MODULE 2 - UNIT 3

.1. PHYSIOLOGY OF LACTATION [THE MAMMALIAN MILK PRODUCTION PROCESS]

Introduction

This unit discusses the physiology of lactation in cattle, however, the principles can be applied to other ruminants. Lactation is the process by which milk is produced in mammals. A good understanding of the lactation process is essential for you to be able to innovatively manage milk production in ruminants. That is to successfully rear sheep, goats, cattle and buffalo for milk production.

Quick Start h

The learning objectives of this unit are: to teach you the internal structure of the udder (the mammary glands and milking apparatus) and the development of the mammary glands, the hormonal regulation of lactation, the roles which the circulatory system and the lymphatic system play in lactation, and how all of this works together to bring about milk evacuation.

The Lesson /

.1.1. Anatomy and Architecture of Mammary Glands

The four mammary glands of the cow are collectively called the ***udder*** and, exclusive of milk, commonly weigh about 30 to 40 pounds (about 14 to 18 kg). A high-producing cow may accumulate 60 to 90 lbs (about 28 to 41 kg) of milk in her udder prior to milking.

NOTE:	Only about 80% is normally removed at milking !!

A desirable udder should have capacity, possess a relatively level floor, and be strongly attached. A good udder should contain a maximum amount of *secretory (glandular) tissue*, a minimum amount of *connective tissue*, and essentially no *fatty tissue*. The connective tissue might be likened to the walls, floor, and ceiling of a large house. The secreting cells fill the rooms.

NOTE:	After milking, the normal high-quality udder feels soft and pliable, with no apparent lumps or knots, which would be indicative of connective tissue resulting from injury or disease. However, it is impossible to predict accurately how productive an udder is by visual inspection or by its size.

The principal supporting structures of the udder are the *median* and *lateral suspensory ligaments*, as illustrated in *Figure 2-10*. The medial suspensory ligaments contain elastic fibres that are stretched laterally and vertically as the udder fills with milk; this stretching allows the squarely placed, perpendicularly hanging teats to protrude obliquely outward and downward. Probably less than 50% of the milk secreted can be stored in the natural storage areas of the udder.

NOTE: High milk production may cause these ligaments to become permanently lengthened and may result in a "breaking away" of the udder from the body, causing a pendulous udder. This condition may be partially alleviated by affixing udder supports. **What are udder supports? A bra? Yes!!!**

The udder is not directly connected with the abdominal cavity, except through the inguinal canal.

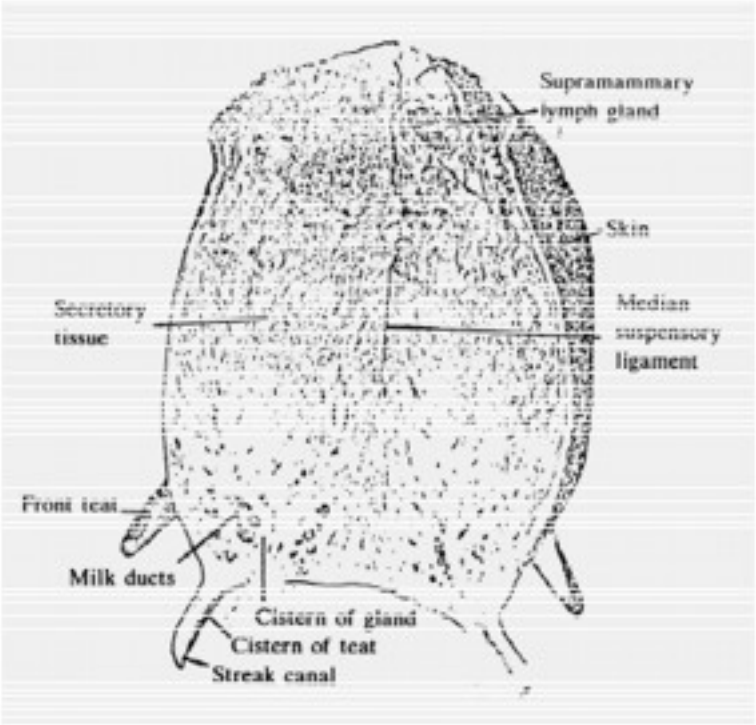

Figure 2-10. Cross-section of the rear quarters of a cow's udder [Missouri Agri. Expt. Sta. Bulletin, 344, 1935]

.1.2. Internal Structure

The udder is divided into halves (right and left) by a heavy membrane: front and rear quarters. They normally represent about 40% to 60% of the udder respectively. The milk from each quarter can be removed only from the teat of that quarter. Thus each quarter is an independent milk-producing unit and has to be independently managed.

At the end of each teat is the opening, *streak canal* or *meatus*, *(Figure 2.8)* through which milk is removed. It is largely the strength (tone) of the sphincter muscles surrounding the streak canal that prevents milk from flowing out and determines the ease, or difficulty with which milk may be withdrawn. Weak and incompetent sphincters that fail to exercise control of the closing of the streak canal contribute to a condition called ***patency***[1] and increase susceptibility to *mastitis*.[2]

The teat widens into its cistern and in turn into the gland cistern (reservoir). There are 10 to 20 large ducts (galactophores) branching into all parts of the gland to collect and convey milk downward. Each gland is divided into lobes separated by connective tissue membranes. The lobes are each drained by a single duct and further branch into lobules (sacs) which are drained by ducts (tubes). The lobules are composed of large numbers of hollow spherical structures resembling bunches of grapes, called ***alveoli***. An alveolus is very small (probably about 600,000 per cubic centimetre) and varies from 0.1 to 0.4 millimetre (mm) in diameter. Its epithelium varies from 0.007 to 0.010 mm in height, depending on its milk-secreting status. Milk constituents are formed in the epithelial cells lining each alveolus secreted into its lumen.[3]

There are millions of "grapes" of alveoli in efficient mammary glands. Completely surrounding an alveolus are groups of fibres. These muscle fibres stretch out as milk is secreted. When a cow is properly stimulated to let down her milk, they contract, forcing out the milk.

.1.2.1. The Circulatory System

The blood supply to the udder during lactation is profuse. There are 300 to 500 volumes of blood passing through the udder for each volume of milk secreted. Therefore the udder must possess an extensive vascular bed (blood circulatory system).

The lymphatic system is composed of lymphatic vessels that carry lymph[4] from mammary tissues to the heart via the venous blood system. In the

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[1] The state of beingad, enlarged, or without obstruction.

[2] Inflammation of the mammary gland. Mastitis is discussed in greater detail in subsequent units.

[3] The inner cavity of a cell or tubular organ (as a gland).

[4] A tranparent, colorless, alkaline fluid which circulates in the lymph vessels. It consists of plasma resembling that of blood and of corpuscles like the white blood corpuscles.

cow, the flow is upward and toward the rear of each half of the udder, where it passes through the supramammary lymph glands.

The glands act as filters that remove or destroy foreign substances (bacteria that may have gained entrance into the tissues). It is through the effective action of lymph glands pouring leucocytes (white blood cells) into the blood vascular system that infections are kept localised and invading microorganisms are destroyed. These lymph nodes (glands) and vessels are especially important in controlling inflammation at parturition and in removing sloughed or injured tissue. Congestion (swelling) in the udder at the time of parturition results from the accumulation of large quantities of lymph and is called oedema.[5]

The lymph capillaries surround the alveoli and absorb part of the plasma and products returning from the intercellular spaces into which they have flowed from the secreting cells.

.1.3. Growth and Development of the Mammary Glands

Mammary glands of the bovine female begin developing in early foetal life. The teats are apparent at birth. The teat and gland cisterns are also present. As the young immature female grows, the udder increases in proportion to the increase in body size. Prior to puberty, there is little duct development or growth of glandular (secretory) tissue. When the heifer reaches sexual maturity, estrogen (produced by the follicles on the ovaries) stimulates the development of the large duct system. With each recurring oestrus cycle, the glandular tissue is stimulated to grow rapidly. After heifers have passed through a number of oestrus cycles, the ducts show much branching into the udder.

The morphogenesis[6] of the mammary gland does not terminate when the adult stage is reached, since pregnancy is essential to the development of its full potentialities.

Udder Development During Pregnancy

During the first pregnancy, growth of the udder becomes continuous rather than cyclic during the recurrence of oestrus. Progesterone causes rapid development of the fine ducts and lobule-alveolar system. During this rapid-growth period (first 5 to 6 months of pregnancy), milk is not secreted and the alveoli remain collapsed.

During the first and second trimesters of pregnancy, the fine ducts and alveoli grow (proliferate) and simply replace fatty (adispose) tissue, giving little external visual evidence of growth.

During late pregnancy (last trimester) the epithelial cells lining the alveoli and fine-duct system begin to function and to secrete *colostrum*.[7] The colostrum is

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[5] A diseased or abnormal accumulation of serous (thin watery) fluid in various organs or tissues. Also spelled *edema*.

[6] The evolution and development of organic forms (considered apart from function).

secreted into the lumen of the alveolus and into the duct system. This causes the alveoli to balloon out (dilate), resulting in an enlarged udder. You should note that this apparently fast mammary gland growth is, in fact, the secretion and accumulation of colostrum by previously formed cells, which is actually accompanied by a small amount of glandular growth. Mammary gland growth in the cow continues during early lactation and is stimulated further by subsequent pregnancies.

Now, let us see how hormones function to regulate lactation.

.1.4. Hormonal Regulation of Lactation

The physiology of the mammary gland is closely related to hormonal and neuronhormonal mechanisms. The mammary gland is a secondary sex characteristic, of which the development, initiation, and maintenance of activity, and finally its involution, are dependent on hormonal balances.

- A number of hormones influence the intensity of lactation.
- Hormones are the only stimulators of lactation.

***Oxytocin* is a hormone secreted in the hypothalamic nuclei and stored in the posterior lobe of the pituitary gland. It is essential for the ejection of milk. It also stimulates the uterine musculature to contraction, induces expulsion of the egg in the hen, and is used to induce active labour in women or to cause contraction of the uterus after delivery of the placenta.**

NOTE: Oxytocin is the most critical hormone for successful lactation.

.1.5. Composition of Milk

Now for your mini-chemistry lesson. Milk proteins appear to result partially from synthesis and partially from filtration. Since milk casein,[8] lactalbumin,[9] and lactoglobulin[10] are not present in blood, they must be synthesized from blood precursors (amino acids). These proteins constitute about 94 % of the protein nitrogen in cow's milk. However, the immunoglobulins and serum albumin appear to be identical in blood and milk and therefore apparently diffuse or are transported into milk unchanged from the blood. It is of interest that normal milk contains only 0.05% to 0.11% immunoglobulins, whereas colostrum may contain 15% or more. *Table 2-3* shows average milk composition for certain species, while *Table 2-5* shows average milk composition for certain breeds of dairy cattle.

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[7] The first milk of a mammal after parturition. See Module Unit Section for further discussion in your manual.

[8] A phosphoprotein found especially in milk, constituing the principal ingredient in cheese.

[9] A water-soluble protein found in milk.

[10] A globulin of milk. **provide more definition**

Table 2-3. Average Composition [Percent of Total Milk] of Milk from Various Mammals

Mammal	Milk Fat	Protein	Lactose[11]	Minerals	Total Solids
Woman	3.7	1.6	7.0	0.2	12.5
Cow	4.0	3.3	5.0	0.7	13.0
Mare	1.3	2.2	5.9	0.4	9.8
Sow	5.3	4.9	5.3	0.9	16.4
Cat	3.3	9.1	4.9	0.6	17.9
Sheep	5.4	4.8	4.6	0.9	15.7
Goat	4.1	3.7	4.2	0.8	12.8
Elephant	15.2	4.9	3.4	0.8	24.3
Reindeer	18.7	11.1	2.7	1.2	33.7
Whale	22.2	12.0	1.8	1.7	38.1

Activity L

1. Examine table 2-3. Take notice of how goat's milk contains more protein and minerals than cow's milk. Surprisingly, judging from size, cat's milk contains the most protein. Can you draw any other conclusions from this table?

Now, let us look at the major breeds of dairy cattle and examine the composition of their milk.

Table 2-4. Average Composition [Percent of Total Milk] of Milk of Major Dairy Breeds

Breed	Fat	Protein	Lactose	Ash	SNF	Total Solids
Ayrshire	4.0	3.5	4.7	0.68	8.9	12.9
Brown Swiss	4.0	3.6	5.0	0.73	9.3	13.3
Guernsey	5.0	3.9	4.9	0.74	9.5	14.5
Holstein	3.4	3.3	4.9	0.68	8.9	12.3
Jersey*	5.4	3.9	4.9	0.71	9.5	14.9

[11] A white, odorless, crystalline disaccharide, $C_{12}H_{22}O_{11}{\cdot}H_2O$, present in milk; also known as milk sugar.

* - Jamaica Hope has 80 - 85% Jersey blod.

SNF - Solids Non Fat

Activity L

1. Examine table 2-4. Which breed has the highest percentage of fat in their milk?

2. Which breed has the lowest percentage of protein?

Carbohydrate in Milk

The principal carbohydrate of milk is lactose, which consists of one molecule of glucose[12] and one of galactose.[13] Glucose is a normal blood component, whereas lactose is not. Determinations of arteriovenous differences have shown glucose to be taken up by the mammary tissues. Arterial blood loses about 25% of its glucose content while passing through the lactating gland.

Fatty Acids in Milk

Approximately 75% of milk fat is synthesized in the mammary gland. In the ruminant, acetate[14] is the principal precursor of milk fatty acids,[15] of chain lengths up to and including the 16-carbon acid, *palmitic*.[16] This explains why cows on high grain and low forage rations often secrete milk having a low fat content (this diet results in the reduced production of acetate in the rumen). Oleic,[17] stearic[18] and higher fatty acids originate primarily from blood glycerides.[19] Glucose is important in the synthesis of the glycerol[20] portion of the fat molecule.

Minerals in Milk

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[12] Dextrose, a monosaccharide carbohydrate having the formula $C_6H_{12}0_6$. It is obtained by the hydrolysis of starch and other carbohydrates. It is fermentable but less sweet than cane sugar.

[13] A sweet crystalline glucose, $C_6H_{12}O_6$, the dextrorotatory form of which is obtained when milk sugar is treated with dilute acids. (Dextrorotatory is causing the plane of polarization of light to rotate to the right or clockwise: said of certain crystals and compounds.)

[14] A salt or ester of acetic acid. An ester is any of a class of organic compounds formed by the reaction of an acid and an alcohol? **provide more definition.**

[15] The physical characteristics of the higher complex fatty acids, as palmitic and stearic acids, give the name to the group.

[16] A crystalline fatty acid, $C_{15}H_{31}CO_2H$, contained in numerous animal and vegetable fats.

[17] An oily compound, $C_{17}H_{33}CO_2H$ contained as an ester.

[18] Designating a white fatty acid, $C_{17}H_{35}COOH$, contained in the more solid animal fats.

[19] An ether or ester of glycerol with a fatty acid.

[20] A sweet, oily, nearly colorless trihydric alcohol, $C_3H_8O_3$, formed by decomposition of natural fats with alkalis.

The minerals of milk are derived from the blood, and reach milk through filtration. Colostrum has a much higher mineral content than normal milk.

Vitamins and Milk. Vitamins enter milk unchanged from their form in blood. Those vitamins (B-complex) synthesized by the rumen flora through fermentation are in constant amounts in milk. On the other hand, the concentrations of fat-soluble vitamins in milk, especially vitamins A and D, are dependent on quantities in the ration and the body stores of the animal. Any variation in the concentration of B-complex vitamins in milk is determined largely by factors such as breed and stage of lactation rather than by diet.

Water in Milk

We have not discussed one major ingredient of the composition of milk. Water. The dominant milk component is water (87% by weight). It is filtered from the blood.

.1.6. Regression (involution) of the Mammary Gland

Failure to evacuate milk from the mammary gland causes ***involution***,[21] even when adjacent glands are evacuated or suckled. Following peak production after parturition, there is a gradual reduction in mammary size (udder size) and in the quantity of milk secreted, until the animal goes dry (non-lactating). Peak production in cows normally occurs about 6 to 12 weeks after calving (*post partum*) and can reach 120 to 180 pounds (12 to 18 gallons or about 55 to 82 kg) daily in very high-producing cows (but these would be exceptional animals).

It is possible that one or more hormones causes a reduction in the rate of cellular division following maximum yield, resulting in slow multiplication of epithelial cells. Thus, after several months of lactation, the total number of secreting cells would be appreciably reduced. The slow loss of cells could continue until the end of the lactation period.

Following the cessation of milking and when the process of involution occurs, there is a rapid shrinking of the mammary glands due to the disappearance of the alveoli. When the milk withdrawal is incomplete, the drying-off process is hastened. When alveoli are not emptied, secretion is further reduced, thus reducing the total amount of milk secreted between milkings.

Three common methods employed to convert a lactator (an actively milking animal) into a nonlactator (dry cow) are:

- Intermittent milking (e.g. alternate days)
- Incomplete milking, and
- Abrupt cessation of milking

[21] The process of a rapid shrinking of the mammary glands due to the disappearance of the alveoli, following the cessation of milking.

NOTE:	All these must be deliberately planned activities, as one cannot turn on and turn off a cow for milk production. See Module 5: Unit 3, Section 5.3.11.3.2. Mastitis Control, Activity L and Readings

Milk and blood are isotonic. This means that there is no osmotic pressure developed on either side of the semipermeable membranes of the milk-secreting cells. Yet milk contains respectively 90, 13, 10, 9 and 5 times as much sugar, calcium, phosphorus, lipids and potassium, but only one-half and one-seventh as much protein and sodium, respectively, as does blood plasma. This apparent paradox is possible because when many of these constituents are synthesized into milk components, they are in a form that does not influence the osmotic pressure to any appreciable extent. For example, calcium is tied with casein to form calcium caseinate in milk. Nearly 75% of the osmotic pressure on the milk side results from the lactose (which is in true solution), whereas the minerals are in a nonionic state.

On the blood side, the chlorides account for approximately 75% of the osmotic pressure. You should note that when mammary tissue is injured or diseased (as in mastitis), the cell permeability is altered and certain blood constituents filter through into the milk in greater amounts, (for example, the chlorides and blood serum proteins). In addition, synthesis of certain constituents within the gland (*i.e.,* lactose) is slowed.

.1.7. Milk Let-down

The evacuation of milk from the udder involves more than pressure (as in hand milking) or vacuum (as in machine milking) to open the teat canal. Vacuum *per se* will cause the galactophores and larger ducts to collapse and prevent emptying of the fine ducts and alveoli. *Unless proper stimulation is provided, only a limited amount of milk may be removed at the onset of milking*. This is because milk is held back in the gland by the small size of the capillary duct leading from each alveolus, the constrictions of each branch of the duct system, and the sag in the ducts at their points of suspension by connective tissue (due largely to the weight of milk). When a cow is properly stimulated, there is a sudden expulsion of milk from the alveoli, which causes a filling and distension of the large ducts and udder cisterns. This is commonly referred to as milk ***let down*** or ***milk expulsion***. It is a conditioneed or reflex action.

What phenomenon is involved? There are several theories but the most accepted one is that which involves the effect of oxytocin on contractile tissue.

On proper stimulus, oxytocin is discharged into the bloodstream and reaches the udder 30 to 40 seconds later. There it causes the myoepithelial cells surrounding the alveoli and ducts to contract. These smooth muscle cells in turn squeeze the alveoli, much like squeezing the bulb of a syringe, and expelling the milk from the lumina down the ducts and into the cisterns of the glands and teats.

Oxytocin is usually effective in maintaining myoepithelial contraction for 8 to 12 minutes. The effect is thus short-term. After this time, there is a decrease in the amount of milk obtained, a decrease in the rate of milk flow, and an increase in the percentage of fat in the residual milk. The residual, or complementary milk is that milk remaining in the mammary glands following the completion of milking. This normally averages about 15% to 20% of the total yield and about one-fourth of the milk fat.

It is possible to obtain residual milk by injecting 10 IUs (International Units) of oxytocin intravenously or by injecting 20 IUs of oxytocin subcutaneously. The latter method of injecting the hormone is much less disturbing to your cow than the former method.

The practice of removing residual milk is often followed prior to antibiotic therapy for mastitis. This practice permits maximum effectiveness of antibiotics and minimal dilution of them with milk.

Residual milk increases in quantity with higher production and advancing age but decreases with advancing lactation. It is therefore important to milk the animals as soon as milk let down is initiated. Your milking procedures should ensure proper stripping to maximise the removal of the residual milk.

Learning Activity L

1. Define a mammary gland.
2. Can milk from the right forequarter be moved by milking the left forequarter? Why?
3. From where or from what are the following milk constituents derived:
   a) Protein
   b) Lactose
   c) Fat
   d) Minerals
   e) Vitamins, and
   f) Water

Do's and Don'ts!

Never hit a cow on her mammary gland. It is a very sensitive area and can lead to mastitis. What is mastitis? This will be covered in Module 5: Unit .

Conclusion

The more you study animal (and human) bodily functioning, you have to be impressed with the way so many systems work together to create life and provide the necessary components to sustain life. The more you understand about these processes, the more successful you will be as a caretaker and producer of any ruminant animal.

You have learned about the operation of the mammary system and the components of milk which should have provided you with a respect for the udder and its care. From these udders come the sustenance for your future herd, as well as the possibility of milk production for your own use and for sale.

In your next unit, you will discover the physiological effects of ecology and environment on your animals. The more knowledge you possess, the more ability you will have to predict, prevent and solve problems, so that your animals have productive, healthy lives.

Worksheet

None

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Accompanying Readings

None

Further Recommended Readings

None

MODULE 2 - UNIT 4

.2. *ENVIRONMENTAL PHYSIOLOGY*

Introduction

Welcome to our discussion on the effects of the environmental factors on your ruminant animal! The nature of an animal's life and performance are shaped by environmental and heredity forces. The environment includes all of the physical, chemical and biological elements that surround the animal. As animal production becomes more intensive in space and time, environmental aspects of animal management become more important.

Animal production is becoming more and more intensified. This can be attributed to the following points listed:

- The scarcity and high cost of labour.
- The extremely high cost of land resulting in more animals being kept in limited space, and needing high levels of waste management.
- More-or-less enclosed housing makes year round operations possible in enterprises which were once seasonal.
- When seasonal effects on production are minimized, the overall economic efficiency of an animal production operation is usually increased.
- The nature of the markets, as large quantities of products to specifications are required at specific time intervals.

Some effects of confinement are, however, detrimental to the animal, principally perhaps because the animal's needs are not understood. Excessive expediency is not always without blame. Additionally, confinement often increases the frequency of the occurrence of certain diseases, unless special preventive steps are taken.

Quick Start h

After studying this unit, you will:

- Understand the factors, which you should consider when raising animals in a tropical environment.
- Recognize the importance of the influence of environmental factors when considering heredity and genetics, animal stress, animal body temperature regulation, and animal production

The Lesson /

In intensive animal production, you should be aware of the importance of thermal (temperature) and light factors, but also of the importance of social (and other behavioural elements) and disease factors. Confinement heightens the unyielding links between the animal and its environment.

.2.1. Heredity and Environment

A given hereditary pattern is itself the product of environment because mutation rates and selective survival are conditioned by the animal's environment. In this way the different climatic regions cause animals to adapt themselves to live in them. This adaptation may be illustrated by the fact that animals which have evolved in cool regions are adapted to cold weather, having an abundance of wool or hair and subcutaneous[22] fat.

However, animals evolved in hot regions are adapted to hot weather by the sparsity of wool or hair and subcutaneous fat. The fat resources of animals in hot climates are stored in the humps (of cattle) and tails (of fat-tails sheep). Fat stored in this way does not affect heat dissipation from the body.

Various components of the environment may either promote or impair animal performance by facilitating or inhibiting productive and reproductive processes. Scientific investigation of environmental effects on animal production is relatively new, probably because most people believed that breeding, feeding, and management research had greater economic impact than improvements in environmental factors. However, as animal production becomes more intensive is space and time, environmental aspects of food-animal management will become more and more important.

.2.2. Genetics and Heat Tolerance

Do you think it is possible to combine the high productivity of the heat-intolerant European breeds with the high heat tolerance and low productivity of the Indian-evolved cattle to obtain a highly productive, heat-tolerant animal?

Wide genetic differences are determined by a series of genes of the multiple type, some genes having an additive and others a non-additive effect.

When breeds are crossed, the genes recombine into new patterns. By combining genes from two or more breeds, backlogs of the evolutionary resources of both may be utilised in developing new breeds. An example is the Santa Gertrudis cattle developed on the King Ranch in Texas. This breed possesses the heat tolerance of their Indian ancestors (Brahmans) and the high-meat-production characteristics of their European ancestors (Shorthorns).

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[22] Situated, found or applied beneath the skin.

Genetic combinations having favourable hereditary characteristics may also be obtained within a breed, but progress is slower.

.2.3. Adaptation to Environment

Climate (from the Greek, *klima*, meaning "slope" or "tilt") depends on topography,[23] or the distribution of vegetation (especially forests) and on large bodies of water. Seventy-one percent of the earth's surface is covered with water. The environment, therefore, is largely reflected in the climate of a particular area.

Animals themselves are simply entities through which materials and energy flow before eventually returning to the environment. The simplicity of this statement does not take away from its impact.

Without the ability to adapt, animals are at the mercy of the environment. When animals are repeatedly or continuously exposed to major environmental changes, they may develop functional and structural changes that result in an increase in their ability to live without stress in the new environment. These changes are collectively referred to as the ***process of acclimatization***.

Animals best adapted to a particular environment have survived and, unless "transplanted" by human beings, populate areas best suited for their survival. However, modern transportation facilities have increased the movement of animals and have placed the selection of breeding stock on a *global* basis, forcing consideration of the question:

> *How do the changed conditions affect the productivity, health, and longevity of animals?*

.2.4. Physical Environmental Factors in Adaptation

Physical environment effects on humans and animals may be classified as *natural* and *artificial*.

The ***natural factors*** are part of the material existences, forces and phenomena in the universe (as distinguished from those caused by man). These include:

- Temperature (heat and cold)
- Air humidity
- Air movements (wind)
- Barometric pressure
- Rainfall and water effects on the skin
- Altitude
- Dust

[23] The detailed description of particular places. The physical features of a place, involving topography, temperature, humidity, rainfall, sunlight, relief, altitude, distance from sea and distance from the equator.

- Radiation (visible, ultraviolet, and infrared), and
- Cosmic radiations and atmospheric electricity

The ***artificial factors*** are all those physical, environmental effects created by man's industrial and chemical products. They include:

- Atmospheric pollution from industry, smog, and gases
- Toxic compounds
- Mechanical factors (noise, ultrasonics)
- Ionizing radiation (isotopes, x-rays)
- Artificial ionization of air.

Humans and animals have certain inherent mechanisms that enable them to adapt to changes in the natural and, to a somewhat lesser degree, the artificial physical environmental forces which exist about them.

.2.5. Stress

A large number of environmental factors may cause an animal to respond homeostatically.[24] Exposure to stressful conditions sometimes result in non-specific increases in secretion by the adrenal glands and frequently in other disorders as well.

In farm animals, one of the most important stress factors from an economic standpoint is *heat stress*. When exposed to high temperatures, the animals exhibit increased respiration. This results in the increased dissipation of heat in two ways:

1. By warming the inspired air, and especially
2. By increasing evaporation from the respiratory passages and lungs.

At high temperatures, livestock and poultry lower their food consumption and thereby reduce heat production. As a result of decreased food consumption, productivity (egg, meat, milk, and wool) is also reduced. Makes sense, does it not?

In understanding the effects of temperature, your informed management can assist your animals in their adaptation to this condition.

[24] Maintain an organic equilibrium; that is, maintain a uniform and beneficial physiological stability within and between its parts.

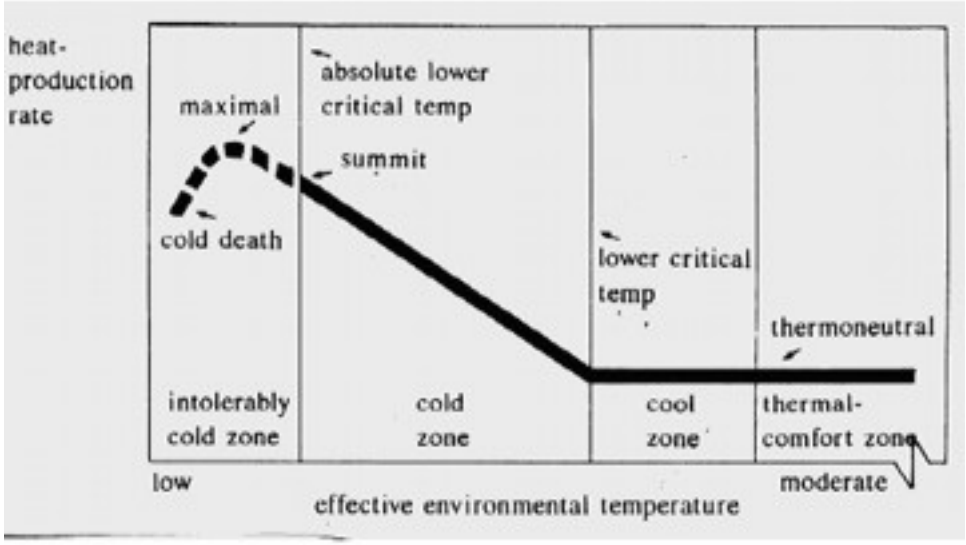

Figure 2-11. Relation Between Heat-Production Rate and ***Lower*** *Environmental Temperatures*

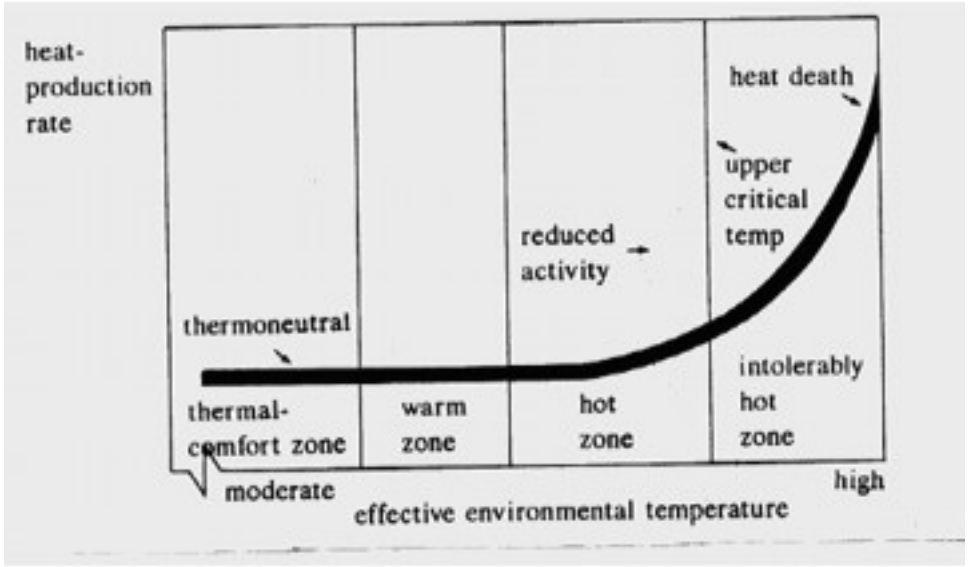

Figure 2-12. Relation Between Heat-Production Rate and ***Higher*** *Environmental Temperatures*

.2.6. Homeostasis and Homeothermy

Homeothermic animals of large body size have no need of annual migration. Homeostasis enables them to adjust to the winter cold. Small homeotherms (*e.g.*, birds) find seasonal migration necessary. This is because small animals have relatively more surface area in comparison with body weight than do large homeothermic animals, and heat dissipation is proportional to body surface area.

Table2-5. Normal Body Temperature [^oC] for Selected Animals

TEMPERATURE RANGE			
101° F	104° F	106° F	109° F
Elephant 96.0	Cat 101.5	Turkey 104.9	Chicken 107.0
Mouse 97.3	Dog 102.0	Goose 105.0	English Sparrow 107.0
Human 98.6	Sheep 102.3	Owl 105.3	Hummingbird 108.0
Rat 99.0	Swine 102.5	Duck 106.0	Robin 109.4
Horse 100.0	Rabbit 103.1		
Monkey 101.0	Goat 103.8		
Cattle 101.0			

Activity L

1. Examine the table. Do you note differences between the animal's temperature and the animal's surface area when based on your limited knowledge of the animal's size?

.2.6.1. Homeotherms (Warm-Blooded Species)

Animals in this category tend to maintain constant internal temperatures as external temperatures vary. As cold weather approaches, the cold-weather homeothermic mechanisms are as listed below:

- Growth of insulating hair and subcutaneous fat
- Increase in thyroid activity
- Consumption of great quantities of food, which, due to their heat increment, warm animals
- Seeking a protective shelter and warming solar radiation
- Grouping together, and

- Increase in activity, voluntary and involuntary (shivering).

All these mechanisms increase heat production. A means of heat conservation is the constricting of superficial blood vessels (vasoconstriction), reducing the blood flow at the skin, to avoid heat loss via conduction, evaporation, radiation, and convection.

As hot weather approaches, the animal's cooling mechanisms become important. These include:

- Moisture vaporization
- Avoidance of solar radiation
- Depression of thyroid activity, and
- Refraining from work or a decrease in the production processes (this includes the agriculturally important productive processes such as egg laying, lactating, and meat production), since this increases heat production.

Moisture vaporisation is the most important cooling mechanism and is the only one experienced in humans during periods when environmental temperature equals or exceeds that of surface temperature. Profusely sweating species can, therefore, withstand very high environmental temperatures. Most non-sweating species attempt to compensate for their inability to sweat by panting, often protruding their tongues and blowing air rapidly over the moisture surface, thereby accelerating the vaporization rate. Swine will die when exposed to an atmospheric temperature of 100°C in dry, sunny confinement, whereas they can withstand that temperature indefinitely when given access to a mud wallow. Water evaporates from mud on a pig's skin at a very high rate, cooling the animal greatly.

.2.6.2. Temperature Regulation

To accomplish homeothermy, the body is able to utilize physiological, behavioural, and anatomical mechanisms. For example, the endocrine system aids the animal in adjusting to seasonal and to short-term temperature changes by its secretion of thyroxine and epinephrine. Thyroxine is associated with slow, seasonal temperature changes; epinephrine is available to cope with rapid temperature changes.

The nervous temperature regulating centre is in the hypothalamus, which is located at the head of the spinal cord, just below the cerebrum. It is an astonishingly accurate thermostat. The hypothalamic thermoregulatory centre is itself sensitive to the temperature of the blood flowing through it, and it integrates this information with other inputs on the body's thermal status, both at the surface and in deeper organs and tissues, as it decides whether thermoregulatory responses are needed and, if so which ones.

The nervous system also stimulates the “ruffling” of feathers or “raising” of hair to decrease heat loss, or thermolysis. (Contraction of smooth muscles of the skin gives rise to “goose bumps” or “goose flesh.”) Furthermore, shivering (tensing of muscles), chattering of teeth, and other muscular activities involved in heat production are also under nervous control.

It is desirable to reduce heat loss in cold weather by such devices as:

- Reduced vaporization (no sweating)
- Lowered respiration rate
- Shunting of blood from the surface to the interior of the body
- Huddling
- Production of warm coats of feathers, fur, hair, or wool
- Disposition of subcutaneous fat, and
- Sheltering from the wind and from the cold

Chemical heat regulation adds to the heat-preservation process through:

- Increased thermogenesis (by exercise)
- Increased shivering and muscle tension
- Increased food intake (increased heat increment of feeding), and
- Increased adrenal and thyroid activity

.2.6.3. Heat Dissipation

Heat produced in domestic animals and humans is primarily dissipated in four ways:

- Conduction[25]
- Convection[26]
- Evaporation,[27] and
- Radiation[28]

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[25] The transmission of heat through matter without motion of the conducting body as a whole.

[26] The diffusion of heat through a liquid, gas or body by the movement of its parts.

[27] The process of drying (or concentrating) by changing or being changed into vapor, specifically, at temperatures below the boiling point.

[28] The energy associated with atoms and molecules undergoing internal changes, as of heat, light or sound.

Also, a small amount of heat is lost by warming and humidifying inspired air and through the feces and urine. Since each of these four factors is important in heat regulation and is closely related to environmental temperature they will be discussed individually.

NOTE:	Under systems of intensive ruminant production, modifying the environment to initiate heat loss via one of the above methods is essential.

.2.6.3.1. Conduction

This means of heat dissipation is based on the principle that heat flows between warm and cold objects. Conduction, therefore, is dependent on:

- the physical contact of the animals with the surrounding surfaces or objects
- the temperatures of these surfaces (temperature gradient), and
- the thermal conductivity and area of the contacting surfaces

High humidity in cold weather increases the feeling of cold because it increases the conductivity of clothing. Cold weather is an efficient and effective means of cooling by conduction. Metals conduct heat readily, whereas air, fat, feathers, hair, nylon, silk, wood, and wool conduct heat less readily.

Therefore, cattle and swine can increase their dissipation of heat via conduction by resting on cold concrete floors.

.2.6.3.2. Convection

Factors influencing the effectiveness of convection in heat dissipation include:

- body surface area
- velocity of air movement
- temperature of the animal's surface, and
- ambient air temperature

Convection is the mechanism by which heat is transmitted from one molecule to another and then is carried away. Heat is transferred to the air, which rises, taking the heat with it. Cooler air comes in to replace warmer air (and vice versa). It is important to note that warm air rises, thereby creating a pull for cool air, and creating a convection current.

The air immediately adjacent to an animal is usually warmer than the surrounding environmental air causing heat to be removed from the animal by convection.

.2.6.3.3. Evaporation

Evaporation is the most important means of heat dissipation during severe heat exposure because the temperature gradient between an animal's surface and the environment becomes increasingly narrow. Evaporation of water from the skin depends on:

- temperature and moisture of the skin,
- skin covering (hair, wool, feathers),
- humidity, velocity, and temperature of the surrounding air,
- respiratory rate and volume,
- water available for evaporation, and
- surface area of the animal.

If your animal has a thick hair coat, it may:

- reduce air movement about the skin, and
- entrap a layer of water vapour over the surface of the animal, thereby reducing the efficiency of evaporative heat dissipation.

Humans, on the other hand, produce skin moisture by the function of:

1. endocrine sweat glands (above 80 ^{o} F);
2. apocrine sweat glands, which open into hair follicles in the axillae, pubic, and anogenital regions;
3. sebaceous sweat glands (anatomically associated with the apocrine in that both enter the hair follicle), which produce sebum, and
4. passive cutaneous moisture diffusion.

There is also vaporization from the respiratory tract (nose, mouth, pharynx, larynx, trachea, bronchi, and lungs). Humans vaporize about one-third of the total moisture from the respiratory tract and about two-thirds from the outer body surface at 95° F.

Evaporative heat loss increases with an increase in environmental temperature, especially at temperatures higher than 85°F. In sweating species, the blood is shunted to the surface, where it is cooled by the vaporization of sweat. The internal blood deficiency

resulting from this may be compensated for by an increased heart rate.

NOTE: The increased heartbeat resulting when blood is shunted to the surface to be cooled is suspected as a major cause of fetal stunting in cows and ewes under heat stress during pregnancy.

.2.6.3.4. Radiation

Radiation is a very important means of heat loss from animals to cooler objects and heat gain by animals from warmer objects. Like a fire, the sun radiates its energy in straight lines as electromagnetic waves of various lengths at the speed of light (299,792 km per second). Radiant energy does not heat the air directly, but indirectly, by heating solid surfaces such as soil, water, buildings, trees, clouds, dust, and animals. In this way radiant energy is changed into thermal energy, which in turn heats the air by conduction and convection. Solid objects are also heated by reflected radiation.

Factors influencing heat loss (or gain) by means of radiation include:

- surface area of the animal,
- temperature of the animal's skin,
- temperature of the air surrounding the animal, and
- emissivity (the ability to absorb and emit heat) of the animal's skin.

.2.7. Effects of Climate on Production

It is now recognized, both commercially and experimentally, that high ambient temperatures directly affect the animal as it does the following which are listed:

- Depresses appetite and feed intake.
- Depresses growth.
- Reduces production.
- Lowers reproductive efficiency.

It may also indirectly affect the animal through its feed supply.

A comfortable cow converts feed into milk more efficiently than one exposed to high ambient temperatures. In one study, when the environmental temperature was increased from 60 ^{o}F to 95 °F, the mean rectal temperature of cows increased from 101 ^{o} F to 104 °F and the daily milk yield declined from 27 to 17 pounds.

Moreover, growth rate is greatly reduced in most European breeds of cattle during hot weather. High ambient temperatures have an adverse effect on spermatogenesis[29] and are also detrimental to the ova and sperm in the female reproductive tract. The results are lower fertility and higher embryonic mortality.

Do's & Don'ts!

Always remember that of you feel thermally uncomfortable in the pens, then the Animals are feeling the same way too!! So remember to see if you are comfortable in the pens, and if you are not, then do something to make yourself feel comfortable and I bet you that the animals will also feel comfortable too!!!

Highlights

Conclusion

You have seen how environmental conditions can affect ruminant production and how these animals can adapt to conditions physiologically. However, under tropical conditions, you will have to assist your animals with these adaptations. Understanding how an animal cools itself under tropical conditions is very important to the success of your production goals.

Worksheet –

None

Activity L

1. Make an appointment to visit a farm in your locale to discuss with the farmer how he helps his animals adapt, the breeds he has purchased, his housing and watering regimen, etc. Does he note a production increase or increase during any seasons of the year? Think of your own questions that you think environmental factors may have some bearing.

Activity E

1. What does environmental physiology deal with?
2. Cite examples of animals that are better adapted to some climatic regions than others.
3. Why are Indian cattle better adapted to warm climates than European cattle?
4. Cite several examples of the natural adaptation of animals to their environment.

[29] The development of spermatozoa.

5. What is homeothermy? Homeostasis?
6. What is meant by thermo-neutral zone? Cite some factors that influence it.
7. Discuss briefly the four primary means of heat dissipation in domestic animals.

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Accompanying Reading

None

Suggested Reading

None

Evaluation Materials

None