Dairy Cattle
Introduction

Fibrous plant material
(grass, forage)

↓

Ruminant
digestive system

↓

Milk
• Before:
  low production (milk enough for one family).
• Now:
  high production (40-50 kg/day).
  by genetic selection and progressive management.
• Milk production $\uparrow$→Nutrition requirement $\uparrow$
• Maintenance requirement for lactation:

**Net Energy for lactation (NE$_L$):**

10 Mcal / day + 0.7 Mcal / kg of milk per day.

• Energy from:
  1. cell-wall carbohydrate (fiber). (structure carbohydrate)
  2. non-fiber carbohydrates (starch, sugar). (non-structure carbohydrate)
  3. protein.
  4. fat.
Challenge in feeding high-production dairy cow:

1. Right balance of nutrients to promote rumen health
2. To maximize feed energy intake.
3. To maximize nutrient flow to the mammary gland for milk synthesis.
4. Need mineral and vitamins, may benefit from feed additives.
Nutrition goal

• To maximize profits.
• Without proper nutrition, cows unable to achieve their genetic potential for milk production.
• Profitability of dairy cows is determined by milk yield.
Dairy cow life cycle

- A dairy cow calves for the first time at 2 years of age and then once every year.
- Weaned between 5 and 8 weeks.
- Breeding occurring at 13-15 months. (Weight gain 800g/day until breeding, and then 900g/day). Heifers weight 630kg just before calving, 570kg after calving.
- Lactation length: 305 days.
- Dried-off: 60 days prepartum.
- Yield peak at 40-60 days postpartum and then gradually declined.
- Cow are in negative energy balance during the first 60 days postpartum.
- Cow must conceive at 85 days postpartum.
- Calving interval is 13 or 14 months. (up to 18 months might be more profitable for modern dairy farms).
• Ability of milk production in cow is determined by:

1. Ability of the mammary gland to produce milk.

2. Ability of the cow to provide the mammary gland with nutrients.

3. Ability of the farmer to manage and care for the cow.
• A good steward in dairy farm is one who
• (1) is environmentally friendly
• (2) made efficient use of the earth natural resources
• (3) produce quality milk and meat
• (4) practice good animal husbandry.
• **Excess feeding** of N and P contributes to air and water pollution. 
ex: ammonia emissions, and eutrophication.

• **Higher milk production** is associated with a greater portion of nutrients being converted to milk.

• **Proper feeding** can have fewer metabolic diseases and better immune function. 
  (good health)
Mammary biology

- Udder contains two tissues: parenchyma and extraparenchyma fat pad.
- The ability of the mammary gland to produce milk is dependent on the number of parenchyma. Parenchyma (實質細胞): contains epithelial cells that produce milk during lactation and is surrounded by the fat pad.
- Parenchyma number is determined both by genetic and the environment during mammary development.
- Mammary development occurs at 2 months of age and ends around the time of puberty at 7-10 months of age.
- Feeding excess energy before puberty will impair mammogenesis and decrease milk production. (growth rate 900 g/day are accepted)
Metabolism during lactation:

- The principal organic components of milk are lactose, triglycerides, proteins.
- Use the glucose, acetate, ketones, fatty acids, and amino acids convert to milk components (lactose, TG, and proteins).
- Milk production will be **greatest** and most efficient when the optimal amounts of each metabolite are supplied.
- The metabolites serve as the building blocks and the fuel for synthesis of milk components (table 23.1).
- A shortage of nutrient in the diet can be overcome in the short time, by mobilization of nutrient from maternal body stores.
- Supply glucose to fasted cow will improve milk yield, but extra glucose (amino acid, acetate) doesn’t increase milk synthesis.
• Mechanisms of inadequate maternal nutrition impairs lactation:

1. Nutrient shortage on the mammary gland (direct).

2. Effect mammary gland through nutritional modulation of the endocrine system (indirect).

• Increasing the milking is enhanced through breeding, biotechnological approach, nutrition of the cow.
Glucose metabolism

- Lactose is the predominant carbohydrate of milk, and also the major osmotic regulator of total milk production.
- Lactose synthesis requires glucose, and cow will preserve glucose for this function.
- Milk contain 5% lactose, 50kg milk → 2.5kg glucose, 1.1kg glucose for mammary metabolic function, 1.4kg for other body function, Thus needs 5kg of glucose daily.
- In the mammary gland of ruminants, glucose is not converted to fatty acids, almost no glucose is oxidized in the TCA cycle.
• Because most carbohydrate is fermented by ruminal microbes, glucose absorption is low.

• Much of the glucose that is absorbed in small intestine is metabolized by gut tissues (very little glucose enters the bloodstream).

• The cows relies on **gluconeogenesis** to meet over 90% of her glucose need.
• Gluconeogenesis:

1. The rate of gluconeogenesis in ruminants is greatest after a meal.

2. The major precursors are propionate (占50-60%), lactate (10%), glycerol (5-10%), and amino acids (5-20%).

3. Most occurs in the liver.
Protein metabolism

• Major milk proteins of ruminants are casein, β-lactoglobulin, and α-lactalbumin.
• Amino acid profile of individual milk proteins is predetermined by the genetic code, not the dietary constraints.
• Protein synthesis in mammary tissue is similar to other tissues.
• Deficiency of a single amino acid will decrease total synthesis of protein.
• In ruminants, methionine is the most limit amino acid for milk synthesis (lysine may be limiting in some situations). Ruminal microbes is high in lysine thus gland receives enough lysine.
• A cow producing 50kg milk → 1600g milk protein secreted → is equivalent 8kg of muscle protein accretion → must absorb 3-4 kg of amino acids daily.

• During lactation, the cow is in body protein equilibrium, and those amino acids that are not captured in milk are catabolized from body protein.

• During early lactation, fed protein-deficient diet, up to 20 kg of body protein can be lost, and must be replenished during min and late lactation.
Lipid metabolism

• Fatty acids of milk derived from:

1. Preformed lipids from blood.

   Palmitic acid, C18 fatty acid, stearic and oleic are the principle fatty acids in plasma lipoprotein. These fatty acids were transport into mammary cells for milk fat synthesis.

2. De novo synthesis of fatty acids within the gland.

   Acetate and β-hydroxybutyrate were the primary substrate for de novo synthesis of fatty acids in the gland. (Acetate accounts for 80%). All of fatty acids with 4-14 carbons (C4-C14 fatty acid) and 60% of palmitic acid are synthesizes de novo.
• The first month of lactation, 1/3 of the energy needed for milk production may be from body reserves, the five to six weeks the body fat mobilized is about 40-60kg.

• As lactation progress, the cow eat enough to meet energy requirement, net lipid mobilization ceases.

• Most lactation diets contain 3-6% lipid for Holstein producing 50kg of milk.

• Milk fat is the saturated fats as C14:0, an atherogenic fatty acid. Conjugated linoleic acid (CLA) is also of major source, such as (cis-9, trans-11C18:2) and( trans-10, cis-12 C18:2).
Acetate and ketone metabolism

• Blood acetate is derived from two sources:
  1. Microbial fermentation.
  2. Endogenous production.
• Acetate is a major metabolic fuel for gut tissues and skeletal muscle.
• Ketones include β-hydroxybutyrate and acetoacetate, which are synthesized from butyrate in the epithelium of the rumen and in the liver.
Ketosis:

• High blood ketones and low blood glucose.
• During early lactation and negative energy balance.
• Incomplete oxidation of NEFA (nonesterified fatty acids) in liver may account for half of ketogenesis.
• Ketogenesis exceed the body’s ability to clear ketones from blood.
Nutrition requirement

• For some nutrients, feeding more than is needed for maximal milk production will result in decrease milk production.

• Nutrients also impact feed intake and nutrient partitioning through neural and endocrine mechanisms.
Nutrition for lactating cows

• cell-wall carbohydrate (fiber) to keep rumen healthy.
• nonfiber carbohydrate (starch and sugar) to provide the glucose precursors needed for making milk.
• Rumen-degradable protein to enable optimal fermentation.
• Rumen-undegradable protein to supply the necessary amino acids to the udder and tissue.
• Fat for essential fatty acids and extra energy.
• Essential minerals and vitamins.
• **In early lactation** (first month postpartum), the cow will mobilize body tissues to help meet the requirements for maintenance and lactation.
Energy nutrition for lactating cow

- Energy intake is a function of the energy density of the diet and feed dry mater intake.
- Energy density is a function of diet composition. (less fiber diet, more available carbohydrate)
- Diet composition affects feed intake.
- Level of intake affects feed passage rate and thus the amount of time available for digestion and the energy available from a diet.
Diet composition and voluntary feed intake

• Feed intake is a major determinant of energy intake.

• Optimal level of fiber for which feed energy intake will be maximized (25-28% NDF).

• Diet contain more NDF, feed energy intake will be lower.

• Diet has less NDF and more starch, the cow may eat less feed because elevated propionate or lactate production (metabolic signal of satiety).
• Long particles of NDF are needed to simulate **rumination**, which stimulates **salivation**, and thus help to **buffer the rumen**.

• The NDF that stimulates rumination is known as **effective NDF** (length > 1 cm).

• If diet contains inadequate effective NDF, the cow will be subject to problems associated with **rumen acidosis**.
  (feed intake↓, milk fat↓, perakeratosis of ruminal papillae, and laminitis of feet.)
• **Optimal NDF** for high-production cow is that at which energy intake is maximized while rumen pH is maintained at an acceptable level for most of the day (usually around 27%).

• **Optimal NDF** will be higher in these conditions:
  1. Diet contains shorter fiber particles.
  2. Diet contains rapidly fermented starches.
  3. Fed **total mixed ration (TMR)**.
Impact of diet composition and intake on nutrient partitioning

• **Feeding high grain diet** increased energy intake, but most of the increased energy intake was partitioned toward body tissue gain.

• **Feeding corn silage** with higher digestibility increased energy intake, with increase milk producing.

• Diet with inadequate protein may limit milk synthesis and thus result in more energy partitioned toward adipose tissue.
Feeding to meet the energy and fiber needs of lactating cows

• The goal for feeding energy to cows in early lactation are:
  1. To meet the cow’s high energy needs.
  2. To provide enough fiber for optimal rumen function.
  3. To supply as much fermentable energy as possible to maximize microbial protein production.
• Energy is provided with fiber, starched, sugars, proteins, and fats.

• Forage to concentrate ratios in the diet will change the profile of acetate and propionate produced.

• When the rumen pH is low and fermentable starch is plentiful, some lactate may also be produced.
• **Starch** (10-20%) passes down to the small intestine, where it is broken down to glucose for absorption.

• **Sugars** rapidly fermented in the rumen, with butyrate being the major fermentation acid.

• **Lipids** may be hydrolyzed and biohydrogenated in the rumen, but most lipid digestion occurs in the small intestine and resulting fatty acids are absorbed there.
• If **protein is degraded in the rumen**, the resulting carbon skeletons of amino acids may be fermented to unique short-chain fatty acids.

• If **protein escapes rumen degradation**, most of it will be digested in the small intestine and absorbed as amino acids or di- or tri-peptides.
• For high milk production, a cow should be fed a minimum amount of forage to meet her fiber requirement, and the forage should be high quality.

• High-quality forage are:
  1. Palatable.
  2. Free of mold.
  3. Well preserved.
  4. Have long enough particles. (stimulate rumination)
  5. Have highly digestible fiber.
• **Silages**, the fermentation acids profile is high in lactate with little butyrate.

• **Grass** forages typically ferment slowly, thus slowing the rate of passage and increasing gut fill.

• Grasses may be the desire forage for low-producing cows because grasses often have as much fermentable energy as alfalfa if the passage rate is slower.
• High-fiber byproduct feeds may replace half of the forage, and they are relatively cheap on nutrient basis.

• Some high-fiber byproduct feeds are also good sources of other nutrients. 
  
ex: cottonseeds (fat), distiller’s grains (rumen undegradable protein), and corn gluten feed (protein).
• Cereal grains are fed to supply starch.
• A blend of **rapidly** and **slowly** fermentable grains is preferable.
• Slowly fermentable grains are more likely to escape rumen fermentation and provide starch to the small intestine.

Rapidly: barley.
Intermediate: corn.
Slowly: milo.
• About 15-20% of animal’s energy intake should come in the form of protein.

• Excess ruminal ammonia and nitrogen from body protein oxidation must be converted to urea for disposal.

• Urea is the major contributor to the energy lost in urine.
• **Fat** can be used to increase the dietary energy density, but decrease feed intake.

• Fat does not provide substrates for bacteria and thus decrease ruminal production of bacterial protein.

• Most fats may impair rumen function.

• Typical diet fat is about 3%, not exceed 7%.
Protein nutrition for the lactating cow

• The goal for feeding protein to lactating cows are:

1. Provide enough metabolizable protein to meet the needs for milk production, maintenance, and metabolic function.

2. Provide enough rumen-degraded protein (RDP) for microbes in the rumen with optimal fiber fermentation.
• Metabolizable protein is defined as the protein that is absorbed and available for use by the cow’s body tissues.

• Metabolizable protein has two sources:
  1. Microbial protein (microbes flush down into the small intestine).
  2. rumen-undegraded protein (RUP) (not degraded in rumen and passes to the small intestine).
• Dietary protein allocates into three fraction: A, B, and C.

A: includes NPN and small particle true protein.

C: completely undegradable.

B: the rest of protein, which is all potentially degradable. (depends on the retention time and rate of passage through the rumen)
• **Microbial protein** is the cheapest source of metabolizable protein.

• Limiting factor for microbial growth are:
  1. Fermentable energy supply.
  2. High-fat diet may limit.
     (fat is not fermentable)
  3. Too much rapidly fermented starch.
     (rumen pH below 5.5)
• RDP (rumen degraded protein):

• Dietary RDP provide a mixture of peptides, free amino acids, and ammonia for microbial growth and synthesis of microbial protein.

The first choice in RDP supplements is urea (cheap). Other most common supplements, including solvent-extracted soybean meal, canola meal, and cottonseed meal, they have more balanced rumen degradability (more than 50% protein will be degraded in rumen).
• **RUP (rumen undegraded protein):**

1. **Low-producing cow:**
   
   RUP in a diet will generally meet the cow’s metabolizable protein requirement.

2. **high-producing cow:**
   
   often supplemented with special RUP (fish meal, expeller soybean meal, corn gluten meal, corn distillers grains, or roasted soybeans).

   **Heat** can decrease rumen protein degradability, but **too much heat** also decrease digestibility in the small intestine.
• Dairy cows require not just a specific amount of protein but also a specific amount of each amino acid.

• **Lysine** and **methionine** are the most limiting amino acids in the metabolizable protein of dairy cattle.

• Microbial protein is relatively high in lysine.

• The most limiting amino acid for cattle depends on the amino acid profile of RUP in the diet.
• In recent years, rumen-protected amino acid products have become available for use in feed dairy cows.

• Cows frequently respond positively to rumen-protected methionine.
Minerals and vitamins for the lactating cow

Minerals

- Lactating cows require a relatively large amount of calcium (supplemented with limestone).
- Phosphorus is often overfed (with dicalcium phosphorus).
- Magnesium often supplemented in corn silage based-diets (with magnesium oxide).
- Salt usually supplemented to provide Na and Cl (0.25-0.5% of the diet DM).
• The seven trace minerals usually fed to dairy cows are **cooper, iron, manganese, zinc, cobalt, iodine, and selenium**.

• Iodine and selenium are almost always needed.

• All the trace minerals are often supplemented at close to 100% of their requirement.
Vitamins

• Fat-soluble vitamins (A, D, and E).
• High concentrations of A and E may be beneficial to cows in late gestation or soon after calving to reduce the incidence of mastitis.
• Generally, water-soluble vitamins are not supplemented.
• Supplemented with niacin, choline, thiamin and/or biotin may benefit to very early lactation or stressed cows.
Feed additives and metabolic modifiers

- Medicated feeds are not used in diet for lactating cows because residues may be carried into milk.

- **Rumen buffers** (sodium bicarbonate and magnesium oxide) are often fed in conjunction with high-grain diets.

- **Monensin** might be useful in early lactation to promote propionate production and thus enhance glucose homeostasis and feed efficiency and prevent ketosis.
Formulating diets for high-milk production

1. Use high quality forage with high fiber digestibility as the base of the diet.
2. Determine the amount of any byproduct feeds that will be included.
3. Use grain to supply starch (balanced fermentation rate will result in maximal energy in take and microbial protein yield).
4. Balance the relative amounts of forages, byproduct feeds, and grains to optimize NDF content and promote optimal rumen function and maximize energy intake.
5. Add fat sources to further increase energy concentration. (Fat may decrease feed intake. Use a rumen-inert fat.)

6. Replace some of the grain with protein supplements to provide about 18% crude protein.

7. Supplement with additional rumen-degraded protein if needed.

8. Determine whether the estimated metabolizable protein supplied by the diet seems adequate.
9. Supplement with macrominerals as needed.
10. Supplement with trace minerals and vitamins A, D, and E at 50 to 100% of recommended concentrations.
11. Consider addition supplements such as rumen buffers, rumen-protected amino acids, monensin, probiotics, and water-soluble vitamins.
12. Carefully monitor the cows when new diets are formulated and refine the diets as needed.
Nutrition of dry cows

• A good dry-cow program results in a cow that has a body condition score of 3.5 to 4.0.

• Too thin may have less body reserves to support high-milk production in early lactation.
• In contrast, calcium homeostasis at calving can be improved by special attention to close-up feeding.

• Close-up dry-cow diets should have low value for **Dietary Cation-Anion Difference (DCAD)**.

• The method to calculate the DCAD value is to subtract the milliequivalents of Cl and S from the milliequivalents of Na and K in a diet.

• DCAD value of -10 mEq per 100 g DM or less will acidify the urine.
Nutrition for calves and heifers

Calf nutrition

• The most critical period for the heifer is the first three weeks of life, when mortality can be high.

• The calf is born with an immature immune system.

• Calves should ingest at least three liters of colostrum within an hour of birth.

• Colostrum provide nutrition, growth factor, and immunoglobulin.
• **Young calf** feeding
• has an immature digestive system.
• Easily digested carbohydrate, protein, and lipids should be fed to meet its requirement.
• Dairy calves are usually fed milk replacer instead of real milk.
• The replacer proteins should be from whey products during the first 3 weeks, but half the protein can be from processed soy, gluten, or plasma products after this period.
• The replacer fat usually from the animal sources, such as tallow.
• Generally, calves are fed milk replacer at 1% of body weight per day on a dry basis.
• Replacers are reconstituted with water to 12% solids, and fed at ~10% of body weight per day.
• Higher rates of milk feeding will enhance growth rates but also decrease grain intake, delay rumen development, and delay the transition to solid diet.
• During the milk-fed stage, the calf should have free access to water and grain.
• Rumen rapid develops as the calf begins to eat dry feed, and hopefully by six weeks, the calf is ready to obtain all its nutrients without liquid feeds.
• It was common to feed hay to young calves to stimulate rumen development, but grain stimulates better than hay.
• Calves may be weaned after consuming 700 g of starter grain mix per day, and usually occurs between 4 – 8 weeks of age.
Heifer nutrition

- Age at first calving = 22 – 24 months
- B.W. after calving = 570 kg
- Height at calving = 140 cm at the withers
- Body condition score (BCS) at calving = 3.0 – 3.5
- Growth rate from 3 to 10 months of age = 750 – 850 g/day
• The most important determinants of age at calving is age at breeding.

• **Breeding should occur when heifers weight 360 – 390 kg and stand 130 cm at the withers** (for Holstein).

• This size will be attained at about 13 – 15 months of age.

• But growing too fast may have impaired mammary development.
• Feeding low-energy diet during breeding.
• After breeding, heifers can be grown at a rapid rate without detriment to mammary development, as long as they are not too fat (BCS > 3.5) at the time of calving.
• Both before and after breeding, the most important aspect of heifer diet formulation is choosing the energy density of the diet.
Feeding inadequate protein can partition more energy toward fat instead of lean gain, and may impair mammary development of heifer.

The requirement for protein relative to energy decreases as the animal ages.

If the energy concentration of a diet is increased, the protein concentration should be increased proportionally.
• Microbial protein supplies a large portion of heifer’s metabolizable protein requirement.
• The recommendations apply to healthy heifers fed a TMR in a comfortable, confined, group-housing environment with water and feed available most of the day.
• In group-housing situations, **ad libitum** can promote more uniform growth rates, and **restricted feeding** is more cost-effective.
• Pasture generally has a very low cost per unit energy.
• Weight and height should be measured at weaning, at about 5 months, at breeding, and just after calving.

• Other factors included DM intake and energy intake.

• If heifers growing too fast, the diet should be changed so that estimated energy intake decreases.
Feeding management (要點)

• Dairy cattle are usually fed in groups.
• Rumen pH drops after each meal.
• Promoting more meals of smaller size would promote consistency in the rumen environment.
• Maximizing DM intake is one of the most important ways to improve profitability by increase milk production.
• Feeding a well-balanced diet with minimum fiber is the first step in maximizing feed intake.
• Forages should have high NDF digestibility.
• All feeds should be palatable and relatively free of mold and other contaminants.
• Feed should be available to cows most of the day.
• Ad libitum intake requires feeding more than cows will eat.
• Freshwater should always be available.
• High-producing cows produce a considerable amount of body heat and have much lower thermoneutral zone and may be heat stressed at 25°C.

• Providing shade and a cool breeze near the bunk will encourage cows to eat.

• Protection of the bunk area from wind and rain.

• Using lights to simulate a long day photoperiod will enhance feed intake and milk production.
Nutritional evaluation

• Metabolic problems are one of the first things managers notice.

• Record the milk output, feed intake, and body condition will be helpful when making ration changes.

• Total daily milk production is affected by many factors other than diet, including cow groupings, milking procedures, and weather.
• Increased energy intake usually will be beneficial for cows, especially in early lactation.
Mammogenesis (mammary development):

- Begin at about a months of age.

- Feeding excess energy before puberty will impair mammogenesis and decrease subsequent milk production.

- Growth rates up to 900 g / day are acceptable.
Lactogenesis (initiation of lactation):

- Major changes in gene expression and protein synthesis (α-lactalbumin, lactose, casein, and enzymes involved in fatty acids synthesis).

- Little impact by nutrition.
Galactopoiesis (synthesis of milk during lactation):

- Milk synthesis is the predominant metabolic priority, especially first 2 months.
- Synthesis milk until the pressure within the alveoli builds up.
- Milked twice per day (relieves the pressure), promotes continued milk synthesis.
- Certainly impact by nutrition.
Mammary involution:

- Gradual loss of lactational capacity and transform back to a nonlactating state.

- Inadequate energy or protein can advance the process, decrease milk production and duration of lactation.