed later in this course.

This Series covers water and carbohydrates; protein and amino acid nutrition; fats and both fat-soluble and water-soluble vitamins; and macro- and microminerals along with supplementation strategy. Recognising deficiency symptoms (and understanding their underlying nutritional cause) is a practical skill with direct relevance to diagnosing and correcting feeding programme problems in real livestock operations.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** explain the functions, sources, and deficiency symptoms of water and carbohydrates (Linked to Part 2.1),
- **SLO 2.2** explain protein and amino acid functions, sources, and deficiency/excess effects (Linked to Part 2.2),
- **SLO 2.3** explain fat functions and sources, and fat-soluble and water-soluble vitamin functions and deficiencies (Linked to Part 2.3), and
- **SLO 2.4** explain macro- and micromineral functions, deficiencies, and supplementation strategy (Linked to Part 2.4).

2.1 Water and Carbohydrates

2.1.1 Functions and sources of water

Water serves numerous essential functions: it is the medium for virtually all metabolic reactions, regulates body temperature (through evaporative cooling, particularly important under heat stress, a connection to the environmental management principles covered in related livestock health courses), transports nutrients and waste products, and constitutes a major proportion of body tissue (typically 60 to 70 percent of body weight in most livestock species).

Water sources include drinking water (the most significant and directly manageable source), water contained within feed (fresh forage contains considerably more water than dry hay or grain), and metabolic water (produced internally as a by-product of nutrient metabolism, a relatively minor source compared to drinking water and feed moisture); ensuring clean, adequate, and accessible drinking water (Series 2 of related livestock health courses) is a fundamental feeding management responsibility.

Fill in the blank: Water typically constitutes 60 to ________ percent of body weight in most livestock species, reflecting its role as a major body tissue component.

2.1.2 Water deficiency and quality

Water deficiency (inadequate intake relative to need) rapidly reduces feed intake (since feed intake and water intake are closely linked) and, if severe or prolonged, causes dehydration, reduced production, and, in extreme cases, death; water requirement increases substantially with high ambient temperature, lactation, and high dietary salt/protein content, requiring proportionally greater attention to water provision under these conditions.

Water quality (free from excessive mineral content, contamination, or harmful temperature extremes, Series 2 of related livestock health courses) affects palatability and, in turn, voluntary water intake; poor quality water that animals are reluctant to drink can functionally cause water deficiency even when water is technically available, illustrating that quantity alone does not guarantee adequate water nutrition.

Fill in the blank: Water requirement increases substantially with high ambient temperature, lactation, and high dietary salt or ________ content.

2.1.3 Carbohydrate functions, sources, and deficiency

Carbohydrates serve primarily as an energy source, supplying glucose (used directly for metabolism) and, in ruminants, fermentable substrate for rumen microbial volatile fatty acid production (Series 1); carbohydrates are classified into simple sugars (readily digestible), starches (digestible by enzymes in monogastric animals, and also fermentable in ruminants), and structural fibre/cellulose (poorly digestible by monogastric enzymes, but fermentable by ruminant and, to a lesser degree, monogastric hindgut microorganisms, Series 1).

Carbohydrate sources include cereal grains (maize, sorghum, rich in starch, Series 3), forages (variable starch and fibre content depending on plant maturity and type, Series 5), and various by-product feeds (Series 3); carbohydrate deficiency (inadequate dietary energy supply relative to need) causes weight loss, reduced growth, and, in lactating animals, reduced milk production as the body draws on fat reserves to meet energy shortfall, with ketosis (introduced in related livestock health courses) representing a severe metabolic consequence of substantial energy deficiency in early lactation dairy cattle specifically.

Fill in the blank: Carbohydrates are classified into simple sugars, starches, and structural fibre/________ , differing considerably in their digestibility by monogastric enzymes versus microbial fermentation.

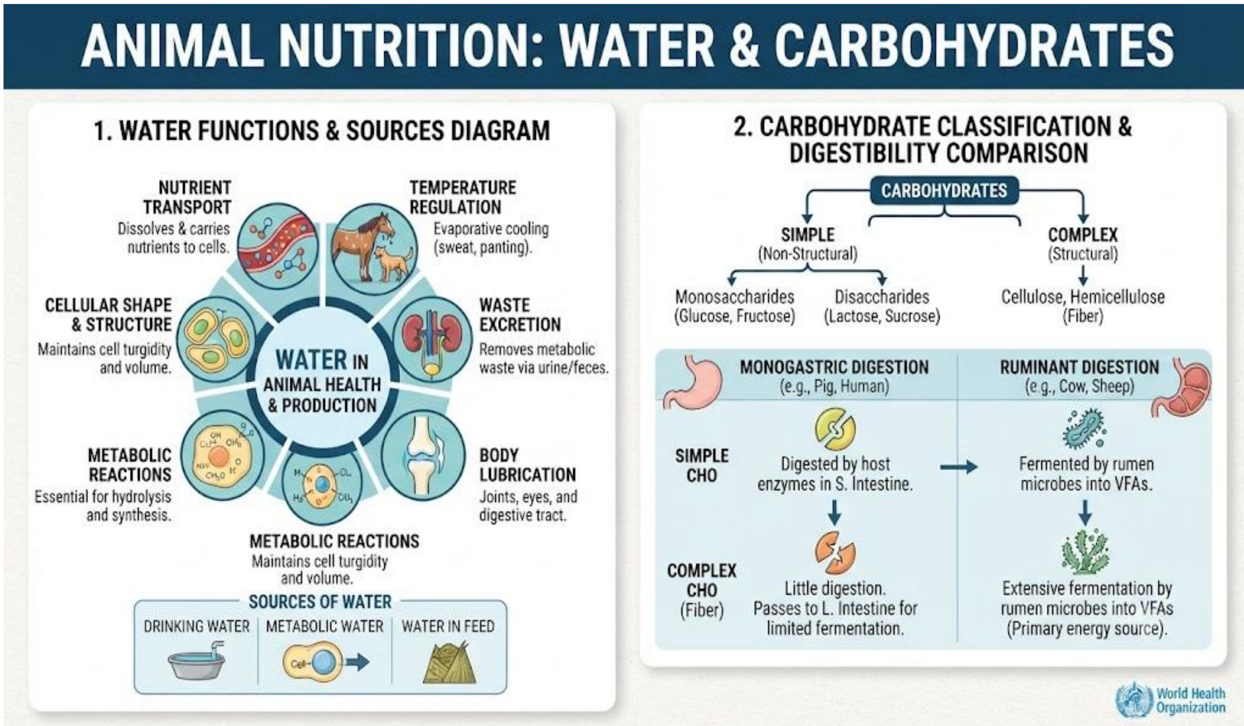


Figure 2.1: Water and carbohydrate nutrition

Pilot questions 2.1

6. Name three functions of water in the animal body.
7. Name three sources of water for livestock.
8. Explain why water deficiency reduces feed intake.
9. Name three classes of carbohydrate and their relative digestibility.
10. Explain the consequence of carbohydrate/energy deficiency in early lactation dairy cattle.

2.2 Protein

2.2.1 Protein functions and amino acids

Protein supplies amino acids, the building blocks for body tissue growth and repair (muscle, organs, skin, hair/wool), enzyme and hormone synthesis, and production of protein-containing products (milk protein, egg protein); amino acids are classified as essential (must be supplied in the diet since the animal body cannot synthesise them in adequate amounts) or non-essential (synthesisable by the animal body from other dietary components, given adequate nitrogen supply).

Essential amino acid requirements differ by species (and, for poultry and pigs specifically, are often expressed relative to a limiting amino acid such as lysine, the essential amino acid most likely to be deficient relative to requirement in typical diets, Series 4); ruminants are somewhat less dependent on specific dietary essential amino acid supply than monogastric animals, given rumen microbial protein synthesis (Series 1) that can supply some amino acids regardless of dietary amino acid profile.

Fill in the blank: ________ amino acids must be supplied in the diet since the animal body cannot synthesise them in adequate amounts, distinguishing them from non-essential amino acids.

2.2.2 Protein sources and quality

Protein sources include plant-based feedstuffs (soybean meal, groundnut cake, and other oilseed meals/cakes, Series 3, generally good but not perfectly balanced amino acid profiles) and animal-based feedstuffs (fish meal, blood meal, and other animal by-products, often with a more complete essential amino acid profile but variable availability and cost, and some restrictions on use in certain livestock feeds for disease control reasons).

Protein quality (how well a protein source amino acid profile matches the requirement of the animal being fed) matters as much as protein quantity, since a high-quantity but poorly balanced protein source may still leave the animal deficient in a specific limiting amino acid (Part 2.2.1); combining complementary protein sources (each supplying different relative amino acid strengths) can improve overall dietary protein quality beyond what either source alone would achieve, a principle applied in practical ration formulation (Series 4).

Fill in the blank: Protein ________ , how well a protein source amino acid profile matches animal requirement, matters as much as protein quantity in determining dietary adequacy.

2.2.3 Protein deficiency and excess

Protein deficiency causes reduced growth rate, poor feed efficiency, reduced milk/egg production, and, in young growing animals particularly, impaired immune function and increased disease susceptibility (a connection to the nutritional factor in livestock health discussed in related courses); visible signs can include poor body condition, rough hair/feather coat, and, in severe prolonged deficiency, oedema (fluid accumulation) in some species.

Excess protein (beyond requirement) is generally wasteful rather than directly harmful in most circumstances, since excess amino acids are deaminated and the nitrogen excreted (with the carbon skeleton potentially used for energy), representing an economic inefficiency (since protein feedstuffs are typically among the more costly ration components, Series 3) and, in some intensive systems, an environmental nitrogen excretion concern (Series 5 of related livestock health courses) rather than a direct toxicity concern at typical excess levels.

Fill in the blank: Excess dietary protein is generally ________ rather than directly harmful, since excess amino acids are deaminated and the nitrogen excreted.

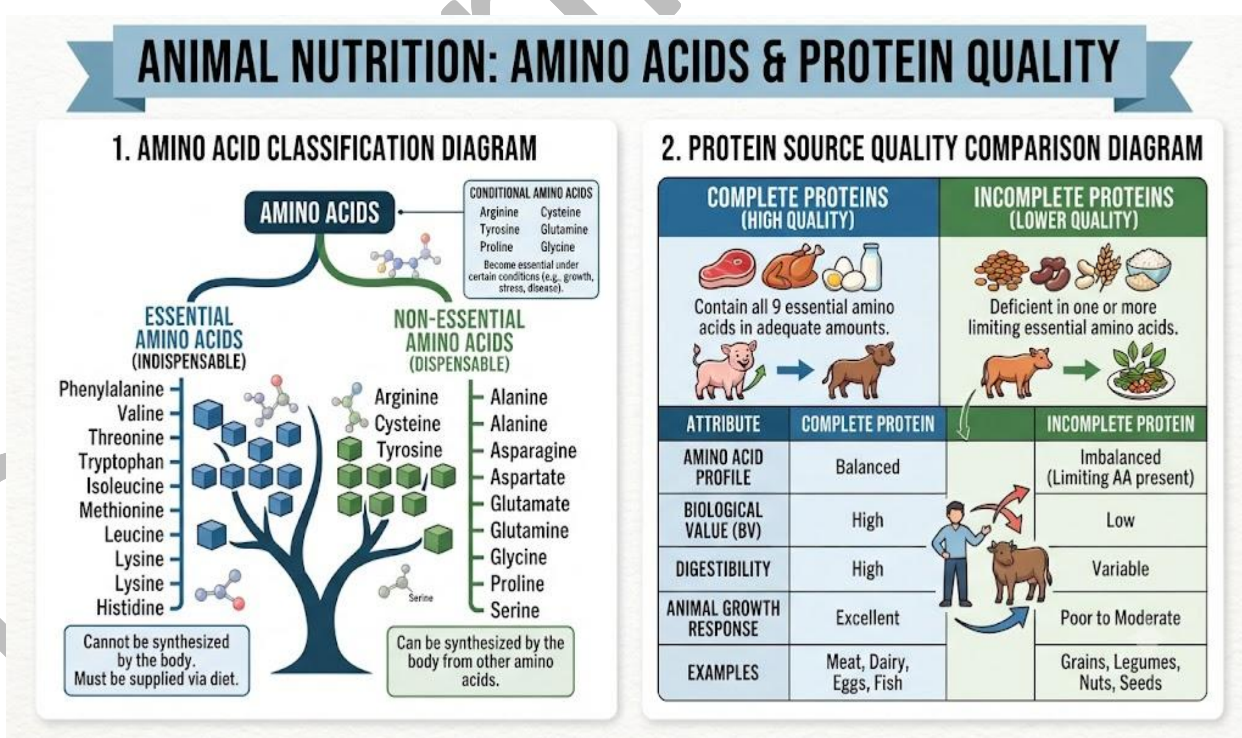


Figure 2.2: Protein and amino acid nutrition

Pilot questions 2.2

1. Name three functions of protein in the animal body.
2. Distinguish between essential and non-essential amino acids.
3. Define limiting amino acid.
4. Name two protein sources used in livestock feeding.
5. Explain why excess dietary protein is wasteful rather than directly harmful.

2.3 Fats and Vitamins

2.3.1 Fat/lipid functions and sources

Fats/lipids serve as a concentrated energy source (containing roughly twice the energy per unit weight of carbohydrates or protein), supply essential fatty acids (which, like essential amino acids, the body cannot synthesise and must obtain from the diet), and support absorption of the fat-soluble vitamins (Part 2.3.2) since these vitamins require dietary fat for efficient intestinal absorption.

Fat sources include the inherent fat content of feedstuffs (cereal grains and oilseed meals contain some fat, Series 3) and added fats/oils (vegetable oils, animal fats, sometimes added to concentrate rations to increase energy density, particularly relevant for high-production animals such as lactating dairy cattle or fast-growing broilers with energy requirements that may be difficult to meet through carbohydrate sources alone given practical feed intake limits).

Fill in the blank: Fats/lipids contain roughly ________ the energy per unit weight of carbohydrates or protein, making them a concentrated energy source.

2.3.2 Fat-soluble vitamin functions and deficiency

Vitamin A (supporting vision, particularly night vision, immune function, and epithelial tissue health) deficiency causes night blindness, increased infection susceptibility, and poor growth/reproduction; vitamin D (supporting calcium and phosphorus absorption and bone mineralisation, synthesisable through sunlight exposure as well as dietary intake) deficiency causes rickets in young growing animals (weak, deformed bones) and osteomalacia in adults.

Vitamin E (an antioxidant, protecting cell membranes from oxidative damage, and supporting immune and reproductive function, often functioning alongside the mineral selenium, Part 2.4.2) deficiency causes muscular dystrophy (white muscle disease, particularly in young ruminants) and reduced reproductive performance; vitamin K (essential for normal blood clotting) deficiency, while less commonly a practical dietary concern given adequate synthesis by gut microorganisms in most circumstances, causes excessive bleeding/clotting problems when it occurs.

Fill in the blank: Vitamin D deficiency causes ________ in young growing animals, characterised by weak, deformed bones due to inadequate calcium and phosphorus absorption/mineralisation.

2.3.3 Water-soluble vitamin functions and deficiency

B-complex vitamins (thiamine, riboflavin, niacin, B12, and others) function primarily as coenzymes supporting energy metabolism and various other metabolic pathways; ruminants are largely protected from B-vitamin deficiency through rumen microbial synthesis (Series 1), while monogastric animals (particularly poultry and pigs) depend more heavily on adequate dietary B-vitamin supply, since they lack this microbial synthesis source in a location allowing efficient absorption.

Vitamin C (ascorbic acid, an antioxidant and supporting various metabolic functions) is synthesised adequately by most livestock species themselves and generally not considered a dietary requirement under normal conditions, differing from the human dietary vitamin C requirement frequently emphasised in human nutrition contexts; this species difference illustrates that nutrient requirements established for one species (including humans) cannot simply be assumed to apply to livestock species without verification.

Fill in the blank: ________ vitamins function primarily as coenzymes supporting energy metabolism, with monogastric animals depending more heavily on dietary supply than ruminants, which benefit from rumen microbial synthesis.

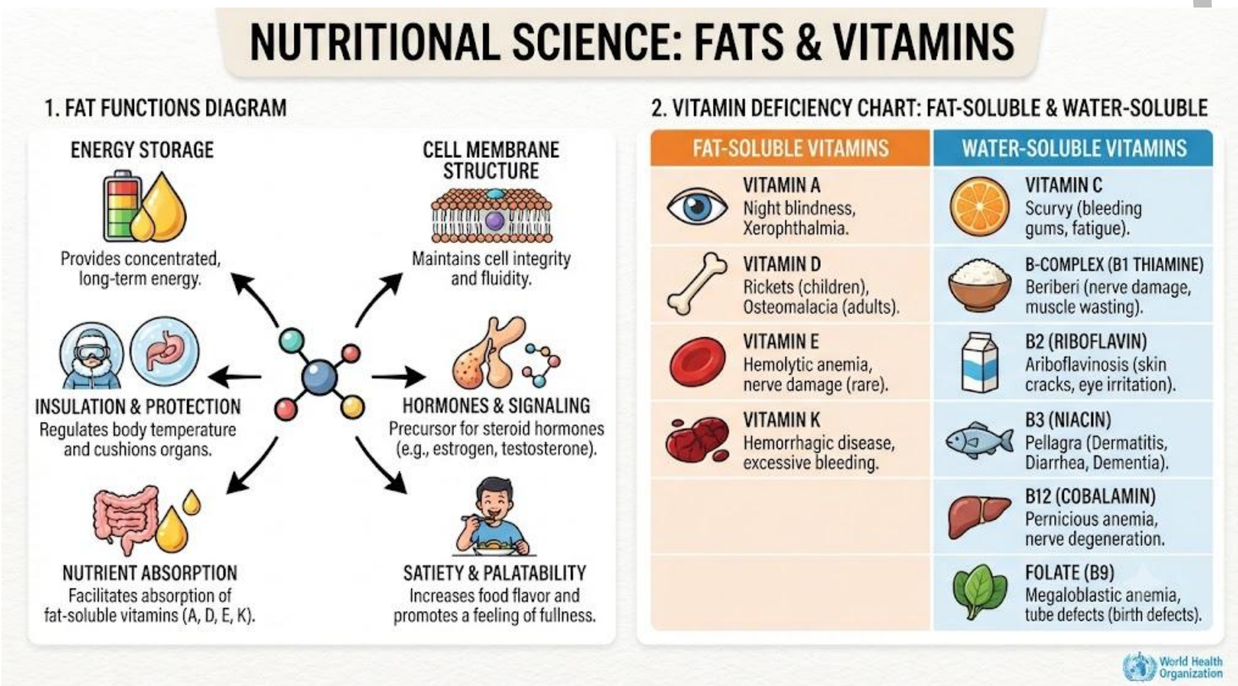


Figure 2.3: Fat and vitamin nutrition

Pilot questions 2.3

1. Name three functions of dietary fat.
2. Explain the relationship between fat-soluble vitamins and dietary fat intake.
3. Describe vitamin A deficiency signs.
4. Describe vitamin D deficiency and its underlying mechanism.
5. Explain why ruminants are less dependent on dietary B-vitamin supply than monogastric animals.

2.4 Minerals

2.4.1 Macrominerals

Macrominerals (required in relatively larger quantities) include calcium and phosphorus (together supporting bone/skeletal structure and numerous metabolic functions, with calcium also critical for milk production and muscle/nerve function, and the calcium-to-phosphorus ratio, not just absolute amounts, mattering for proper utilisation); sodium and chloride (electrolyte balance, nerve/muscle function, typically supplied via salt, sodium chloride, supplementation); and magnesium and potassium (additional electrolyte and enzyme cofactor roles).

Calcium deficiency causes rickets/osteomalacia (similar to vitamin D deficiency, Part 2.3.2, since the two nutrients work together) and, in dairy cattle specifically, milk fever around calving (introduced in related livestock health courses as a metabolic disorder with direct nutritional/mineral cause); phosphorus deficiency causes poor growth, reduced fertility, and, in severe cases, pica (abnormal chewing of non-feed materials, an attempt to obtain missing minerals).

Fill in the blank: The calcium-to-phosphorus ________ , not just absolute amounts of each mineral, matters for proper mineral utilisation in livestock diets.

2.4.2 Microminerals (trace elements)

Microminerals (trace elements, required in much smaller quantities than macrominerals but still essential) include iron (haemoglobin synthesis, oxygen transport, with deficiency causing anaemia, particularly relevant for young animals with limited iron reserves, a connection to the piglet iron supplementation practice introduced in related production courses); copper and zinc (enzyme cofactors supporting numerous metabolic functions, immune function, and, for zinc specifically, skin/hoof health).

Selenium (an antioxidant function closely linked with vitamin E, Part 2.3.2, with deficiency contributing to white muscle disease similarly to vitamin E deficiency) and iodine (essential for thyroid hormone synthesis, with deficiency causing goitre, an enlarged thyroid gland, and reduced metabolic rate and reproductive performance) complete the major micromineral concerns, with deficiency patterns often reflecting locally deficient soil/forage mineral content in specific Nigerian regions, similar to the regional deficiency patterns discussed for crop production in related agricultural courses.

Fill in the blank: ________ deficiency causes goitre, an enlarged thyroid gland, along with reduced metabolic rate and reproductive performance, since this micromineral is essential for thyroid hormone synthesis.

2.4.3 Mineral supplementation strategy

Mineral supplementation strategy should be informed by knowledge of likely local deficiency patterns (based on regional soil/forage mineral content where known, and observed deficiency signs in local livestock) rather than generic, one-size-fits-all supplementation, since different regions and even different farms within a region can have quite different baseline mineral status depending on local geology and forage type.

Practical mineral supplementation methods include mineral licks/blocks (allowing animals some self-regulation of intake, suited to extensive grazing systems), mineral premixes added to compounded concentrate feed (more precise control, suited to intensive systems where total diet is formulated, Series 4), and, for specific acute deficiencies, injectable mineral supplements (under veterinary guidance) providing more rapid correction than oral supplementation alone.

Fill in the blank: Mineral supplementation strategy should be informed by knowledge of likely local deficiency patterns based on regional soil/forage mineral content, rather than generic, one-size-fits-all ________ .

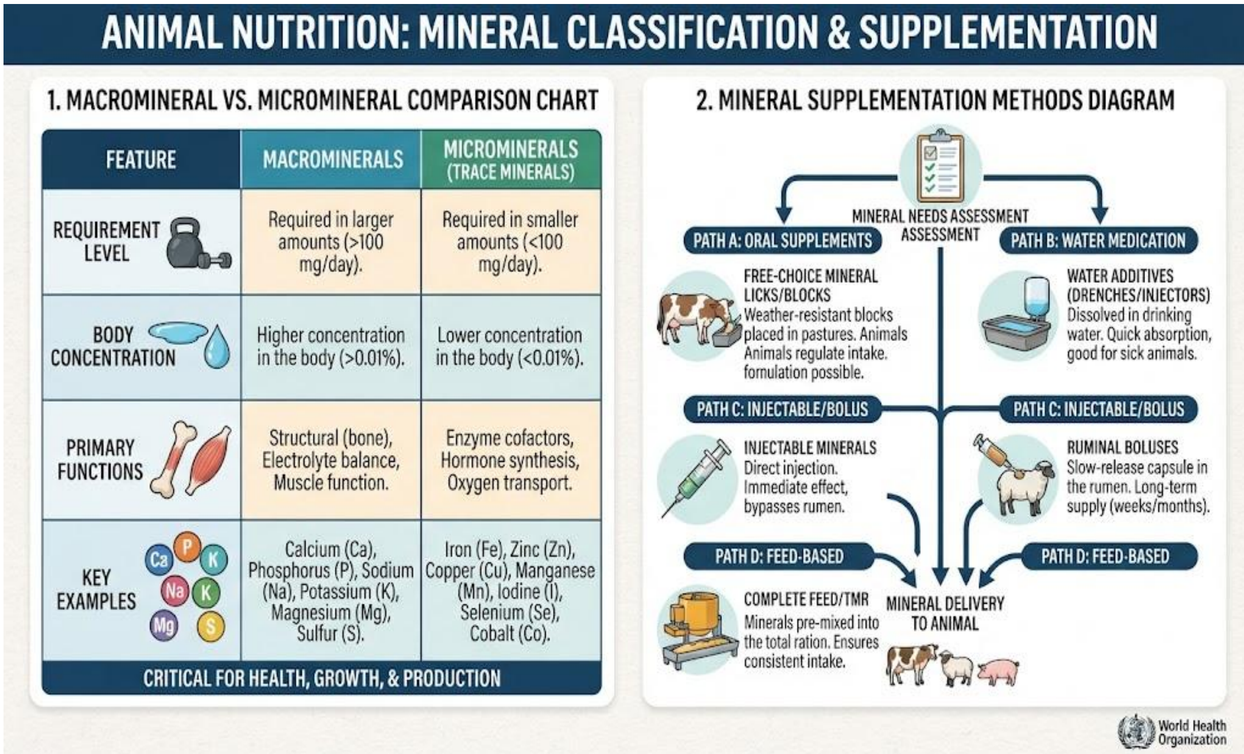


Figure 2.4: Mineral nutrition and supplementation

Pilot questions 2.4

1. Name three macrominerals and one function of each.
2. Explain the significance of the calcium-to-phosphorus ratio.
3. Name three microminerals/trace elements and one function of each.
4. Describe iodine deficiency and its underlying mechanism.
5. Name three methods of mineral supplementation.

Series Summary

This Series examined **the major nutrients required by livestock and their roles in health, growth, and production**. **Water**, which makes up **60–70% of body weight**, is essential for temperature regulation, nutrient transport, digestion, and metabolism. **Carbohydrates** (sugars, starches, and fibre) are the primary energy source, and deficiency results in weight loss and reduced production. **Proteins** supply amino acids for growth, tissue repair, enzyme and hormone production, with essential amino acids needing dietary supply and the limiting amino acid determining protein quality. Protein deficiency impairs growth and immunity, while excess protein is wasteful and increases nitrogen excretion. **Fats** provide concentrated energy, essential fatty acids, and aid absorption of fat-soluble vitamins. Fat-soluble vitamins (**A, D, E, and K**) have specific physiological functions, while ruminants benefit from microbial synthesis of most **B vitamins**.

The Series also covered **mineral nutrition and supplementation strategies**. **Macrominerals** such as calcium, phosphorus, and sodium are required in large amounts, with maintaining an appropriate **calcium-to-phosphorus (Ca:P) ratio** being important for normal growth and prevention of disorders such as milk fever. **Microminerals**, including iron, copper, zinc, selenium, and iodine, are needed in small quantities but are essential for metabolism, immunity, and reproduction, with deficiencies varying by region. Mineral supplementation may be provided through mineral licks, premixes, injectable preparations, or other methods selected according to local deficiency patterns and livestock requirements. By completing this Series, students should achieve SLOs 2.1–2.4.

Glossary of Terms

- **Essential amino acid:** an amino acid that must be supplied in the diet since the animal body cannot synthesise it in adequate amounts.
- **Goitre:** an enlarged thyroid gland resulting from iodine deficiency.

- **Limiting amino acid:** the essential amino acid most likely to be deficient relative to requirement in a typical diet.
- **Macromineral:** a mineral required in relatively large quantities, such as calcium, phosphorus, or sodium.
- **Micromineral (trace element):** a mineral required in small quantities but still essential, such as iron, copper, zinc, selenium, or iodine.
- **Rickets:** a bone deformity disease in young growing animals caused by calcium, phosphorus, or vitamin D deficiency.
- **White muscle disease:** a muscular dystrophy condition in young ruminants caused by vitamin E or selenium deficiency.

Concept Check Questions [Series 2]

Objective Questions

1. Water typically constitutes 60 to ________ percent of body weight in most livestock species. (Linked to SLO 2.1)
2. ________ amino acids must be supplied in the diet since the body cannot synthesise them adequately. (Linked to SLO 2.2)
3. Vitamin D deficiency causes ________ in young growing animals, with weak, deformed bones. (Linked to SLO 2.3)
4. ________ deficiency causes goitre, due to its role in thyroid hormone synthesis. (Linked to SLO 2.4)
5. Fats/lipids contain roughly ________ the energy per unit weight of carbohydrates or protein. (Linked to SLO 2.3)

Short-Answer Questions

1. Name three functions of water. (Linked to SLO 2.1)
2. Define limiting amino acid. (Linked to SLO 2.2)
3. Name two fat-soluble vitamins and one function of each. (Linked to SLO 2.3)
4. Name three macrominerals. (Linked to SLO 2.4)
5. Explain why ruminants are less dependent on dietary B-vitamins than monogastric animals. (Linked to SLO 2.3)

Long-Answer Questions

1. Explain the functions, sources, and deficiency symptoms of water and carbohydrates. (Linked to SLO 2.1)
2. Explain protein and amino acid functions, sources, and deficiency/excess effects. (Linked to SLO 2.2)
3. Explain fat and vitamin functions/deficiencies, and mineral functions/deficiencies/supplementation. (Linked to SLOs 2.3, 2.4)

Answers to Concept Check Questions [Series 2]

Objective Questions

1. 70.
2. Essential.
3. Rickets.
4. Iodine.
5. Twice/double.

Short-Answer Questions

1. Temperature regulation, metabolic medium, and nutrient/waste transport.
2. The essential amino acid most likely to be deficient relative to requirement in a typical diet.
3. Vitamin A (vision/immune function) and vitamin D (calcium/phosphorus absorption and bone mineralisation).
4. Calcium, phosphorus, and sodium (or magnesium, potassium, chloride).
5. Rumen microbial synthesis supplies B-vitamins to ruminants, a source monogastric animals lack.

Long-Answer Questions

1. Water regulates temperature, transports nutrients, and forms 60-70% of body weight; deficiency reduces feed intake and causes dehydration. Carbohydrates (sugars, starches, fibre) supply energy; deficiency causes weight loss and reduced production.
2. Protein supplies amino acids for growth, enzymes, and production; sourced from plant and animal feedstuffs; deficiency impairs growth and immunity, while excess is wasteful rather than harmful.
3. Fats provide concentrated energy and support fat-soluble vitamin (A, D, E, K) absorption; deficiencies cause specific syndromes like rickets and white muscle disease. Macrominerals (calcium, phosphorus) and microminerals (iron, zinc, selenium, iodine) support skeletal, enzymatic, and metabolic functions, with supplementation matched to local deficiency patterns.

Answers to Pilot Questions [Series 2]

Part 2.1

1. Temperature regulation, metabolic medium for reactions, and nutrient/waste transport.
2. Drinking water, water in feed, and metabolic water.
3. Feed intake and water intake are closely linked, so inadequate water reduces voluntary feed consumption.
4. Simple sugars (highly digestible), starches (enzyme and fermentation digestible), and structural fibre (mainly fermentation digestible).
5. It can cause ketosis, a severe metabolic consequence of substantial energy deficiency in early lactation.

Part 2.2

1. Tissue growth/repair, enzyme/hormone synthesis, and production of milk/egg protein.
2. Essential amino acids must come from the diet; non-essential amino acids can be synthesised by the body.
3. The essential amino acid most likely to be deficient relative to requirement in a typical diet, such as lysine.
4. Soybean meal and fish meal (or groundnut cake, blood meal).
5. Excess amino acids are deaminated and nitrogen excreted, rather than causing direct toxicity at typical excess levels.

Part 2.3

1. Concentrated energy source, essential fatty acid supply, and fat-soluble vitamin absorption support.
2. Fat-soluble vitamins require dietary fat for efficient intestinal absorption.
3. Vitamin A deficiency causes night blindness, increased infection susceptibility, and poor growth/reproduction.
4. Vitamin D deficiency causes rickets due to inadequate calcium/phosphorus absorption and bone mineralisation.
5. Rumen microbial synthesis supplies B-vitamins to ruminants, a source monogastric animals lack.

Part 2.4

1. Calcium (bone/milk), phosphorus (bone/metabolism), and sodium (electrolyte/nerve function).
2. Proper mineral utilisation depends on the correct ratio between the two, not just their absolute amounts.
3. Iron (haemoglobin), zinc (skin/hoof health, enzymes), and selenium (antioxidant function with vitamin E).
4. Iodine deficiency impairs thyroid hormone synthesis, causing goitre and reduced metabolic/reproductive performance.
5. Mineral licks/blocks, premixed concentrate feed, and injectable supplements.

References and Attributions

Textual References (Books and External Sources)

- McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., & Morgan, C. A. (2010). Animal nutrition (7th ed.). Pearson.
- National Research Council (NRC). (2001). Nutrient requirements of dairy cattle (7th ed.). National Academies Press.
- National Research Council (NRC). (1994). Nutrient requirements of poultry (9th ed.). National Academies Press.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 2.1: Water and carbohydrate nutrition Attribution: AI generated. Suggested OER search string: "water function carbohydrate classification livestock nutrition deficiency OER".
- Figure 2.2: Protein and amino acid nutrition Attribution: AI generated. Suggested OER search string: "protein amino acid essential nonessential livestock nutrition deficiency OER".
- Figure 2.3: Fat and vitamin nutrition Attribution: AI generated. Suggested OER search string: "fat soluble vitamin deficiency livestock nutrition vitamin A D E B-complex OER".
- Figure 2.4: Mineral nutrition and supplementation Attribution: AI generated. Suggested OER search string: "macromineral micromineral trace element supplementation livestock nutrition deficiency OER".

Series 3: Feedstuff Characterization and Classification

- **Part 3.1: Principles of Feed Analysis**
  - Sub Part 3.1.1: Proximate analysis
  - Sub Part 3.1.2: Energy evaluation
  - Sub Part 3.1.3: Digestibility and feed quality
- **Part 3.2: Classification of Feedstuffs**
  - Sub Part 3.2.1: Concentrates versus roughages
  - Sub Part 3.2.2: Energy feeds versus protein feeds
  - Sub Part 3.2.3: Other feedstuff classifications
- **Part 3.3: Concentrate Feeds: Cereal Grains and By-Products**
  - Sub Part 3.3.1: Major cereal grain feedstuffs
  - Sub Part 3.3.2: Cereal milling by-products
  - Sub Part 3.3.3: Other energy by-product feeds
- **Part 3.4: Concentrate Feeds: Protein Sources and Miscellaneous**
  - Sub Part 3.4.1: Plant protein feeds
  - Sub Part 3.4.2: Animal protein feeds
  - Sub Part 3.4.3: Miscellaneous feed additives

Introduction

Sound ration formulation depends entirely on accurate knowledge of feedstuff nutrient composition; this Series introduces the principles of feed analysis and the classification systems used to organise the vast range of available feedstuffs, before examining specific cereal grain, by-product, and protein feedstuffs commonly used in Nigerian livestock feeding.

This Series covers proximate analysis, energy evaluation, and digestibility as feed quality measures; the major feedstuff classification systems (concentrates versus roughages, energy versus protein feeds); cereal grains and their milling by-products; and plant and animal protein feeds along with miscellaneous feed additives. This detailed feedstuff knowledge directly supports the ration formulation skills developed in Series 4.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** explain the principles of proximate analysis, energy evaluation, and digestibility as feed quality measures (Linked to Part 3.1),
- **SLO 3.2** classify feedstuffs by type, including concentrates, roughages, and energy/protein feeds (Linked to Part 3.2),
- **SLO 3.3** describe major cereal grain feedstuffs and their milling by-products (Linked to Part 3.3), and
- **SLO 3.4** describe plant and animal protein feeds and miscellaneous feed additives (Linked to Part 3.4).

3.1 Principles of Feed Analysis

3.1.1 Proximate analysis

Proximate analysis, a standard laboratory feed analysis system, partitions feedstuff dry matter into six fractions: moisture (water content, affecting storage stability and the basis for expressing other components), crude protein (estimated from nitrogen content, Series 2), ether extract (crude fat content), crude fibre (a measure of structural plant material, though now considered a somewhat crude/imprecise fibre measure compared to more modern detergent fibre systems), ash (mineral content), and nitrogen-free extract (calculated by difference, representing mainly sugars and starches).

While proximate analysis remains widely used and reported in feed composition tables, more refined fibre analysis systems (such as neutral detergent fibre and acid detergent fibre, distinguishing different fibre fractions with different digestibility implications, particularly relevant for forage evaluation in Series 5) provide additional precision valuable for more sophisticated ration formulation, supplementing rather than entirely replacing proximate analysis in modern feed evaluation practice.

Fill in the blank: Proximate analysis partitions feedstuff dry matter into six fractions: moisture, crude protein, ether extract, crude fibre, ash, and nitrogen-free ________ .

3.1.2 Energy evaluation

Energy content (the single most important feedstuff characteristic for most ration formulation purposes, Series 4) is evaluated at several levels of precision: gross energy (total heat released on complete combustion, a relatively crude measure since it does not account for digestibility); digestible energy (gross energy minus energy lost in faeces, accounting for digestibility); and metabolisable energy (digestible energy minus energy lost in urine and, for ruminants, methane, representing energy actually available to the animal for maintenance and production).

Net energy systems (further subtracting the heat increment of feeding, the energy cost of digestion and metabolism itself, to estimate energy genuinely available for maintenance or production) provide the most precise energy evaluation but require more complex calculation; different energy systems are used by convention for different species and purposes (metabolisable energy commonly used for poultry, for example, while net energy systems are common in some cattle feeding contexts), a practical detail relevant to interpreting feed composition tables correctly in Series 4.

Fill in the blank: ________ energy is calculated as digestible energy minus energy lost in urine and, for ruminants, methane, representing energy actually available to the animal.

3.1.3 Digestibility and feed quality

Digestibility (the proportion of a nutrient consumed that is actually absorbed rather than excreted in faeces) varies considerably between feedstuffs and is influenced by factors including fibre content (generally reducing digestibility, particularly for monogastric animals, Series 1), processing (some processing methods, such as grinding or heat treatment, can improve digestibility of certain feedstuffs), and animal species/age (young animals and monogastric species generally show lower fibre digestibility than mature ruminants).

Digestibility trials (feeding a known quantity of a feedstuff and measuring nutrient content of faecal output to calculate the difference) provide direct digestibility measurement, though published feed composition tables (incorporating previously measured digestibility values for common feedstuffs) are more commonly used in routine practical ration formulation than conducting new digestibility trials for every feeding decision.

Fill in the blank: ________ trials, feeding a known quantity of feedstuff and measuring faecal nutrient content, provide direct measurement of how much of a nutrient is actually absorbed by the animal.

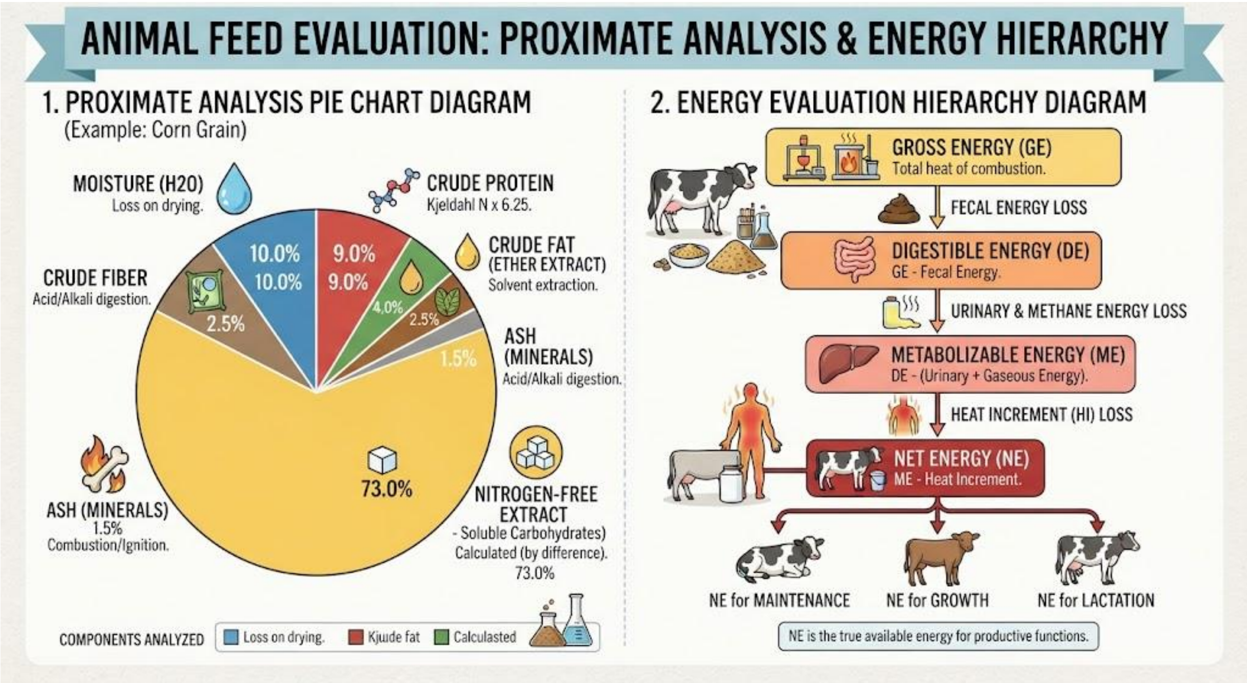


Figure 3.1: Principles of feed analysis

Pilot questions 3.1

1. Name the six fractions of proximate analysis.
2. Distinguish between gross energy and digestible energy.
3. Define metabolisable energy.
4. Define digestibility.
5. Name two factors influencing feedstuff digestibility.

3.2 Classification of Feedstuffs

3.2.1 Concentrates versus roughages

Concentrates (feedstuffs low in fibre and high in energy and/or protein density, such as cereal grains and oilseed meals, Parts 3.3-3.4) are distinguished from roughages/forages (feedstuffs high in fibre, generally lower in energy density, such as pasture, hay, and silage, examined in detail in Series 5), a fundamental classification reflecting the comparative digestive efficiency principles introduced in Series 1.

Most practical livestock rations combine both concentrate and roughage components in proportions reflecting the species comparative digestive capacity (Series 1) and the specific production target: ruminant rations can incorporate substantial roughage proportions (sometimes the majority of the diet for maintenance-level or extensive grazing animals), while monogastric (pig and poultry) rations rely predominantly on concentrate feeds given limited fibre digestion capacity.

Fill in the blank: ________ are feedstuffs low in fibre and high in energy and/or protein density, distinguished from roughages/forages which are high in fibre and generally lower in energy density.

3.2.2 Energy feeds versus protein feeds

Within the concentrate category, feedstuffs are further distinguished by their primary nutrient contribution: energy feeds (cereal grains and many cereal by-products, Part 3.3, contributing primarily carbohydrate/starch energy with relatively modest protein content, often below 12-15 percent crude protein) versus protein feeds (oilseed meals/cakes and animal protein sources, Part 3.4, contributing substantial protein, often 30-50+ percent crude protein, alongside some energy).

This energy-versus-protein distinction directly informs ration formulation strategy (Series 4): rations are typically built around an energy feed base (usually the largest single ingredient by weight, given the central importance of meeting energy requirement) supplemented with protein feeds and other ingredients to meet remaining nutrient requirements, a practical formulation logic explored in detail in the next Series.

Fill in the blank: ________ feeds (oilseed meals/cakes and animal protein sources) contribute substantial protein, often 30-50+ percent crude protein, distinguishing them from energy feeds.

3.2.3 Other feedstuff classifications

Feedstuffs are also classified by additional dimensions relevant to practical feeding: by-product feeds (residues or co-products of food/industrial processing, such as wheat bran or brewers grains, Part 3.3.2, often economically attractive given their lower cost relative to primary feedstuffs); mineral and vitamin supplements (Series 2, providing concentrated specific nutrients rather than general energy/protein, used in relatively small dietary proportions); and feed additives (substances added in very small amounts for specific functional purposes beyond basic nutrient supply, Part 3.4.3, such as enzymes, probiotics, or growth promoters where permitted).

Understanding these multiple, complementary classification dimensions (concentrate/roughage, energy/protein, by-product status, supplement/additive category) together, rather than relying on any single classification system alone, supports a fuller, more practically useful understanding of how a given feedstuff fits into overall ration formulation strategy, the subject of Series 4.

Fill in the blank: ________ feeds, residues or co-products of food/industrial processing such as wheat bran or brewers grains, are often economically attractive given their lower cost relative to primary feedstuffs.

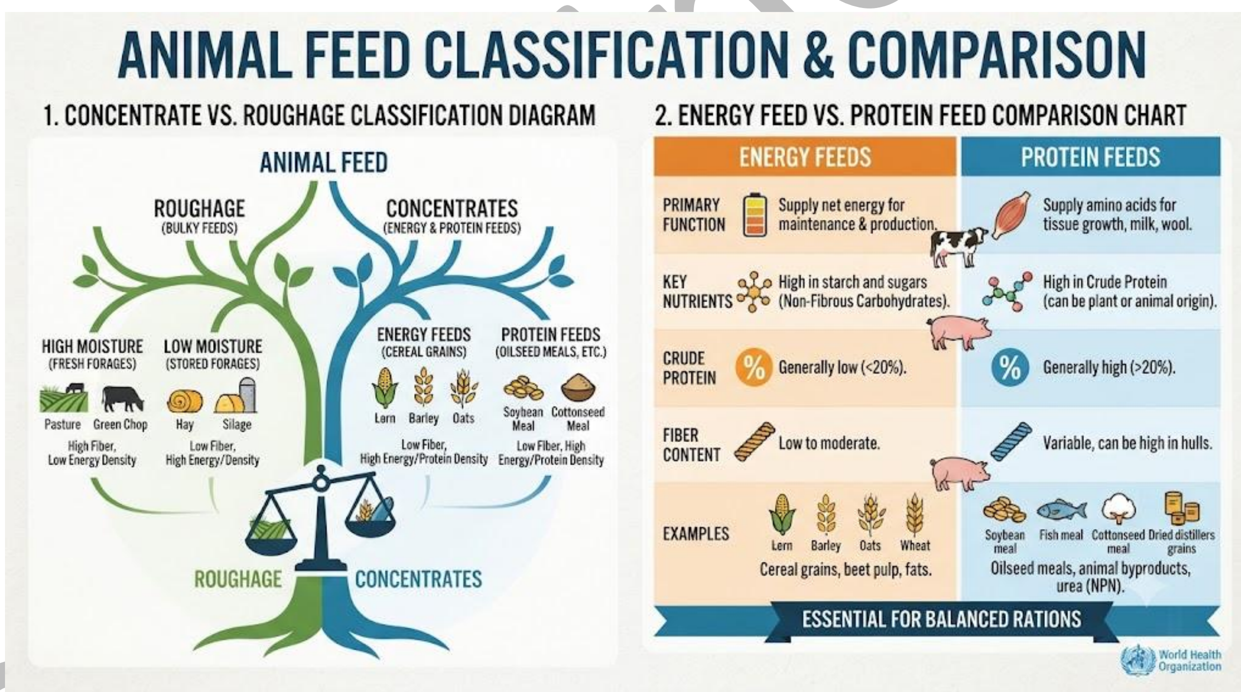


Figure 3.2: Feedstuff classification systems

Pilot questions 3.2

1. Distinguish between concentrates and roughages.
2. Explain why ruminant rations can include more roughage than monogastric rations.

3. Distinguish between energy feeds and protein feeds.
4. Explain the typical role of an energy feed in ration formulation.

6. Define by-product feed and give one example.

3.3 Concentrate Feeds: Cereal Grains and By-Products

3.3.1 Major cereal grain feedstuffs

Maize (the dominant energy feedstuff in most Nigerian livestock rations given its high energy density, good palatability, and relatively wide availability, Series 1-2 of related crop production courses) typically supplies 8-9 percent crude protein alongside its primary starch energy contribution; sorghum and millet (alternative energy feedstuffs, particularly relevant where maize is less available or more costly, with broadly similar but sometimes slightly lower energy value than maize) serve similar formulation roles.

Wheat (less commonly used as a primary livestock energy feed in Nigeria given competing human food use and import dependence, Series 1 of related agricultural marketing courses, but occasionally used, particularly its by-products, Part 3.3.2) and rice (whole rice less commonly fed directly to livestock than its milling by-products, Part 3.3.2, given human food preference for the milled grain) complete the major Nigerian cereal grain feedstuff considerations.

Fill in the blank: ________ is the dominant energy feedstuff in most Nigerian livestock rations given its high energy density, good palatability, and relatively wide availability.

3.3.2 Cereal milling by-products

Wheat bran (the outer layers of the wheat grain removed during milling, a by-product of flour production with higher fibre and protein content than whole wheat grain, widely used as a moderate-energy, moderate-protein feedstuff, particularly in poultry and pig rations) and rice bran/rice polishings (by-products of rice milling, similarly higher in fibre and fat than milled white rice, used as energy and partial protein sources) represent significant, often economically attractive Nigerian feedstuffs given the substantial scale of wheat flour milling and rice processing industries.

Maize bran/maize offal (by-products of maize milling/processing, with composition varying depending on the specific milling process and the proportion of grain components retained) similarly provide a generally lower-cost alternative to whole maize grain, though with correspondingly different (often lower) energy density given the higher fibre content typical of milling by-products compared to the original whole grain.

Fill in the blank: ________ bran, a by-product of flour milling with higher fibre and protein content than the whole grain, is widely used as a moderate-energy, moderate-protein feedstuff in poultry and pig rations.

3.3.3 Other energy by-product feeds

Cassava-based by-products (cassava peel, and processed cassava products such as dried cassava chips/pellets, Series 1-2 of related crop production courses) provide an abundant, low-cost Nigerian energy feedstuff option given the country major cassava production, though requiring attention to processing (reducing cyanogenic glycoside/cyanide-related antinutritional content, an important practical consideration for safe cassava-based feed use) and generally lower protein content than cereal grains, requiring protein supplementation alongside cassava-based energy feeding.

Brewers dried grains (a by-product of beer brewing, with moderate protein and fibre content, a useful feedstuff particularly for ruminants given its fibre tolerance, and available in significant quantity near major Nigerian brewing operations) and molasses (a concentrated sugar by-product of sugar refining, providing a highly palatable, rapidly fermentable energy source useful in moderate quantities for improving ration palatability and providing readily available energy, particularly for ruminants) complete a selection of significant Nigerian energy by-product feedstuffs.

Fill in the blank: Cassava-based feedstuffs require attention to processing in order to reduce cyanogenic glycoside/________ -related antinutritional content before safe use in livestock feeding.

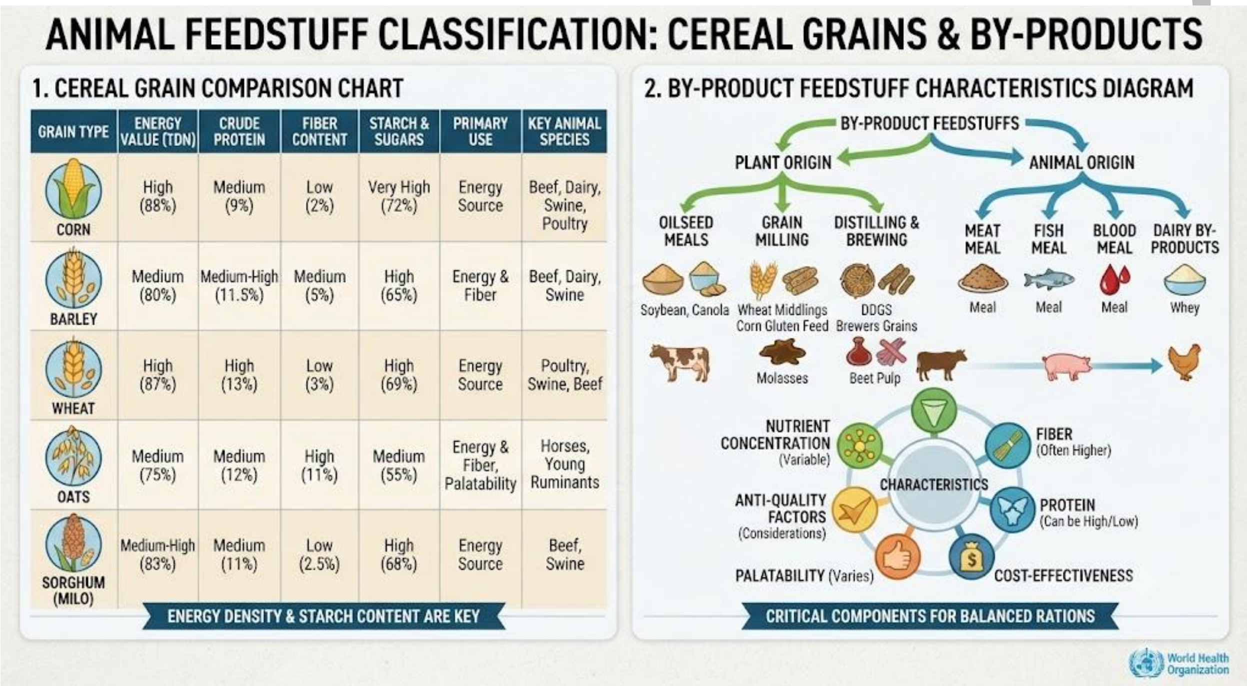


Figure 3.3: Cereal grains and energy by-product feedstuffs

Pilot questions 3.3

7. Explain why maize is the dominant energy feedstuff in Nigerian livestock rations.
8. Name two alternative cereal grain energy feedstuffs to maize.
9. Describe wheat bran and its typical use.
10. Explain the processing consideration needed for cassava-based feedstuffs.
11. Describe molasses and its typical role in ration formulation.

3.4 Concentrate Feeds: Protein Sources and Miscellaneous

3.4.1 Plant protein feeds

Soybean meal (a by-product of soybean oil extraction, among the highest quality and most widely used plant protein feedstuffs globally and increasingly in Nigeria given growing domestic soybean production, Series 2 of related crop production courses, typically 44-48 percent crude protein with a relatively well-balanced amino acid profile) is a benchmark protein feedstuff against which other protein sources are often compared.

Groundnut cake (a by-product of groundnut oil extraction, a traditional and widely available Nigerian protein feedstuff, typically 40-50 percent crude protein, though requiring attention to aflatoxin contamination risk, Series 2 of related crop production courses, particularly under poor storage conditions) and cottonseed cake (a by-product of cotton oil extraction, moderate protein content but containing gossypol, a naturally occurring compound requiring careful inclusion rate management, particularly for non-ruminant species more sensitive to gossypol toxicity than ruminants) are other significant Nigerian plant protein feedstuffs.

Fill in the blank: ________ cake, a by-product of groundnut oil extraction, is a traditional Nigerian protein feedstuff requiring attention to aflatoxin contamination risk, particularly under poor storage conditions.

3.4.2 Animal protein feeds

Fish meal (made from processed fish or fish processing by-products, typically 55-65+ percent crude protein with an excellent, well-balanced amino acid profile including good levels of lysine and methionine, valuable particularly in poultry and pig rations where amino acid balance, Series 2, matters considerably) is among the highest quality animal protein feedstuffs, though cost and, in some regions, availability can limit its inclusion level in practical rations.

Blood meal (a by-product of animal slaughter/processing, very high protein content but with a less balanced amino acid profile than fish meal, generally used at lower inclusion rates) and other animal by-product meals (such as bone meal, contributing both protein and mineral content, particularly calcium and phosphorus, Series 2) complete the significant animal protein feedstuff category, used judiciously given cost, amino acid balance, and, in some contexts, disease transmission risk considerations affecting animal by-product feed use regulation internationally.

Fill in the blank: ________ meal, made from processed fish or fish processing by-products, is among the highest quality animal protein feedstuffs given its excellent, well-balanced amino acid profile.

3.4.3 Miscellaneous feed additives

Feed additives (substances included in rations at very low inclusion rates for specific functional purposes beyond basic nutrient supply) include enzymes (improving digestibility of specific feed components, such as phytase improving phosphorus availability from plant-based phosphorus sources, particularly valuable in monogastric rations given limited natural phytase activity), and probiotics/prebiotics (supporting beneficial gut microorganism populations, particularly relevant given the gut microbial digestion principles introduced in Series 1).

Antioxidants (preventing feed/fat rancidity during storage, protecting feed quality and the fat-soluble vitamin content discussed in Series 2) and, where permitted by relevant regulation, other specific functional additives complete the miscellaneous feed additive category; responsible additive use should follow relevant regulatory guidance and manufacturer recommendations given the typically very low, precisely calibrated inclusion rates involved, quite different from the proportionally much larger energy and protein feedstuff inclusion rates discussed elsewhere in this Series.

Fill in the blank: ________ , such as phytase improving phosphorus availability from plant-based sources, are feed additives that improve digestibility of specific feed components, particularly valuable in monogastric rations.

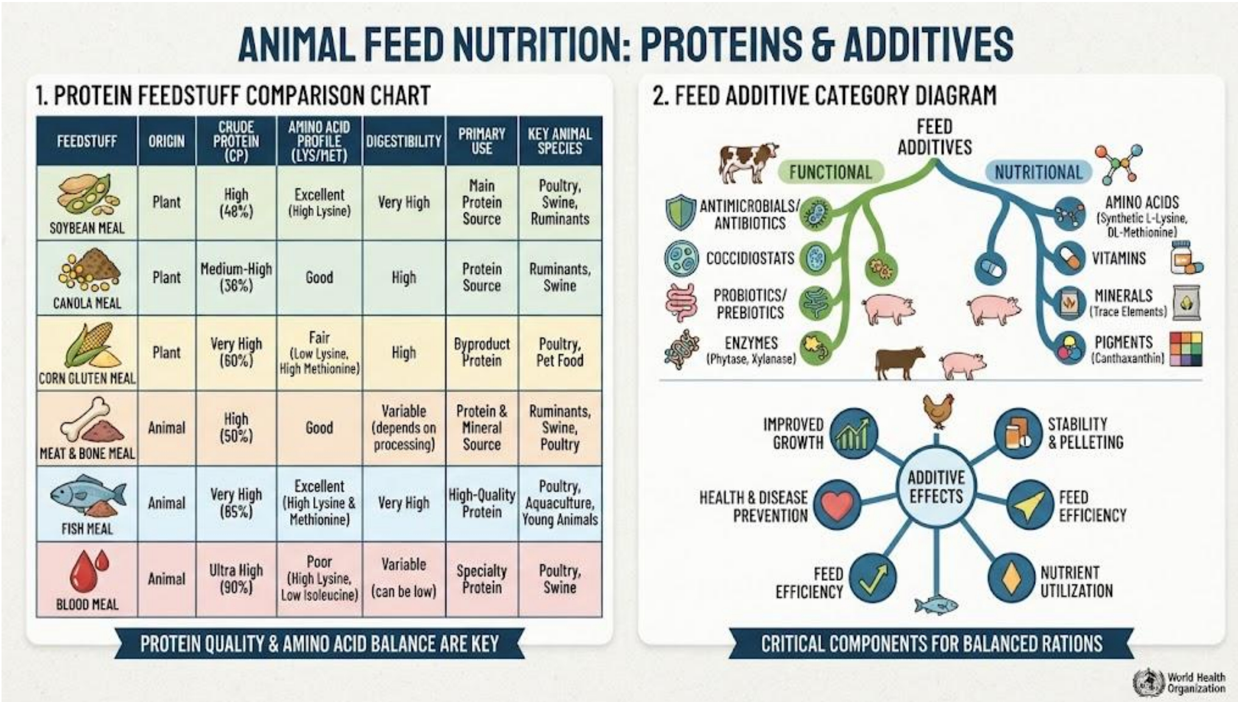


Figure 3.4: Protein feedstuffs and feed additives

Pilot questions 3.4

1. Describe soybean meal and its typical crude protein content.
2. Explain the aflatoxin concern associated with groundnut cake.
3. Explain the gossypol concern associated with cottonseed cake.
4. Describe fish meal and explain why it is valued in poultry/pig rations.
5. Define feed additive and give one example with its function.

Series Summary

This Series examined **feed evaluation and the classification of livestock feedstuffs**. Feed quality is commonly assessed using **proximate analysis**, which divides feeds into six fractions, while energy is evaluated as **gross energy (GE), digestible energy (DE), metabolisable energy (ME), and net energy (NE)**. Feed digestibility represents the proportion of nutrients absorbed by the animal and is influenced by fibre content, feed processing, and animal species. Feedstuffs are classified as **concentrates or roughages**, **energy or protein feeds**, and may also include by-products, supplements, and feed additives. Major energy feeds include **maize** (the dominant cereal energy source), sorghum, millet, wheat bran, rice bran, cassava by-products (which require proper processing to remove cyanide), brewers' grains, and molasses.

The Series also covered **protein feed resources and feed additives**. Important protein feeds include **soybean meal** (the standard protein feed), groundnut cake (with aflatoxin risk), cottonseed cake (containing gossypol), fish meal (a high-quality animal protein source), and blood meal. Feed additives such as **enzymes, probiotics, and antioxidants** are included at low levels to improve feed utilisation, animal health, and performance. By completing this Series, students should achieve SLOs 3.1–3.4.

Glossary of Terms

- **By-product feed:** a feedstuff that is a residue or co-product of food or industrial processing, such as wheat bran.
- **Concentrate:** a feedstuff low in fibre and high in energy and/or protein density, such as cereal grains or oilseed meals.
- **Digestibility:** the proportion of a nutrient consumed that is actually absorbed rather than excreted in faeces.
- **Gossypol:** a naturally occurring compound in cottonseed products requiring careful inclusion rate management, especially for non-ruminants.
- **Metabolisable energy:** digestible energy minus energy lost in urine and, for ruminants, methane.

- **Proximate analysis:** a standard laboratory system partitioning feedstuff dry matter into moisture, crude protein, ether extract, crude fibre, ash, and nitrogen-free extract.
- **Roughage/forage:** a feedstuff high in fibre and generally lower in energy density, such as pasture, hay, or silage.

Concept Check Questions [Series 3]

Objective Questions

1. Proximate analysis includes moisture, crude protein, ether extract, crude fibre, ash, and nitrogen-free ________ . (Linked to SLO 3.1)
2. ________ are feedstuffs low in fibre and high in energy/protein density. (Linked to SLO 3.2)
3. ________ is the dominant energy feedstuff in most Nigerian livestock rations. (Linked to SLO 3.3)
4. ________ meal is among the highest quality animal protein feedstuffs given its balanced amino acid profile. (Linked to SLO 3.4)
5. Cassava-based feedstuffs require processing to reduce ________ -related antinutritional content. (Linked to SLO 3.3)

Short-Answer Questions

1. Name the six fractions of proximate analysis. (Linked to SLO 3.1)
2. Distinguish between concentrates and roughages. (Linked to SLO 3.2)
3. Name two cereal grain feedstuffs. (Linked to SLO 3.3)
4. Name two plant protein feedstuffs and one concern with each. (Linked to SLO 3.4)
5. Define feed additive. (Linked to SLO 3.4)

Long-Answer Questions

1. Explain proximate analysis, energy evaluation, and digestibility as feed quality measures. (Linked to SLO 3.1)
2. Classify feedstuffs and describe cereal grains and their by-products. (Linked to SLOs 3.2, 3.3)
3. Describe plant and animal protein feeds and feed additives. (Linked to SLO 3.4)

Answers to Concept Check Questions [Series 3]

Objective Questions

1. Extract.
2. Concentrates.
3. Maize.
4. Fish.
5. Cyanogenic glycoside/cyanide.

Short-Answer Questions

1. Moisture, crude protein, ether extract, crude fibre, ash, and nitrogen-free extract.
2. Concentrates are low-fibre, high energy/protein density; roughages are high-fibre, lower energy density.
3. Maize and sorghum (or millet, wheat, rice).
4. Groundnut cake (aflatoxin risk) and cottonseed cake (gossypol).
5. A substance included in rations at very low rates for a specific functional purpose beyond basic nutrient supply.

Long-Answer Questions

1. Proximate analysis partitions feed into six fractions. Energy evaluation progresses from gross to digestible to metabolisable to net energy, each subtracting specific losses. Digestibility measures the proportion of nutrient actually absorbed, varying with fibre, processing, and species.
2. Feedstuffs are classified as concentrates or roughages, and as energy or protein feeds. Cereal grains (maize, sorghum) provide energy, while milling by-products (wheat bran, rice bran) and cassava by-products provide lower-cost alternatives requiring some processing or supplementation.
3. Plant protein feeds (soybean meal, groundnut cake, cottonseed cake) and animal protein feeds (fish meal, blood meal) supply protein at varying quality and cost, with specific contamination/toxin concerns. Feed additives (enzymes, probiotics, antioxidants) serve specific functional purposes at low inclusion rates.

Answers to Pilot Questions [Series 3]

Part 3.1

1. Moisture, crude protein, ether extract, crude fibre, ash, and nitrogen-free extract.
2. Gross energy is total combustion heat; digestible energy subtracts energy lost in faeces, accounting for digestibility.
3. Metabolisable energy is digestible energy minus energy lost in urine and, for ruminants, methane.
4. Digestibility is the proportion of a nutrient consumed that is actually absorbed rather than excreted.
5. Fibre content and processing method (or animal species/age).

Part 3.2

1. Concentrates are low in fibre and high in energy/protein density; roughages are high in fibre and lower in energy density.
2. Ruminants have rumen microbial fermentation enabling efficient fibre digestion, unlike monogastric animals.
3. Energy feeds contribute mainly carbohydrate energy with modest protein; protein feeds contribute substantial protein.
4. An energy feed is usually the largest single ingredient by weight, since meeting energy requirement is central to formulation.
5. A by-product feed is a residue or co-product of processing, such as wheat bran from flour milling.

Part 3.3

1. Maize has high energy density, good palatability, and relatively wide availability in Nigeria.
2. Sorghum and millet.
3. Wheat bran is a milling by-product, higher in fibre/protein than whole grain, used in poultry and pig rations.
4. Processing is needed to reduce cyanogenic glycoside/cyanide-related antinutritional content.

5. Molasses is a concentrated sugar by-product, used in moderate amounts to improve palatability and provide rapid energy.

Part 3.4

1. Soybean meal is a soybean oil extraction by-product, typically 44-48 percent crude protein with a balanced amino acid profile.
2. Groundnut cake can carry aflatoxin contamination risk, particularly under poor storage conditions.
3. Cottonseed cake contains gossypol, requiring careful inclusion rate management, especially for non-ruminants.
4. Fish meal has high, well-balanced protein including good lysine and methionine, valuable where amino acid balance matters.
5. A feed additive is a substance used at very low rates for a specific function; example: phytase improves phosphorus availability.

References and Attributions

Textual References (Books and External Sources)

- McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., & Morgan, C. A. (2010). Animal nutrition (7th ed.). Pearson.
- National Research Council (NRC). (2001). Nutrient requirements of dairy cattle (7th ed.). National Academies Press.
- National Research Council (NRC). (2012). Nutrient requirements of swine (11th ed.). National Academies Press.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 3.1: Principles of feed analysis Attribution: AI generated. Suggested OER search string: "proximate analysis feed energy evaluation digestible metabolisable livestock nutrition OER".
- Figure 3.2: Feedstuff classification systems Attribution: AI generated. Suggested OER search string: "feedstuff classification concentrate roughage energy protein feed livestock OER".
- Figure 3.3: Cereal grains and energy by-product feedstuffs Attribution: AI generated. Suggested OER search string: "maize sorghum wheat bran rice bran cassava molasses livestock feedstuff Nigeria OER".
- Figure 3.4: Protein feedstuffs and feed additives Attribution: AI generated. Suggested OER search string: "soybean meal groundnut cake fish meal feed additive enzyme livestock nutrition OER".

Series 4: Ration Formulation and Feeding Systems

- **Part 4.1: Principles of Ration Balancing**
  - Sub Part 4.1.1: Steps in ration formulation
  - Sub Part 4.1.2: The Pearson square method
  - Sub Part 4.1.3: Least-cost formulation
- **Part 4.2: Non-Ruminant Ration Applications**
  - Sub Part 4.2.1: Feeding poultry
  - Sub Part 4.2.2: Feeding swine
  - Sub Part 4.2.3: Feeding companion animals
- **Part 4.3: Ruminant Ration Applications**
  - Sub Part 4.3.1: Principles of ruminant ration formulation
  - Sub Part 4.3.2: Dairy cattle rations
  - Sub Part 4.3.3: Beef and small ruminant rations
- **Part 4.4: Feeding Systems and Management**
  - Sub Part 4.4.1: Feeding system types
  - Sub Part 4.4.2: Feed processing and form
  - Sub Part 4.4.3: Monitoring and adjusting feeding programmes

Introduction

This Series brings together the nutrient knowledge of Series 2 and the feedstuff knowledge of Series 3 into the practical skill of ration formulation, balancing rations to meet animal nutrient requirements using available feedstuffs, applied to both non-ruminant (poultry, swine, companion animal) and ruminant (dairy, beef, small ruminant) feeding contexts.

This Series covers the principles and methods of ration balancing, including the Pearson square method and least-cost formulation; non-ruminant ration applications for poultry, swine, and companion animals; ruminant ration applications for dairy cattle, beef cattle, and small ruminants; and feeding system types, feed processing, and ongoing monitoring/adjustment of feeding programmes.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** explain the principles and methods of ration balancing, including the Pearson square and least-cost formulation (Linked to Part 4.1),
- **SLO 4.2** apply ration formulation principles to poultry, swine, and companion animal feeding (Linked to Part 4.2),
- **SLO 4.3** apply ration formulation principles to dairy cattle, beef cattle, and small ruminant feeding (Linked to Part 4.3), and
- **SLO 4.4** describe feeding system types, feed processing, and monitoring/adjustment of feeding programmes (Linked to Part 4.4).

4.1 Principles of Ration Balancing

4.1.1 Steps in ration formulation

Ration formulation follows a systematic sequence: first, determine the animal nutrient requirements (Series 1-2, based on species, life stage, and production target, using published requirement tables such as those from the National Research Council); second, identify available feedstuffs and their nutrient composition (Series 3, using feed composition tables or, ideally, farm-specific feed analysis where available); third, calculate the combination of feedstuffs that meets the requirements; and fourth, evaluate the resulting ration for practical feasibility (palatability, physical form, cost, Part 4.1.3) before finalising.

This systematic approach contrasts with informal or traditional feeding practice based purely on convention or guesswork, directly applying the scientific approach to feeding decisions introduced in Series 1; even relatively simple formulation methods (Part 4.1.2) bring meaningfully more precision and reliability than unstructured feeding decisions, making basic ration balancing skills valuable even without access to sophisticated computer formulation software.

Fill in the blank: Ration formulation begins with determining animal nutrient ________ , based on species, life stage, and production target, before identifying available feedstuffs and calculating the combination needed.

4.1.2 The Pearson square method

The Pearson square is a simple, widely taught manual method for combining two feedstuffs (typically one higher and one lower in the nutrient of interest, often crude protein) to achieve a specific target nutrient level, using a graphical square arrangement and basic arithmetic (subtracting diagonally across the square) to calculate the proportion of each feedstuff needed.

While limited to balancing for a single nutrient at a time using exactly two feedstuffs (a significant simplification compared to real-world rations combining many ingredients and balancing multiple nutrients simultaneously, typically requiring computer-based linear programming for full precision, Part 4.1.3), the Pearson square remains valuable as a teaching tool building foundational ration balancing understanding and for quick, approximate field calculations when more sophisticated tools are unavailable.

Fill in the blank: The Pearson square method is limited to balancing for a single nutrient using exactly ________ feedstuffs, a simplification compared to real-world multi-ingredient, multi-nutrient rations.

4.1.3 Least-cost formulation

Least-cost formulation (typically performed using computer-based linear programming software in commercial practice) identifies the combination of available feedstuffs that meets all specified nutrient requirements at the lowest possible total ingredient cost, formally incorporating the economic dimension of feeding decisions introduced in Series 1 alongside the purely nutritional requirements.

Least-cost formulation requires accurate nutrient requirement specifications (Series 2), accurate feedstuff composition data (Series 3), current feedstuff prices, and any practical constraints (minimum/maximum inclusion levels for specific ingredients, reflecting palatability, antinutritional factor, Series 3, or other practical limits) as inputs; the resulting optimised ration changes as feedstuff prices and availability change, making periodic reformulation a standard commercial feed manufacturing practice rather than a one-time calculation.

Fill in the blank: Least-cost formulation identifies the feedstuff combination meeting all nutrient requirements at the lowest possible total ________ cost.

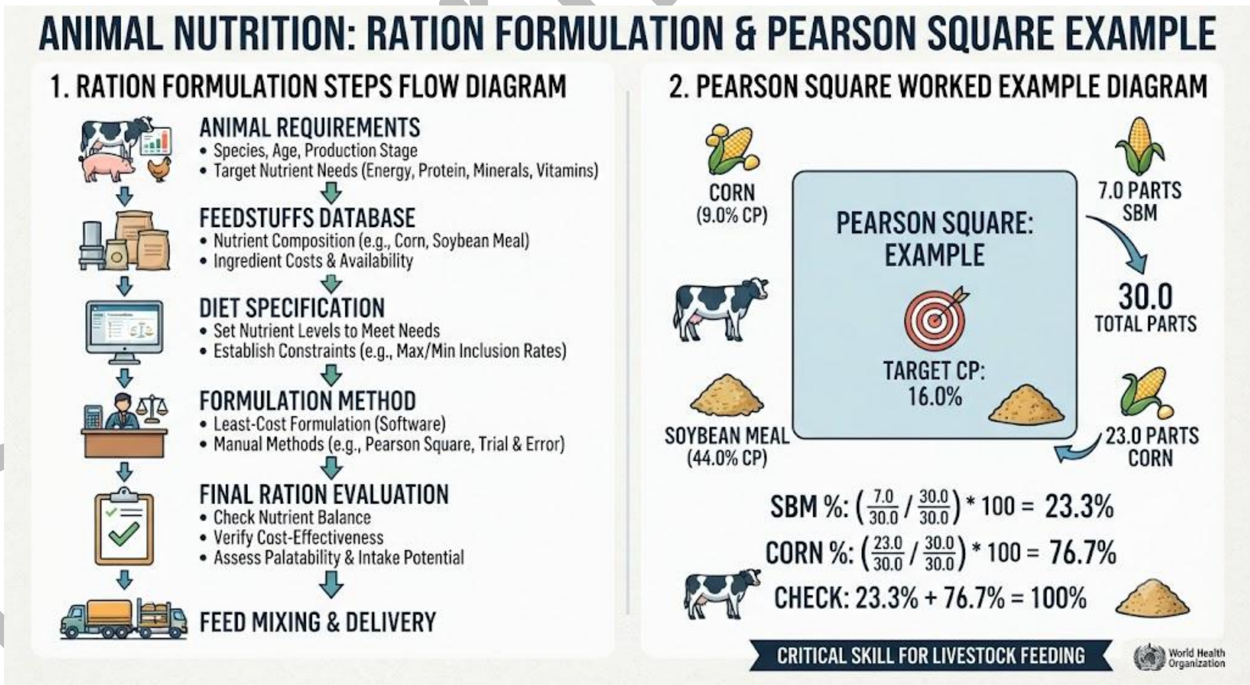


Figure 4.1: Principles of ration formulation

Pilot questions 4.1

1. List the four steps in ration formulation.
2. Describe the Pearson square method and its main limitation.
3. Define least-cost formulation.
4. Name two inputs required for least-cost formulation.
5. Explain why rations are periodically reformulated in commercial practice.

4.2 Non-Ruminant Ration Applications

4.2.1 Feeding poultry

Poultry rations are formulated in distinct phases matching production stage (Series 2 of related production courses): starter rations (high protein, 20-23 percent crude protein, for young chicks), grower rations (moderate protein, for growing pullets or finishing broilers), and layer rations (moderate protein but elevated calcium, 3.5-4 percent, supporting eggshell formation), each requiring careful amino acid balance (Series 2) given poultry limited capacity to synthesise certain amino acids and inability to benefit from rumen microbial protein synthesis.

Broiler rations specifically emphasise high energy density and balanced amino acids (particularly lysine and methionine, Series 2) to maximise growth rate and feed efficiency over the short production cycle, while layer rations balance adequate but not excessive energy (to avoid excessive body fat that can reduce laying performance) against the calcium and other nutrient demands of sustained egg production.

Fill in the blank: Layer poultry rations require elevated calcium, typically 3.5 to ________ percent, supporting eggshell formation during sustained egg production.

4.2.2 Feeding swine

Pig rations similarly follow phase feeding (Series 2 of related production courses): creep, weaner, grower, and finisher rations with progressively changing protein and energy density as the pig matures, alongside distinct gestation and lactation rations for breeding sows reflecting their substantially different nutrient demands (Series 2 of this course) compared to growing pigs.

Pig rations, like poultry rations, require careful amino acid balance given limited rumen-equivalent microbial protein synthesis, with lysine again typically the first limiting amino acid (Series 2) in common cereal-grain-based pig rations, requiring protein supplementation (soybean meal or other protein feeds, Series 3) calibrated to meet this specific amino acid need alongside overall crude protein requirement.

Fill in the blank: Lysine is typically the first ________ amino acid in common cereal-grain-based pig rations, requiring protein supplementation calibrated to meet this specific need.

4.2.3 Feeding companion animals

Companion animal nutrition (dogs and cats, included within the broader scope of this course given shared underlying monogastric nutritional principles, Series 1) follows similar fundamental principles to livestock monogastric nutrition but with some important species-specific differences: cats, as obligate carnivores, have specific dietary requirements (such as dietary taurine and preformed vitamin A, which cats cannot synthesise adequately from plant-based precursors unlike dogs and many other species) not shared with dogs or most livestock species.

Commercial companion animal feed (dry kibble or wet/canned formats) is typically formulated to complete nutritional adequacy standards (analogous in principle to the livestock nutrient requirement standards discussed throughout this course, though governed by different specific regulatory/industry standards), reducing the need for individual ration balancing by pet owners compared to the more frequently farm-level ration formulation practice common in commercial livestock production.

Fill in the blank: Cats, as obligate carnivores, require dietary taurine and preformed vitamin A, since they cannot adequately synthesise these from plant-based ________ unlike dogs and many other species.

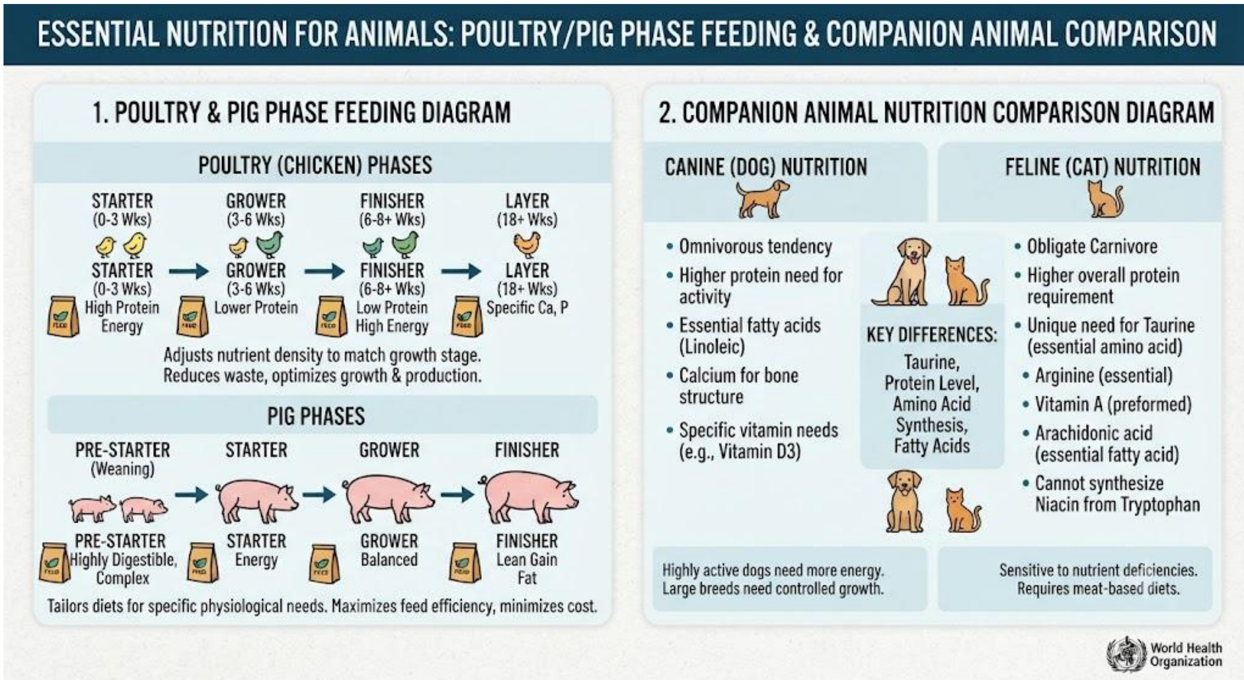


Figure 4.2: Non-ruminant ration applications

Pilot questions 4.2

1. Name three poultry ration phases.
2. Explain why layer rations require elevated calcium.
3. Explain why lysine is often the first limiting amino acid in pig rations.
4. Name two pig ration phases beyond starter/creep.
5. Name two nutrients required by cats but not by most other species.

4.3 Ruminant Ration Applications

4.3.1 Principles of ruminant ration formulation

Ruminant ration formulation must account for rumen function (Series 1): adequate effective fibre is needed to maintain normal rumen function (cud chewing, saliva production, rumen pH stability), even when formulating for high-production animals where energy density might otherwise tempt excessive concentrate inclusion at the expense of fibre, since inadequate fibre risks digestive disorders (acidosis, introduced in related livestock health courses).

Ruminant rations are often expressed and balanced on a forage-to-concentrate ratio basis (Series 5) reflecting the central role of forage in ruminant nutrition, with the appropriate ratio varying by production level and life stage (lower forage/higher concentrate proportions for high-producing dairy cows or finishing beef cattle; higher forage proportions for maintenance-level or extensively grazed animals).

Fill in the blank: Adequate effective ________ is needed to maintain normal rumen function, even when formulating high-energy rations for high-production ruminant animals.

4.3.2 Dairy cattle rations

Dairy cattle rations must meet the substantial energy and protein demands of milk production (Series 1-2), with requirements varying considerably across the lactation cycle (peak demand in early-to-mid lactation, declining demand toward late lactation and the dry/non-lactating period before the next calving), requiring distinct rations for different lactation stages rather than a single uniform ration throughout.

The transition period (late pregnancy through early lactation, a particularly high-risk period for the metabolic disorders introduced in related livestock health courses, such as milk fever and ketosis) requires especially careful ration management, balancing the rapidly rising nutrient demand of early lactation against the cow limited feed intake capacity immediately around calving, a key practical challenge in commercial dairy ration formulation.

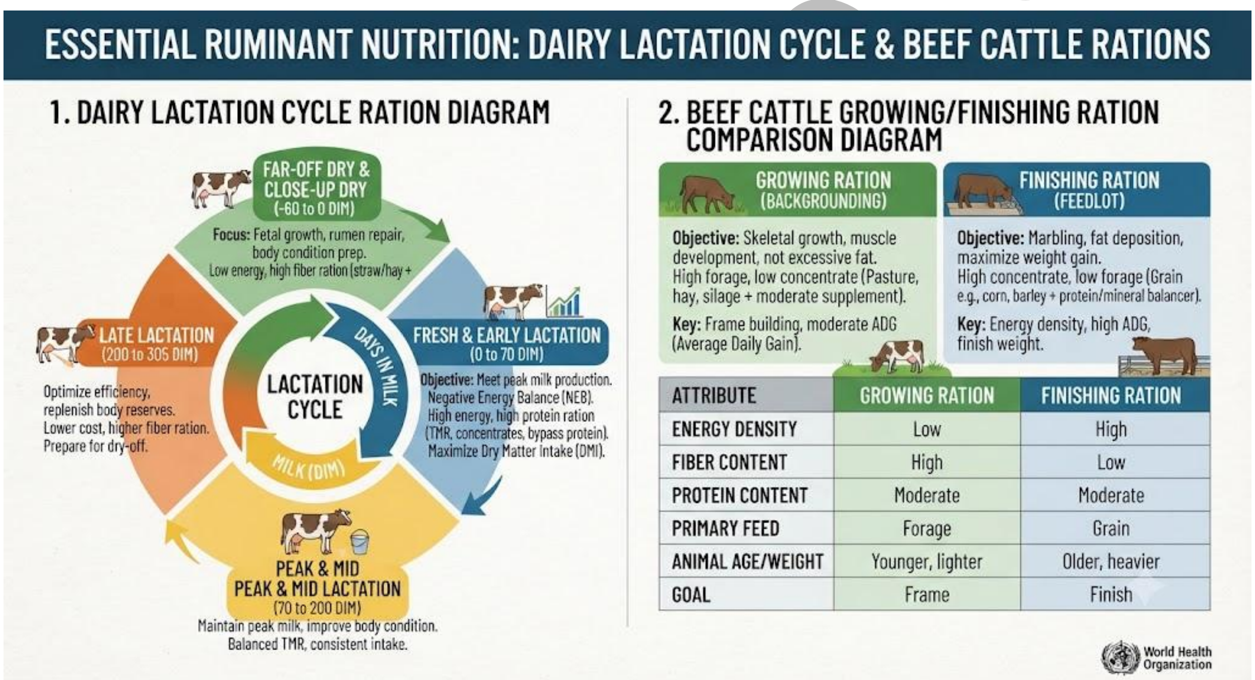
Fill in the blank: The transition period, late pregnancy through early lactation, requires especially careful ration management given its association with metabolic disorders such as milk fever and ________ .

4.3.3 Beef and small ruminant rations

Beef cattle rations differ by production phase: growing/stocker cattle (often grazing-based with modest supplementation) versus finishing cattle (typically higher concentrate proportion to maximise growth rate and achieve desired carcass finish/fat cover before slaughter, a notably more concentrate-intensive approach than typical growing-phase feeding).

Sheep and goat rations generally require lower absolute nutrient quantities than cattle given their smaller body size, but proportionally similar nutrient density principles apply, with particular attention to mineral balance (calcium-to-phosphorus ratio, Series 2) important for preventing urinary calculi (a mineral-related health problem particularly relevant in male sheep/goats fed high-concentrate rations), illustrating that ration formulation must consider species-specific health risks alongside general nutrient requirement principles.

Fill in the blank: Finishing beef cattle rations typically use a higher ________ proportion than growing-phase rations, to maximise growth rate and achieve desired carcass finish before slaughter.



ATTRIBUTE	GROWING RATION	FINISHING RATION
ENERGY DENSITY	Low	High
FIBER CONTENT	High	Low
PROTEIN CONTENT	Moderate	Moderate
PRIMARY FEED	Forage	Grain
ANIMAL AGE/WEIGHT	Younger, lighter	Older, heavier
GOAL	Frame	Finish

Figure 4.3: Ruminant ration applications

Pilot questions 4.3

1. Explain why adequate effective fibre is needed even in high-energy ruminant rations.
2. Explain why dairy cattle require different rations across the lactation cycle.
3. Define the transition period in dairy cattle and explain why it is high-risk.
4. Distinguish between growing/stocker and finishing beef cattle rations.
5. Explain the mineral-related health concern relevant to small ruminant ration formulation.

4.4 Feeding Systems and Management

4.4.1 Feeding system types

Total mixed ration (TMR) systems (mixing all ration components, forage and concentrate, into a single uniform blend before feeding, common in larger commercial dairy operations) ensure consistent nutrient intake per bite and reduce selective feeding (animals sorting out preferred components and leaving others), compared to component feeding (offering forage and concentrate separately, allowing some selective consumption, more common in smaller-scale or extensively managed operations).

Ad libitum feeding (continuous free access to feed, common for poultry broilers and pig growers/finishers seeking maximum growth rate, Series 1-2) contrasts with restricted/controlled feeding (limiting feed quantity or timing, used for breeding animals or layers where excessive intake/weight gain could reduce reproductive or laying performance), illustrating that feeding system choice depends on production goal as much as species or scale.

Fill in the blank: ________ mixed ration (TMR) systems blend all ration components into a single uniform mix before feeding, reducing selective feeding compared to offering forage and concentrate separately.

4.4.2 Feed processing and form

Feed processing (grinding, pelleting, or other physical/mechanical treatment) can improve feed efficiency, reduce wastage, and, for some feedstuffs, improve digestibility (Series 3), though processing adds cost, requiring an economic as well as nutritional justification for the specific processing method and degree applied to a given feeding situation.

Pelleting (compressing ground feed into uniform pellets) reduces feed sorting/selective feeding (Part 4.4.1), can improve handling/storage characteristics, and, for poultry specifically, often improves feed intake and growth performance compared to mash/loose feed form, though the magnitude of this benefit varies by species, age, and specific feed formulation, making processing decisions another practical formulation consideration alongside the nutrient-balancing principles of Parts 4.1-4.3.

Fill in the blank: ________ , compressing ground feed into uniform pellets, reduces feed sorting and, for poultry specifically, often improves feed intake and growth performance compared to loose feed form.

4.4.3 Monitoring and adjusting feeding programmes

Ongoing performance monitoring (growth rate, feed conversion, milk yield, egg production, body condition, Series 1) against expected targets (based on the formulated ration nutrient content and published performance expectations for the species/breed/production level) allows identification of feeding programme problems, whether arising from formulation error, feedstuff quality variation (Series 3), or other management factors.

Periodic ration reformulation (responding to changing feedstuff availability/price, Part 4.1.3, changing animal nutrient requirements as production level or life stage changes, Parts 4.2-4.3, or performance monitoring findings, Part 4.4.3) reflects the dynamic, ongoing nature of sound feeding management, consistent with the continuous improvement principle relevant across livestock management generally and completing the practical application of the ration formulation skills developed throughout this Series.

Fill in the blank: Periodic ration ________ , responding to changing feedstuff prices, animal requirements, or performance monitoring findings, reflects the dynamic, ongoing nature of sound feeding management.

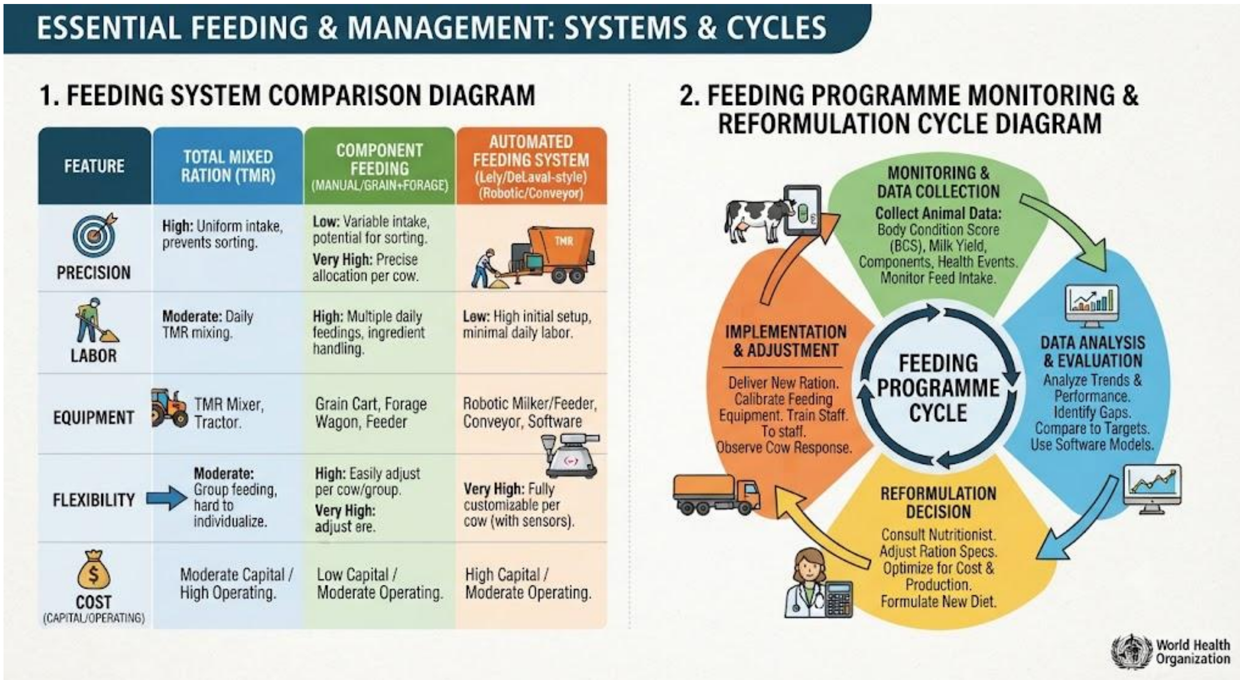


Figure 4.4: Feeding systems and programme management

Pilot questions 4.4

1. Define total mixed ration (TMR) and state one benefit.
2. Distinguish between ad libitum and restricted feeding.
3. Explain the benefit of pelleting feed.
4. Name three performance indicators used to monitor a feeding programme.
5. Explain why rations require periodic reformulation rather than a one-time calculation.

Series Summary

This Series examined **ration formulation and feeding systems for different classes of livestock**. Ration balancing follows a **four-step process**: determining nutrient requirements, selecting suitable feedstuffs, calculating the ration, and evaluating its practical and economic feasibility. Common formulation methods include the **Pearson Square**, used for balancing two feed ingredients for a single nutrient, and **least-cost formulation**, a computer-based approach that optimises multiple ingredients and nutrients at minimum cost. For **non-ruminants**, ration formulation must consider species and production stage, including starter, grower, and layer diets for poultry, phase feeding with lysine balance for swine, and special nutritional requirements of companion animals such as taurine and vitamin A for cats.

The Series also covered **feeding programmes for ruminants and practical feeding systems**. Ruminant diets must provide adequate **effective fibre** to maintain rumen health, while dairy cattle require stage-specific feeding throughout the lactation cycle, particularly during the high-risk transition period. Beef cattle feeding differs between growing and finishing phases, and small ruminants require careful mineral balance to prevent disorders such as urinary calculi. Common feeding systems include **Total Mixed Rations (TMR)** and component feeding, as well as **ad libitum** and restricted feeding. Feed processing methods such as grinding and pelleting can improve feed utilisation, while regular performance monitoring and periodic ration reformulation ensure continued nutritional adequacy and cost-effectiveness. By completing this Series, students should achieve SLOs 4.1–4.4.

Glossary of Terms

- **Ad libitum feeding:** continuous free access to feed, allowing maximum voluntary intake.
- **Least-cost formulation:** computer-based ration formulation identifying the lowest-cost feedstuff combination meeting all nutrient requirements.
- **Pearson square:** a simple manual method for combining two feedstuffs to achieve a target nutrient level.

- **Pelleting:** compressing ground feed into uniform pellets to reduce sorting and improve handling.
- **Total mixed ration (TMR):** a feeding system blending all ration components into a single uniform mix before feeding.
- **Transition period:** the period from late pregnancy through early lactation in dairy cattle, associated with high metabolic disorder risk.
- **Urinary calculi:** mineral-related urinary stones, a health risk particularly relevant in male sheep/goats fed high-concentrate rations.

Concept Check Questions [Series 4]

Objective Questions

1. The Pearson square method balances a single nutrient using exactly ________ feedstuffs. (Linked to SLO 4.1)
2. Layer poultry rations require elevated ________ supporting eggshell formation. (Linked to SLO 4.2)
3. The dairy cattle ________ period, late pregnancy through early lactation, is high-risk for metabolic disorders. (Linked to SLO 4.3)
4. ________ mixed ration (TMR) systems blend all components into a single uniform mix. (Linked to SLO 4.4)
5. Lysine is typically the first ________ amino acid in cereal-grain-based pig rations. (Linked to SLO 4.2)

Short-Answer Questions

1. Name the four steps in ration formulation. (Linked to SLO 4.1)
2. Name three poultry ration phases. (Linked to SLO 4.2)
3. Explain why dairy cattle require different rations across the lactation cycle. (Linked to SLO 4.3)
4. Distinguish between ad libitum and restricted feeding. (Linked to SLO 4.4)
5. Name two reasons for periodic ration reformulation. (Linked to SLO 4.4)

Long-Answer Questions

1. Explain ration balancing principles, including the Pearson square and least-cost formulation. (Linked to SLO 4.1)
2. Describe ration applications for poultry, swine, and ruminants. (Linked to SLOs 4.2, 4.3)
3. Explain feeding system types, feed processing, and monitoring/adjustment. (Linked to SLO 4.4)

Answers to Concept Check Questions [Series 4]

Objective Questions

1. Two.
2. Calcium.
3. Transition.
4. Total.
5. Limiting.

Short-Answer Questions

1. Determine requirements, identify feedstuffs, calculate combination, and evaluate feasibility.
2. Starter, grower, and layer (or finisher).
3. Nutrient demand changes substantially across the lactation cycle, peaking in early-to-mid lactation.
4. Ad libitum allows continuous free access; restricted feeding limits quantity or timing.
5. Changing feedstuff prices/availability and changing animal nutrient requirements (or performance monitoring findings).

Long-Answer Questions

1. Ration balancing follows four steps: requirements, feedstuffs, calculation, feasibility. The Pearson square balances one nutrient with two feedstuffs; least-cost formulation uses computer optimisation across many ingredients and nutrients at lowest cost.
2. Poultry rations use phase feeding with careful amino acid balance; pig rations similarly phase-feed with lysine as the typical limiting amino acid. Ruminant rations require effective fibre and vary by lactation stage (dairy) or growing/finishing phase (beef).
3. Feeding systems include TMR versus component feeding and ad libitum versus restricted feeding. Feed processing (pelleting) improves efficiency and reduces sorting. Ongoing monitoring against performance targets supports periodic reformulation.

Answers to Pilot Questions [Series 4]

Part 4.1

1. Determine requirements, identify feedstuffs, calculate combination, and evaluate feasibility.
2. It combines two feedstuffs to reach a target nutrient level; its main limitation is handling only one nutrient and two ingredients.
3. Least-cost formulation identifies the feedstuff combination meeting all nutrient requirements at lowest total cost.
4. Nutrient requirement specifications and feedstuff composition data (or current prices, inclusion constraints).
5. Feedstuff prices and availability change, requiring the optimised ration to be recalculated periodically.

Part 4.2

1. Starter, grower, and layer rations.
2. Calcium supports eggshell formation during sustained egg production.
3. Cereal grains are naturally low in lysine relative to pig requirement, making it the first limiting amino acid.
4. Weaner and finisher (or gestation, lactation).
5. Taurine and preformed vitamin A.

Part 4.3

1. Adequate fibre maintains rumen pH stability and normal rumination, preventing digestive disorders like acidosis.
2. Nutrient demand changes substantially across the cycle, peaking in early-to-mid lactation and declining later.
3. The transition period is late pregnancy through early lactation, high-risk due to rapidly rising demand against limited intake capacity.
4. Growing/stocker rations are often grazing-based with modest supplementation; finishing rations use higher concentrate proportions.
5. Urinary calculi, a mineral-related health problem particularly relevant in male sheep/goats on high-concentrate rations.

Part 4.4

1. TMR blends all ration components into one uniform mix; it reduces selective feeding/sorting.
2. Ad libitum allows continuous free access; restricted feeding limits quantity or timing for specific production goals.
3. Pelleting reduces sorting and often improves feed intake and growth performance, particularly in poultry.
4. Growth rate, feed conversion, and milk yield/egg production (or body condition).
5. Feedstuff prices/availability and animal requirements change over time, requiring updated formulation to remain optimal.

References and Attributions

Textual References (Books and External Sources)

- National Research Council (NRC). (2001). Nutrient requirements of dairy cattle (7th ed.). National Academies Press.
- National Research Council (NRC). (2012). Nutrient requirements of swine (11th ed.). National Academies Press.
- National Research Council (NRC). (1994). Nutrient requirements of poultry (9th ed.). National Academies Press.
- McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., & Morgan, C. A. (2010). Animal nutrition (7th ed.). Pearson.

Figures, Plates, Tables, and Boxes

- Figure 4.1: Principles of ration formulation Attribution: AI generated. Suggested OER search string: "ration formulation Pearson square least cost livestock feed OER".
- Figure 4.2: Non-ruminant ration applications Attribution: AI generated. Suggested OER search string: "poultry pig phase feeding companion animal nutrition cat dog requirements OER".
- Figure 4.3: Ruminant ration applications Attribution: AI generated. Suggested OER search string: "dairy cattle ration lactation beef cattle finishing small ruminant feeding OER".
- Figure 4.4: Feeding systems and programme management Attribution: AI generated. Suggested OER search string: "feeding system TMR ad libitum feed processing pelleting livestock monitoring OER".

Series 5: Forages and Intake Management

- **Part 5.1: Grasses and Legumes as Forage**
  - Sub Part 5.1.1: Characteristics of forage grasses
  - Sub Part 5.1.2: Characteristics of forage legumes
  - Sub Part 5.1.3: Grass-legume mixtures
- **Part 5.2: Residue Feeds and Crop By-Products**
  - Sub Part 5.2.1: Cereal crop residues
  - Sub Part 5.2.2: Legume and root crop residues
  - Sub Part 5.2.3: Treatment of low-quality residues
- **Part 5.3: Forage Intake and Dry Matter Consumption**
  - Sub Part 5.3.1: Factors affecting dry matter intake
  - Sub Part 5.3.2: Forage quality and intake
  - Sub Part 5.3.3: Predicting and managing intake
- **Part 5.4: Forage Harvest and Conservation**
  - Sub Part 5.4.1: Pasture/grazing management
  - Sub Part 5.4.2: Hay making
  - Sub Part 5.4.3: Silage making

Introduction

This final Series of AGE 405 focuses specifically on forages, the grasses, legumes, and crop residues that form the foundation of ruminant nutrition (Series 1, 4), and on the factors governing how much of these (and other feedstuffs) an animal will actually voluntarily consume, a practical limiting factor in feeding programme design distinct from but closely related to the nutrient balancing skills developed in Series 4.

This Series covers forage grasses and legumes and their mixtures; crop residue feeds and treatment of low-quality residues; dry matter intake and the factors affecting it; and forage harvest and conservation through grazing management, hay making, and silage making. This draws together the digestive, feedstuff, and ration formulation knowledge developed across all previous Series of AGE 405.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** describe forage grasses, legumes, and their mixtures (Linked to Part 5.1),
- **SLO 5.2** describe crop residue feeds and treatment methods for low-quality residues (Linked to Part 5.2),
- **SLO 5.3** explain dry matter intake and the factors affecting feed consumption (Linked to Part 5.3), and
- **SLO 5.4** describe pasture management, hay making, and silage making (Linked to Part 5.4).

5.1 Grasses and Legumes as Forage

5.1.1 Characteristics of forage grasses

Forage grasses (the dominant forage type in most Nigerian grazing systems, including both natural/native pasture species and introduced/improved varieties such as Panicum maximum and various Pennisetum and Cynodon species) provide the bulk dietary fibre and energy base for grazing ruminants, with nutritional quality declining considerably as the plant matures (increasing fibre/lignin content and declining protein and digestibility, Series 3, as the plant moves from vegetative growth toward flowering/seed production).

Grass growth and quality are strongly influenced by rainfall season (Nigerian wet season supporting active grass growth, with quality and quantity declining considerably during the dry season, a major seasonal feed availability challenge for Nigerian grazing livestock systems), soil fertility, and grazing/cutting management (Part 5.4.1), making grass forage quality considerably more variable across the year than the relatively stable concentrate feedstuffs discussed in Series 3.

Fill in the blank: Forage grass nutritional quality declines considerably as the plant matures, with increasing fibre/lignin content and declining ________ and digestibility as the plant moves toward flowering.

5.1.2 Characteristics of forage legumes

Forage legumes (such as Centrosema, Stylosanthes, and Leucaena species used in Nigerian pasture/browse systems) generally offer higher protein content and digestibility than grasses at a comparable growth stage, alongside the biological nitrogen fixation benefit (Series 1 of related crop production courses) that can also improve the nutritional quality of companion grass in mixed swards (Part 5.1.3) through nitrogen transfer to the soil.

Legume forage quality also declines with maturity, though generally less dramatically than grasses given legume typically lower structural fibre content at a comparable stage; some legume species (Leucaena notably) contain antinutritional compounds (mimosine in Leucaena) requiring management attention (limiting inclusion proportion, or in some cases requiring animal adaptation/rumen microbial adaptation) to avoid toxicity concerns.

Fill in the blank: Some forage legume species, such as Leucaena, contain antinutritional compounds (mimosine in Leucaena specifically) requiring management attention to avoid ________ concerns.

5.1.3 Grass-legume mixtures

Grass-legume pasture mixtures combine the higher yield and ground cover/erosion protection typical of grasses with the higher protein and nitrogen-fixation benefits of legumes, often achieving better overall forage quality and yield stability across the season than either species grown alone, an application of the intercropping/diversification principles introduced in related crop production courses applied specifically to forage/pasture systems.

Maintaining a desired grass-to-legume ratio over time requires ongoing management attention, since legumes can be more vulnerable to overgrazing or unfavourable conditions than competing grasses in some mixtures, potentially shifting the pasture composition toward grass dominance over time without active management (rotational grazing, Part 5.4.1, or periodic legume reseeding) to sustain the legume component.

Fill in the blank: Maintaining a desired grass-to-legume ratio over time requires ongoing management attention, since legumes can be more vulnerable to ________ than competing grasses in some mixtures.

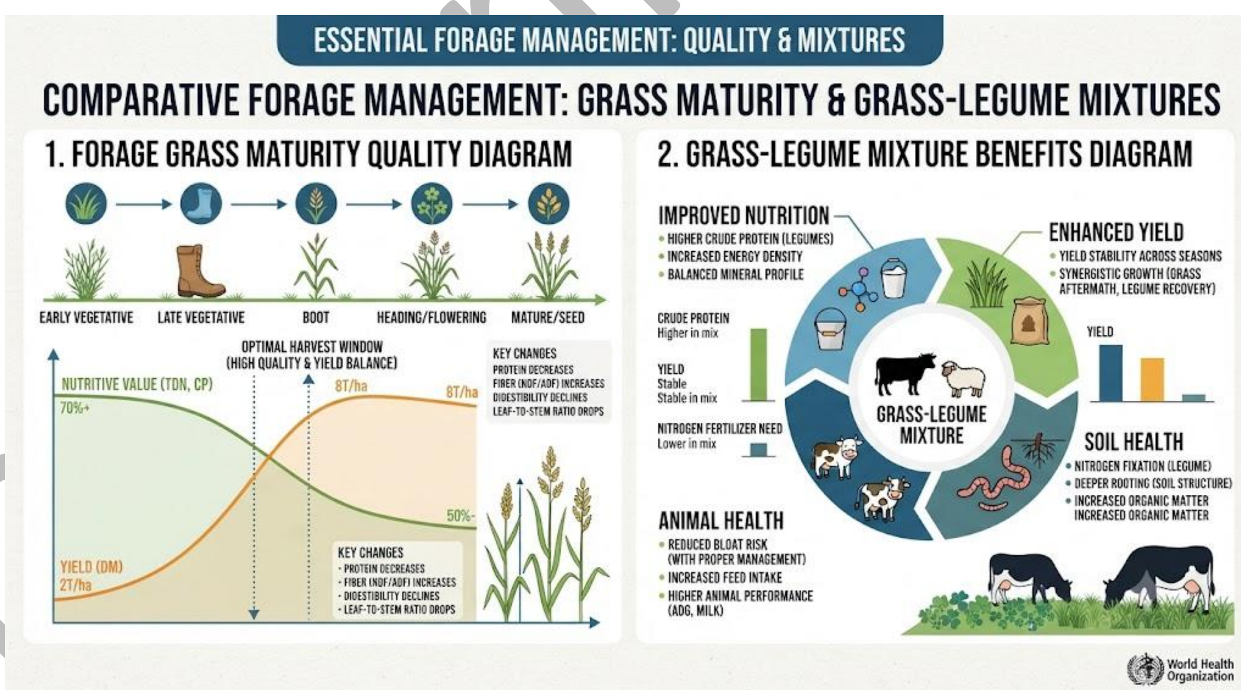


Figure 5.1: Forage grasses, legumes, and mixtures

Pilot questions 5.1

1. Explain how forage grass nutritional quality changes as the plant matures.
2. Explain the seasonal challenge facing Nigerian grazing livestock systems.
3. Name two benefits forage legumes offer compared to grasses.
4. Describe the antinutritional concern associated with Leucaena.
5. Explain the benefit of grass-legume pasture mixtures.

5.2 Residue Feeds and Crop By-Products

5.2.1 Cereal crop residues

Cereal crop residues (maize stover, rice straw, sorghum stalks, the above-ground plant material remaining after grain harvest, Series 1-2 of related crop production courses) represent an abundant, low-cost Nigerian ruminant feed resource, particularly valuable during the dry season when fresh forage availability declines (Part 5.1.1), though generally low in protein and digestibility given their high lignified fibre content at the mature harvest stage.

Effective use of cereal residues typically requires protein/mineral supplementation (Series 2-3) to correct their inherent nutritional limitations, and, for some residues, the treatment methods discussed in Part 5.2.3 to improve digestibility; nonetheless, cereal residues remain an economically important feed resource given their abundance and low/zero direct cost (as a by-product of grain production already undertaken for the primary crop) relative to purpose-grown forage or purchased concentrate feeds.

Fill in the blank: Cereal crop residues such as maize stover and rice straw are generally low in protein and ________ given their high lignified fibre content at the mature harvest stage.

5.2.2 Legume and root crop residues

Legume crop residues (groundnut hay/vines, cowpea husks, Series 2 of related crop production courses) generally offer higher protein content than cereal residues (Part 5.2.1), reflecting the underlying legume nutritional characteristics discussed in Part 5.1.2, making them a valuable, relatively higher-quality residue feed option where available, often used to balance the lower protein content of cereal residues in mixed feeding.

Root/tuber crop residues (cassava peels and leaves, sweet potato vines, Series 2 of related crop production courses) provide additional residue feed options, with cassava peel requiring the same cyanogenic glycoside processing consideration discussed for cassava-based concentrate feeds in Series 3, and cassava/sweet potato leaves and vines offering reasonable protein content relative to many other residue feed options.

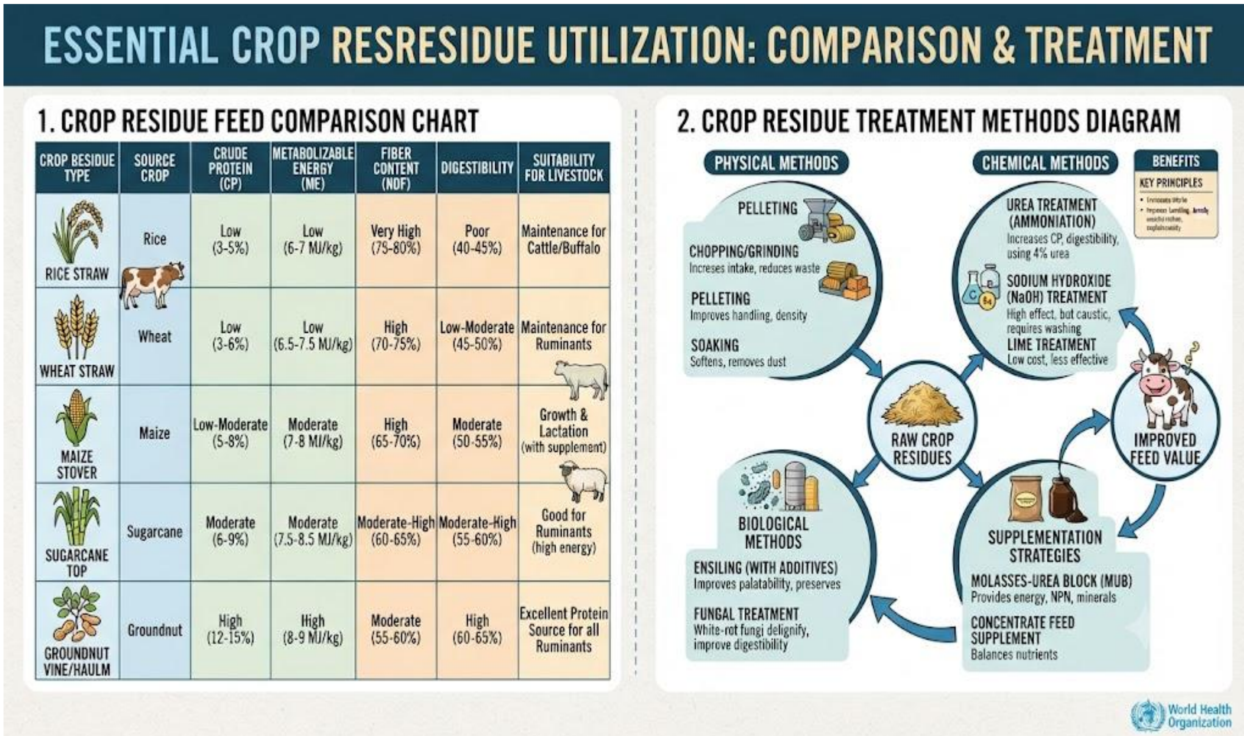
Fill in the blank: Legume crop residues such as groundnut hay and cowpea husks generally offer higher ________ content than cereal residues, making them valuable for balancing mixed residue feeding.

5.2.3 Treatment of low-quality residues

Chemical treatment (such as urea or alkali/sodium hydroxide treatment, breaking down lignin-fibre bonds and improving digestibility of low-quality cereal residues, Part 5.2.1) and physical treatment (chopping or grinding, increasing surface area for microbial fermentation and reducing selective sorting/wastage) are established methods for improving the feeding value of otherwise low-quality crop residues.

Urea treatment specifically also adds non-protein nitrogen (Series 1) usable by rumen microorganisms for microbial protein synthesis, simultaneously improving both digestibility and effective protein content of treated residue, though requiring careful application (correct urea concentration and adequate treatment time) to be both effective and safe, since excessive urea application risks ammonia toxicity.

Fill in the blank: ________ treatment of crop residues breaks down lignin-fibre bonds, improving digestibility, while also adding non-protein nitrogen usable by rumen microorganisms.



CROP RESIDUE TYPE	SOURCE CROP	CRUDE PROTEIN (CP)	METABOLIZABLE ENERGY (ME)	FIBER CONTENT (NDF)	DIGESTIBILITY	SUITABILITY FOR LIVESTOCK
RICE STRAW	Rice	Low (3-5%)	Low (6-7 MJ/kg)	Very High (75-80%)	Poor (40-45%)	Maintenance for Cattle/Buffalo
WHEAT STRAW	Wheat	Low (3-6%)	Low (6.5-7.5 MJ/kg)	High (70-75%)	Low-Moderate (45-50%)	Maintenance for Ruminants
MAIZE STOVER	Maize	Low-Moderate (5-8%)	Moderate (7-8 MJ/kg)	High (65-70%)	Moderate (50-55%)	Growth & Lactation (with supplement)
SUGARCANE TOP	Sugarcane	Moderate (6-9%)	Moderate (7.5-8.5 MJ/kg)	Moderate-High (60-65%)	Moderate-High (55-60%)	Good for Ruminants (high energy)
GROUNDNUT VINE/HAULM	Groundnut	High (12-15%)	High (8-9 MJ/kg)	Moderate (55-60%)	High (60-65%)	Excellent Protein Source for all Ruminants

Figure 5.2: Crop residue feeds and treatment

Pilot questions 5.2

1. Name three examples of cereal crop residues.
2. Explain why cereal residues are valuable despite their nutritional limitations.
3. Compare legume residues to cereal residues in protein content.
4. Name two treatment methods for improving low-quality residue feeding value.
5. Explain the dual benefit of urea treatment.

5.3 Forage Intake and Dry Matter Consumption

5.3.1 Factors affecting dry matter intake

Dry matter intake (the quantity of feed dry matter an animal voluntarily consumes, the fundamental constraint determining how much of any nutrient an animal can actually obtain from a given diet, regardless of the diet nutrient density on paper, Series 3-4) is influenced by animal factors (body size, physiological state such as lactation or pregnancy increasing intake capacity/demand, and health status, since sick animals generally reduce voluntary intake, a connection to the livestock health principles introduced in related courses).

Feed/diet factors (palatability, physical form, Series 4, and, particularly for forage, fibre content and digestibility, Part 5.3.2) and environmental factors (heat stress reducing intake, Series 2 of related livestock health courses, and feeding management such as feeding frequency and bunk/trough space availability) together determine actual realised intake, making dry matter intake a genuinely multi-factorial outcome rather than a simple, fixed animal characteristic.

Fill in the blank: Dry matter intake is the fundamental constraint determining how much of any nutrient an animal can actually obtain from a diet, regardless of the diet nutrient ________ on paper.

5.3.2 Forage quality and intake

Forage fibre content and digestibility directly affect voluntary intake through a physical fill mechanism: high-fibre, low-digestibility forage occupies more rumen space relative to its energy contribution and is digested/passed through more slowly, physically limiting how much an animal can consume before reaching rumen fill capacity, a distinct intake-limiting mechanism from the metabolic/chemical satiety signals that limit intake of more digestible, energy-dense diets.

This physical fill limitation means that simply offering more low-quality forage does not necessarily increase nutrient intake proportionally, since the animal may reach physical capacity before consuming enough forage to meet nutrient requirements from that forage alone, a key practical reason why low-quality residue feeds (Part 5.2) often require supplementation (protein, energy concentrate) rather than relying on residue quantity alone to meet animal nutrient needs.

Fill in the blank: High-fibre, low-digestibility forage limits intake through a physical ________ mechanism, since it occupies rumen space and passes through more slowly relative to its energy contribution.

5.3.3 Predicting and managing intake

Dry matter intake is often estimated as a percentage of body weight (varying by species, production level, and diet quality, with higher percentages for high-producing dairy cattle on high-quality diets than for maintenance-level animals on low-quality forage), providing a practical starting estimate for ration formulation (Series 4) even though actual intake varies considerably around such general estimates depending on the specific factors discussed in Part 5.3.1.

Practical intake management strategies include improving forage quality (earlier harvest/grazing at a less mature growth stage, Part 5.1.1, and supplementation correcting specific nutrient deficiencies that themselves can limit intake, such as protein supplementation sometimes increasing the intake of low-protein forage by improving rumen microbial fibre digestion efficiency) and ensuring adequate feed access/bunk space, completing the practical link between the intake principles of this Part and the ration formulation skills of Series 4.

Fill in the blank: Dry matter intake is often estimated as a percentage of body ________ , varying by species, production level, and diet quality, as a practical starting point for ration formulation.

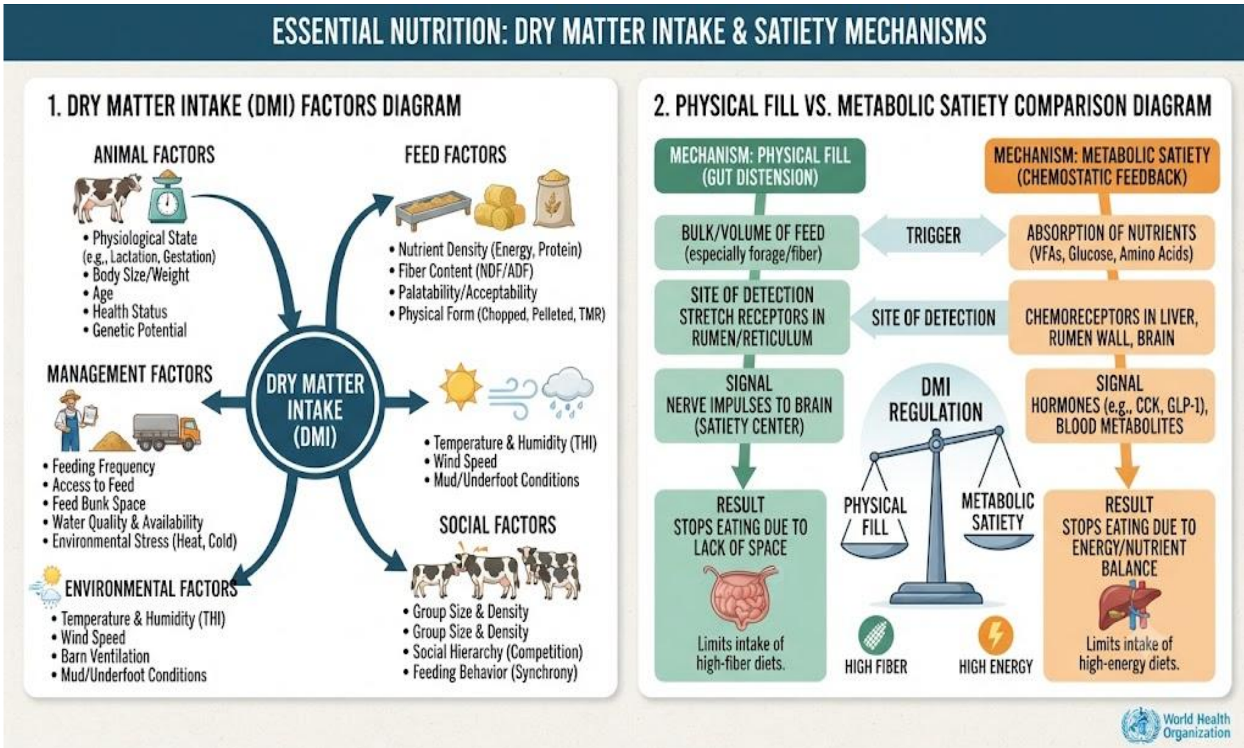


Figure 5.3: Dry matter intake factors and management

Pilot questions 5.3

1. Define dry matter intake and explain its practical importance.
2. Name three animal factors affecting dry matter intake.
3. Explain the physical fill mechanism limiting forage intake.
4. Explain why simply offering more low-quality forage may not increase nutrient intake proportionally.
5. Explain how protein supplementation can sometimes increase intake of low-protein forage.

5.4 Forage Harvest and Conservation

5.4.1 Pasture/grazing management

Rotational grazing (dividing pasture into paddocks and moving animals between them on a planned schedule, allowing grazed paddocks a rest/regrowth period before re-grazing) generally supports better long-term pasture productivity and quality than continuous grazing (animals having constant access to the entire pasture area), since rest periods allow plant recovery and help maintain desired species composition (Part 5.1.3) including legume persistence in mixed swards.

Stocking rate (the number of animals per unit pasture area) must be matched to pasture growth capacity (itself varying seasonally, Part 5.1.1) to avoid overgrazing (excessive grazing pressure degrading pasture condition, reducing future productivity, and increasing erosion risk on bare/degraded ground) while still making productive use of available pasture resources, a balance requiring ongoing management judgement rather than a fixed, never-adjusted stocking decision.

Fill in the blank: ________ grazing, dividing pasture into paddocks moved between on a planned schedule, generally supports better long-term pasture productivity than continuous grazing.

5.4.2 Hay making

Hay making (cutting forage at an appropriate growth stage, then field-drying to a low moisture content, typically below 15-20 percent, suitable for safe storage without spoilage) preserves forage nutritional value for use during periods when fresh forage is unavailable (notably the Nigerian dry season, Part 5.1.1), provided drying is completed relatively quickly to minimise nutrient loss (particularly leaf loss and some vitamin degradation) during the field curing process.

Hay quality depends heavily on harvest timing (cutting at an appropriately immature growth stage balances yield against nutritional quality, similar to the maturity-quality tradeoff discussed for fresh forage in Part 5.1.1) and weather conditions during curing (rain during field drying causing nutrient leaching and mould risk, a significant practical challenge for hay making timing in regions with unpredictable rainfall patterns).

Fill in the blank: Hay is field-dried to a low moisture content, typically below 15 to ________ percent, suitable for safe storage without spoilage.

5.4.3 Silage making

Silage making (chopping forage and storing it under anaerobic/oxygen-excluded conditions, typically in a pit, bunker, or sealed bag/bunker, allowing lactic acid fermentation by naturally present bacteria to lower pH and preserve the forage) offers an alternative forage conservation method less dependent on extended dry weather than hay making, since silage forage is harvested at higher moisture content and preserved through fermentation rather than field drying.

Successful silage making requires adequate forage sugar content (supporting sufficient lactic acid fermentation, sometimes assisted by additives where natural sugar content is marginal), effective compaction and sealing (excluding oxygen to prevent spoilage organism growth and support the desired anaerobic fermentation), and correct harvest moisture content (neither too wet, risking effluent loss and poor fermentation, nor too dry, making adequate compaction difficult); well-made silage offers a valuable, less weather-dependent forage conservation option compared to hay, particularly relevant in regions with less reliable extended dry periods for hay curing.

Fill in the blank: Silage making relies on ________ fermentation under anaerobic, oxygen-excluded conditions to lower pH and preserve forage, in contrast to hay making which relies on field drying.

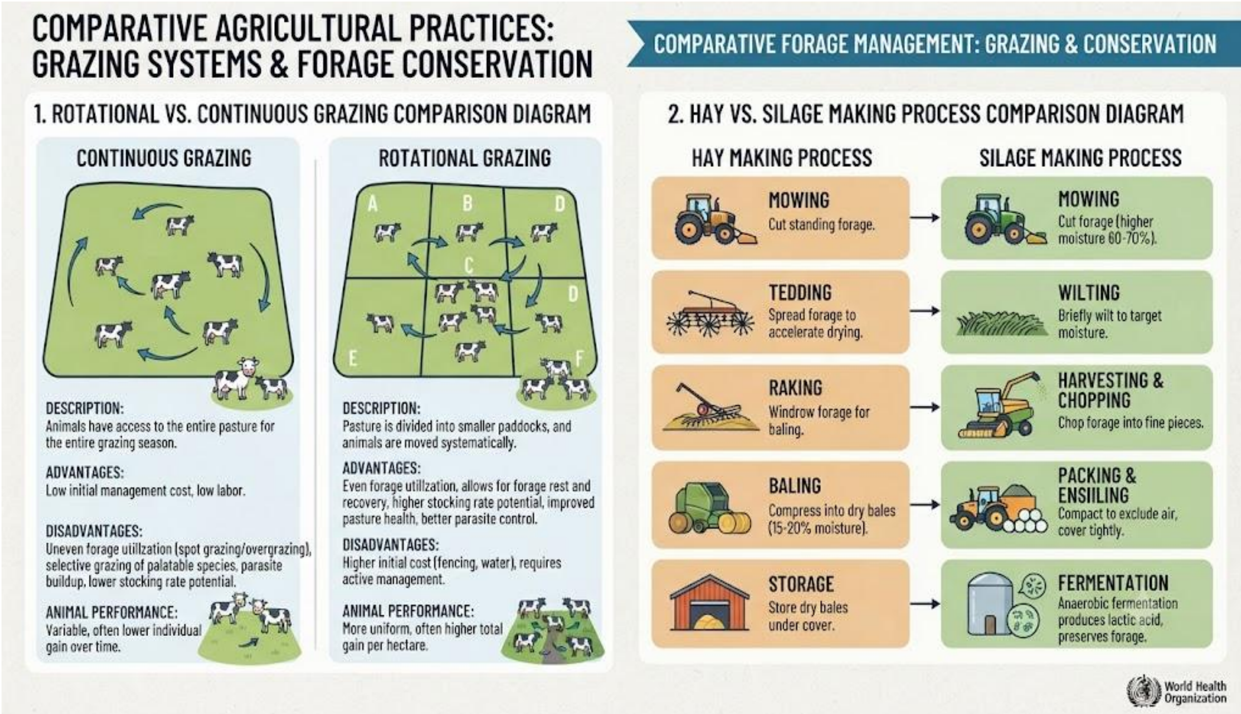


Figure 5.4: Pasture management and forage conservation

Pilot questions 5.4

1. Distinguish between rotational and continuous grazing.
2. Explain the concept of stocking rate and why it must be matched to pasture growth.
3. Describe the hay making process and its target moisture content.
4. Explain the main weather-related risk facing hay making.
5. Describe silage making and explain why it is less weather-dependent than hay making.

Series Summary

This Series examined **forage resources, crop residues, feed intake, and forage conservation for livestock production**. **Grasses** are the dominant forage source in Nigeria, although their nutritional quality declines with maturity and varies seasonally. **Legumes** provide higher protein, improve soil fertility through nitrogen fixation, and complement grasses, though some contain anti-nutritional factors such as **mimosine**. Properly managed **grass–legume mixtures** improve forage quality and productivity. Crop residues also serve as important feed resources, including cereal residues, which are abundant but low in protein and digestibility, and legume or root-crop residues, which generally have higher protein value. Processing methods such as **urea or alkali treatment**, chopping, and grinding improve digestibility, with urea treatment also supplying additional nitrogen.

The Series also covered **dry matter intake and forage conservation techniques**. Dry matter intake is influenced by animal, feed, and environmental factors, with low-quality forages often limiting intake through the physical fill effect. Intake is commonly estimated as a percentage of body weight and can be improved through better forage quality and supplementation. Sustainable forage management includes **rotational grazing**, which promotes pasture recovery, compared with continuous grazing. Forage may be conserved as **hay** through field drying, although weather can affect quality, or as **silage** through anaerobic fermentation, which is less dependent on favourable weather conditions. By completing this Series, students should achieve SLOs 5.1–5.4 and all **AGE 405** course outcomes.

Glossary of Terms

- **Dry matter intake:** the quantity of feed dry matter an animal voluntarily consumes.
- **Hay:** forage cut and field-dried to a low moisture content for storage.
- **Mimosine:** an antinutritional compound found in Leucaena forage, requiring management to avoid toxicity.

- **Physical fill:** an intake-limiting mechanism in which high-fibre, low-digestibility forage occupies rumen space, limiting consumption before nutrient needs are met.
- **Rotational grazing:** a grazing system dividing pasture into paddocks moved between on a planned schedule to allow rest and regrowth.
- **Silage:** forage preserved through anaerobic lactic acid fermentation at higher moisture content than hay.
- **Stocking rate:** the number of animals per unit pasture area, matched to pasture growth capacity.

Concept Check Questions [Series 5]

Objective Questions

1. Forage grass nutritional quality declines as the plant matures, with declining protein and ________ . (Linked to SLO 5.1)
2. Cereal crop residues are generally low in protein and digestibility given high lignified ________ content. (Linked to SLO 5.2)
3. High-fibre, low-digestibility forage limits intake through a physical ________ mechanism. (Linked to SLO 5.3)
4. ________ grazing supports better long-term pasture productivity than continuous grazing. (Linked to SLO 5.4)
5. Hay is field-dried to a moisture content typically below 15 to ________ percent. (Linked to SLO 5.4)

Short-Answer Questions

1. Name two forage legume species used in Nigerian systems. (Linked to SLO 5.1)
2. Name three examples of crop residue feeds. (Linked to SLO 5.2)
3. Name three factors affecting dry matter intake. (Linked to SLO 5.3)
4. Distinguish between hay and silage making. (Linked to SLO 5.4)
5. Explain why urea treatment improves both digestibility and protein content of residues. (Linked to SLO 5.2)

Long-Answer Questions

1. Describe forage grasses, legumes, and their mixtures. (Linked to SLO 5.1)
2. Explain crop residue feeds, treatment methods, and dry matter intake factors. (Linked to SLOs 5.2, 5.3)
3. Describe pasture management, hay making, and silage making. (Linked to SLO 5.4)

Answers to Concept Check Questions [Series 5]

Objective Questions

1. Digestibility.
2. Fibre.
3. Fill.
4. Rotational.
5. 20.

Short-Answer Questions

1. Centrosema and Stylosanthes (or Leucaena).
2. Maize stover, rice straw, and groundnut hay (or cassava peel, cowpea husks).
3. Body size, physiological state, and feed palatability/digestibility (or health status, environment).
4. Hay is field-dried at low moisture; silage is fermented anaerobically at higher moisture content.
5. Urea breaks down lignin-fibre bonds and supplies non-protein nitrogen usable by rumen microorganisms.

Long-Answer Questions

1. Grasses dominate Nigerian forage but decline in quality with maturity. Legumes offer higher protein and nitrogen fixation, with some antinutritional concerns. Mixtures combine grass yield with legume protein benefits, requiring ratio management.
2. Crop residues (cereal, legume, root) provide abundant but often low-quality feed, improved through chemical/physical treatment. Dry matter intake, governed by animal, feed, and

environmental factors, determines actual nutrient consumption regardless of diet density on paper.

3. Rotational grazing and matched stocking rate support pasture productivity. Hay making preserves forage through field drying; silage making preserves forage through anaerobic fermentation, offering a less weather-dependent alternative.

Answers to Pilot Questions [Series 5]

Part 5.1

1. Quality declines as fibre/lignin rises and protein/digestibility fall with maturity toward flowering.
2. Wet season supports active growth, but quality and quantity decline considerably during the dry season.
3. Higher protein/digestibility and nitrogen fixation benefiting companion grass.
4. Leucaena contains mimosine, an antinutritional compound requiring management to avoid toxicity.
5. Mixtures combine grass yield/ground cover with legume protein/nitrogen fixation for better overall quality and stability.

Part 5.2

1. Maize stover, rice straw, and sorghum stalks.
2. They are abundant and low/zero direct cost as a by-product of grain production already undertaken.
3. Legume residues generally offer higher protein content than cereal residues.
4. Chemical treatment (urea/alkali) and physical treatment (chopping/grinding).
5. It improves digestibility by breaking lignin-fibre bonds while also adding usable non-protein nitrogen.

Part 5.3

1. Dry matter intake is the quantity of feed dry matter voluntarily consumed; it is the fundamental constraint on nutrient supply regardless of diet density.
2. Body size, physiological state (lactation/pregnancy), and health status.
3. Low-digestibility, high-fibre forage occupies rumen space and passes slowly, physically limiting further consumption.

4. The animal may reach physical capacity before consuming enough forage to meet nutrient requirements from it alone.
5. It improves rumen microbial fibre digestion efficiency, allowing more forage to be processed and consumed.

Part 5.4

1. Rotational grazing moves animals between paddocks on a schedule; continuous grazing gives constant access to the whole area.
2. Stocking rate is animals per unit area; it must match seasonal pasture growth capacity to avoid overgrazing.
3. Forage is cut and field-dried to below 15-20 percent moisture for safe storage.
4. Rain during field drying causes nutrient leaching and mould risk.
5. Silage is chopped forage preserved via anaerobic lactic acid fermentation at higher moisture, avoiding dependence on extended dry weather needed for hay curing.

References and Attributions

Textual References (Books and External Sources)

- McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., & Morgan, C. A. (2010). Animal nutrition (7th ed.). Pearson.
- National Research Council (NRC). (2001). Nutrient requirements of dairy cattle (7th ed.). National Academies Press.
- Tindall, H. D. (1983). Vegetables in the tropics. Macmillan Press, London.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 5.1: Forage grasses, legumes, and mixtures Attribution: AI generated. Suggested OER search string: "forage grass legume maturity quality mixture pasture Nigeria livestock OER".
- Figure 5.2: Crop residue feeds and treatment Attribution: AI generated. Suggested OER search string: "crop residue feed maize stover groundnut hay cassava peel treatment livestock OER".
- Figure 5.3: Dry matter intake factors and management Attribution: AI generated. Suggested OER search string: "dry matter intake factors physical fill forage quality livestock nutrition OER".
- Figure 5.4: Pasture management and forage conservation Attribution: AI generated. Suggested OER search string: "rotational grazing hay making silage making forage conservation livestock OER".