DAIRY PRODUCTION IN TONGA,

MAINLY FROM GRAZED PASTURES:

WITH ANALYSES AND RECOMMENDATIONS

BASED ON EVIDENCE FROM

TROPICAL AND TEMPERATE CONDITIONS

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This thesis is dedicated to my parents, Halafihi and Melape Fisi'ihoi, who devoted their lives to educating us in all dimensions of life, physically, mentally and spiritually.

ABSTRACT

This study **aimed** to combine information from temperate and tropical dairy farming systems as a means to improve milk production in Tonga. Modern management techniques have been established and used successfully in larger tropical dairy industries (e.g. in Australia), optimising milk yields. Similarly, in temperate countries such as New Zealand, expert management techniques have been applied to increase production, particularly in feeding and grazing management. The intention of the present study is to identify methods which are relevant to dairy farming in Tonga, specifically, methods of management and resource control.

This study was conducted through a review of published literature, which analysed, compared and contrasted various systems of dairying management in temperate and tropical conditions. The recommendations and management techniques discussed here were selected on the basis of their feasibility, simplicity and profitability in relation to the environment and potential resources in Tonga.

The **results** obtained in this research reveal that milk production can be increased in Tonga. Several studies have examined various management techniques aimed at optimising milk yield in both tropical and temperate countries and produced excellent results. Production can be increased when cows of heat tolerant breeds are given shade, sprinkled with water, grazed in higher quality pastures and provided with improved feeding systems. Not only is the milk yield increased by using such methods, but live weight, feed intake, health and fertility are also all improved. Pasture feeding value can be improved by management techniques such as mowing or slashing pastures, proper timing of rotational grazing, increased used of grass-legumes mixtures and maintaining nutrient cycling within the pasture ecosystem.

In **conclusion,** the improvement of milk production in Tonga will depend on the influence of environmental factors, financial resources and skilful management of the cows and their environment by farmers. Milk yields will not be as high as those in temperate regions, but the improvements are expected to benefit both animals and

farmers and result in an increase in current production levels. The recommended management systems mentioned in this paper will undoubtedly increase milk yields, but it is the farmers' responsibility to modify and incorporate these recommendations in relation to the environmental temperatures, feeding systems and available resources. Not all dairying techniques can be used, but an awareness of them may be useful for future dairy farming development and research. Lastly, it is the individuals' responsibility to challenge the use of various techniques and to face the difficulties of farming dairy cattle in the tropics.

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CHAPTER 1:

GENERAL INTRODUCTION

Improving the feeding value of grazing pastures as a means of increasing milk production is very important in Tonga. Several limiting factors contribute towards lower milk production in Tonga, including grazing pastures of lower feed quality, high environmental temperatures (< 27°C) and lack of feed management. These factors reduce the voluntary feed intake, grazing times and the digestibility of feed, resulting in lower milk yields throughout the year.

There is limited information and research available on milk production in Tonga, particularly on how to improve grazing pastures, feeding techniques and milk yield. There is a general lack of skills and knowledge of dairy production, including a shortage of sufficient land for dairy farming. However, small dairy herds (80-100 cows) are suitable and recommended for Tonga.

The main focus of this review of the published literature is to adopt suitable systems from larger tropical and temperate dairy industries that can be modified to suit the environmental and feeding conditions in Tonga. Discussed in this document are factors which affect pasture quality, voluntary feed intake, health, fertility and milk production. Explanations are given on how to best manage these factors in order to increase milk production. Several effective management methods have already been adopted from both tropical and temperate countries, and are currently being utilised to reduce problems that cows may face in tropical conditions, such as heat stress.

This research has revealed that milk production in tropical regions suffers from problems caused by tropical pasture species (mainly C_4 pasture species), the use of certain dairy breeds and poor quality feeds and feeding systems. Changes in these areas are necessary for the adoption of the dairying systems discussed in this paper. However, the most important requirement for improving milk production in Tonga is the need to have a better understanding of the three major topics outlined in this paper: factors affecting pasture in the tropics, the effects of feed and environment on the performance of dairy cattle and pastoral dairy production in Tonga; in addition to excellent farm management skills. Finally, the improvement of milk production in tropical areas faces more difficulties and limitations than would be experienced in temperate conditions.

CHAPTER 2:

FACTORS AFFECTING PASTURE PRODUCTION IN THE TROPICS

2.1. ABSTRACT

A number of environmental factors affect pasture production and the effects of one factor may markedly influence others. In addition, a number of conditions imposed by humans and animals alter plant productivity. The main **purpose** of this chapter is to determine the factors which have the potential to influence pastoral production. Some significant factors have been recognised including soil, nutrient cycles, plant species and chemical composition of pasture species. The **method** used to do this involved reviewing the literature and other relevant references. The research mainly focused on tropical pastoral systems, particularly the soil, nutrient cycle and forage species. It is assumed that the productivity of tropical pastures is dependent on the soil and its fertility, as well as pasture species and their chemical compositions. Several authors have found significant **results** indicating that tropical soils are infertile for pastoral development and milk production. In tropical pastures the focus should be on improving C_4 plant species rather than using C_3 species. To maintain higher pastoral productivity in Tonga, a grass-legume mixture is highly recommended instead of single grass pastures. In addition, the productivity of pastures will depend on maintaining soil moisture and the nutrient cycle. The effect of a hot environment is an ongoing factor, influencing lower productivity in both the soil and pasture species. In **conclusion**, there are a few management techniques that could be used to amend the problems related with infertile soils and pasture species and their chemical composition. The productivity of the pastures is very much dependent on the influence of environmental factors, soil factors and skilful management applied to pasture.

Key words: soil fertility; temperatures; grass species; nutrient; climates; minerals; protein; soil; chemical composition; nutrient cycle; productivity; tropical; temperate.

2.2. INTRODUCTION

Pastures are mixed communities of plant species that have adapted to being grazed. Tropical pastures are developed considering specific environmental conditions; the emphasis is on pasture improvement, particularly grass-legume pastures. This development is based on knowledge of soil fertility which is measured by the amount of nitrogen (N) in the soil. A general philosophy is that legume-rhizobium symbiosis provides an economical source of N (Moog, 2006). The quality of grazing forages is best indicated through livestock performance. However, since this is only an indirect measure of what is in the soil, some real indicators of forage quality that are relatively easy to measure should be understood. Therefore, crude protein (CP) is normally used to estimate the feeding value (FV) of the feedstuffs and total digestible nutrients (TDN) for digestibility, bearing in mind that forage maturity is the greatest factor affecting CP and TDN in tropical forages.

Generally, tropical forages have higher dry matter (DM) yields and lower nutritional value (NV) compared to temperate forages. The former has the potential for year round growth as it is influenced by the energy of light, high concentrations of carbon dioxide (CO_2), availability of nutrients and water, and prevailing temperature. The NV of forages depends on the type of management practices, available nutrients, growth stages and particular climatic conditions. In the tropics, there is a drastic shortage of rainfall during the year and the soil is extremely infertile (Crowder and Chheda, 1982).

This chapter will focus on the specific factors believed to affect pasture production in Tonga. These include soil fertility, forage species and their chemical composition (CC), plant physiology and nutrient cycle. How and what these factors affect in pasture productivity and other matters in the pastoral system is of particular concern. Most of the current knowledge has been gleaned from tropical countries around the world that have similar conditions to Tonga. Although the emphasis is on pasture systems with limited NV, evidence presented in this chapter will serve as guidelines to assist the day-to-day and long-term plans for feeding Tongan cows and enable a more proficient use of pasture.

2.3. SOIL

Soil is the main source of all mineral elements found in plants. The mineral deficiencies which are found in livestock are directly related to both soil mineral concentrations and soil characteristics. Plants can only remove a small fraction of the total mineral concentration found in soils. However, the availability of soil minerals to the plants depends upon their effective concentration in the soil solution (Reid and Harvath, 1980). Soils derived from igneous rocks usually have a higher readily soluble mineral content and have important trace elements that are later available for use by plants. Reid and Harvath (1980) also concluded that the distribution of trace elements was related to the humus and clay content of the soils, which accumulates in the upper horizons with high organic matter (OM). In addition, accumulations of OM in the soils under pasture tend to improve the physical properties of the soil (soil structure) with beneficial effects on rooting, macropore continuity, aeration and microbial activities. However, soil minerals can be easily leached and eroded, especially in regions with higher annual rainfall and poor physical soil formation.

2.3.1. SOIL FERTILITY

Soil fertility can be defined as the capacity of soil to supply adequate quantities of mineral nutrients to meet plant requirements. Therefore, the productivity of the pastoral forages depends on the level of soil fertility and its combination with other biological, chemical and physical factors will determine both pasture and animal production. The potential productivity of pasture (or plant community) at a particular site (or country) is determined primarily by climate (e.g. tropical or temperate), but the actual productivity is often determined edaphically by natural soil fertility (Kemp *et al.*, 1999).

Plant nutrients are divided into *macronutrients* and *micronutrients* that are produced from organic and chemical sources. All nutrients must be in soluble forms in order to be absorbed or enter the plant root systems. Plants favour mainly macronutrients and require them in larger quantities than micronutrients for normal plant growth. Macronutrients include nitrogen (N), phosphorous (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg), which are derived from the soil. Oxygen (O), hydrogen (H) and carbon

(C) all come from the air, and water (H_2O) makes up 95-99% of a plant's weight. In almost all soils above pH 6, Ca and Mg are usually present in non-limiting quantities.

Typically, in fertile soils where forages and crops are continuously removed, N, S and P are the earliest to become growth limiting factors. Soil pH is a general indicator of the availability of soil nutrients, the presence of free lime (calcium carbonate) and excessive availability of some ions including sodium (Na), aluminium (Al), H and Mg (Brady and Weil, 2000). In acidic soils (pH < 6), high concentration of hydrogen ions (H^+) are often attached to clay and OM. Acidification of the soil can be exacerbated by types of parent materials, rainfall, types of vegetation, leaching of nitrate, the removal of cations (positively charged ions) by plants and animals and the continuous use of ammonium-based acid-forming fertilisers. In addition, some areas that have been used for long-term crops and pastures are becoming acidic and will become a growth limiting factor in pastoral management. Acid soil can be amended with acid neutralising agents such as lime (calcium hydroxide), limestone (calcium carbonate), or dolomitic limestone (a combination of calcium and magnesium carbonate) (Brady and Weil, 2000), in tons per acre to bring up the pH level to 6 or higher.

Plant micronutrients are needed in only very small quantities. Essential micronutrients are Boron (Bo), Chloride (Cl), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo) and Zinc (Zn), and if deficient they can be applied to soil in pounds per acre.

Both tropical and temperate soils have similar deficiencies in certain soil minerals. In New Zealand, soils are naturally deficient in N and P and in some areas other macronutrients are scarce as are micronutrients such as Cu, Co, Bo and Mo (Kemp *et al.*, 2002). Soil in New Zealand is generally acidic and requires the application of lime to correct this tendency. Pasture growth and the availability of nutrients like Mo are decreased by low pH. The relationship between soil fertility and the pastoral system is complex. Most of the mineral nutrients essential for the growth of pasture species are also essential for animal growth. Dairy farmers can alter soil fertility by the application of particular fertilisers; however, other factors are not so easy to control. The objective of applying fertiliser is to maintain, or increase pasture production (Kemp *et al.,* 2002), livestock production by providing the essential minerals nutrients required for pasture and animal growth, without polluting the environment through excessive nutrient loss.

It is important to understand that pasture species differ in nutrient requirements resulting in relative competitiveness of different species of soil fertility. For example, legumes require more P than grasses, and in general legumes require more Mo and Co for N-fixation. As most of the N input in pastoral systems in New Zealand comes from N-fixation by legumes, phosphatic fertiliser is the main form of fertiliser used in New Zealand (Holmes *et al.*, 2002). The responses of pastures and livestock to fertiliser applications can be affected by soil properties. Soil texture and parent materials affect the application rate of fertiliser nutrients needed to get the desired response and also influence the rates at which mobile nutrients such as N, S and K are leached from the soil. The soil chemical properties like pH, cation exchange capacity (CEC) and P retention influence the availability of nutrients applied in fertiliser. The CC of the soil, the level of OM and the history of vegetation and land use on a soil can all affect the supply of nutrients from the soil.

The soil of Tonga is derived from a mixture of volcanic ash and coral, which is suitable for cultivating root and tree crops as well as pastoral farming. According to Lee and MacFarlane (1996), Tonga generally has a cooler subtropical climate, largely due to its southern latitude and consistent trade winds that limit humidity and moderates temperature over the land. The annual rainfall is around 1,900 mm and the dry period last for two months and occasionally for up to four months, during the period of July-November (Situa, 1996).

In general, Tongan soil is of low fertility, which is the main problem for tropical pastures. The main nutrient resource of Tonga soil is from dead OM and animal manures. The use of artificial fertiliser (N, P and K) is uncommon due to economic reasons. The level of soil fertility can be diagnosed by observing various mineral deficiencies that are expressed by the plants. Some deficiencies can be correctly identified based on plant symptoms, solid analysis and by recognising the characteristics of some particular soils with associated vegetation (Humphreys, 1987). In the cases of N, S, Mg, P, K and Mg deficiencies, symptoms are easily identified in young and older leaves (Figure 2.1).

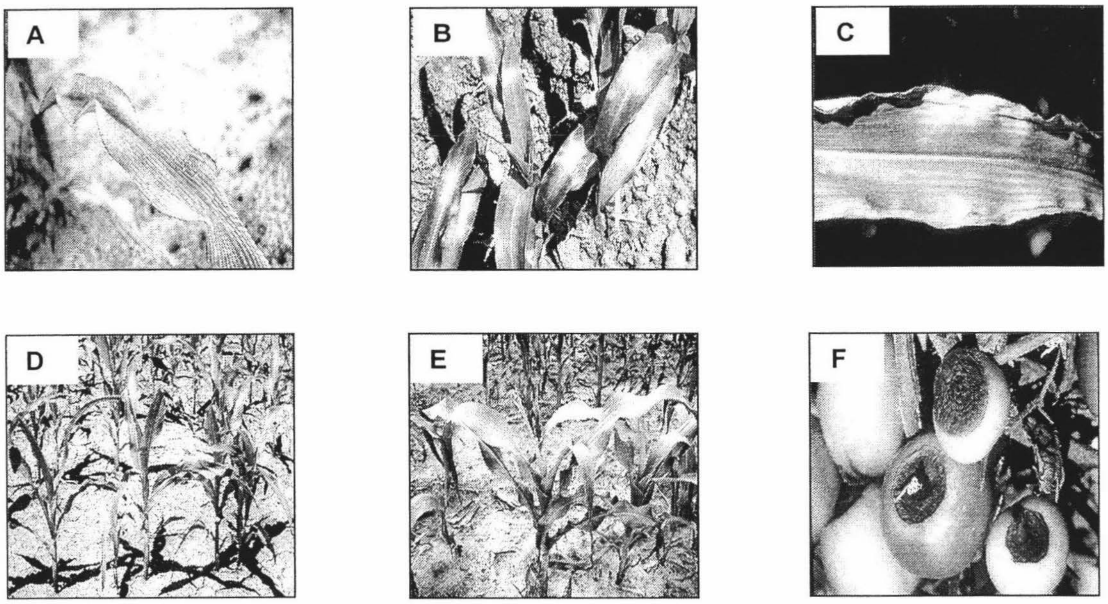

Figure 2.1. Symptoms of nutrient deficiency in corn (**A-E**) and tomato (**F**) plants. **A**: magnesium deficiency; **B**: phosphorous deficiency; **C**: potassium deficiency; **D**: nitrogen deficiency; **E**: sulphur deficiency; **F**: calcium deficiency (Mosaic Company, 2005).

Deficiencies in the less mobile nutrients can be seen first at the meristems (plant tissue responsible for growth) and young leaves (Humphreys, 1987). However, the quality of a soil is expressed on the pasture growth characteristics, DM yield and milk production. According to Chamberlain (1989), the main limitations to improvement of pasture in the tropics are poor soil fertility and lack of expert knowledge regarding pasture management under these conditions.

Chamberlain (1989) identified tropical soils to be low in N and these pastures respond well to N fertiliser, which increases both DM and protein content (PC). However, the exclusion of legumes and grasses leads to low soil fertility. Legume plants make a significant contribution to the nutrient status of the soil, as they increase N content within the soil and provide protein for companion grasses (Humphreys, 1987). Therefore, in addition to utilising inorganic fertiliser, leguminous species are invaluable for upgrading soil fertility.

Pasture rotation methods should be practised. A crop cultivation program will improve compacted soil and enhance its physical and biological properties, thus improving soil fertility, pasture yield and animal production. Good pasture management and practice will enhance the nutrient cycle by maintaining the movement of C, N, P and water. In addition to relying on natural nutrients, the application of fertiliser once every two or three years to maintain the productivity of the soil is probably wiser than struggling with low product yields from infertile soil (Chamberlain, 1989). The failure to improve tropical pasture is mainly due to a lack of attention to soil fertility. Where fertility is low, there is very little opportunity for pastures based on poor soil to improve.

All natural fertilisers such as legumes, crop residues, animal manures and all sources of OM should be utilised to fortify and maintain the fertility level of the soil. However, if these natural nutrients were likely to be depleted then, if possible, it would be prudent to replenish soil fertility by the regular addition of artificial fertiliser (Chamberlain, 1989).

2.3.2. SOIL MOISTURE

Different geographic regions have different levels of soil moisture, depending on soil properties and climatic conditions. However, the overall effects of moisture on pasture productivity are well recognised. Even moderate water deficiencies can result in a marked reduction of pasture growth, especially if the deficit occurs when new tillers are emerging from the plant (Vickery, 1981). Severe water deficits, because of prolonged droughts, usually result in substantial plant death and loss of plant cover within the pasture, which is exacerbated if coupled with heavy grazing. Yet, if drought is accompanied by high temperatures, leguminous species seem to tolerate these periods of moisture stress better (Vickery, 1981).

Many studies have determined the effects of water deficit on plants, including the reduction in photosynthetic capacity (El-Sharkway and Hesketh, 1964). For example, when plants such as sorghum were grown under intense light, the stomata (epidermal pores that control the passage of gases in and out of plants) limited photosynthesis by closing and the plants wilted slowly as the water deficit increased. Many pasture plants abruptly decrease net photosynthesis due to a lack of moisture in the soil (about -1.0 bars), followed by reducing the moisture content in their leaves.

Plant species vary in susceptibility to moisture stress. Species such as red clover (*Trifolium pratense*) and lucernes (*Medicago sativa*) are highly resistant to moisture stress while some temperate grasses (e.g. Italian ryegrass, *Lolium multiflorum* and cocksfoot, *Dactylis glomerata*) are among the most vulnerable. The tropical and temperate species also show differences in their water use efficiency. The C_4 pathway of tropical species allows partial stomatal closure to conserve water without restricting photosynthesis and this enables them to produce more DM/unit moisture transpired than the temperate species (Blach, 1971; Hatch, 1971).

Sufficiently severe droughts can stop growth and kill all above ground herbage. This undoubtedly limits animal production due to insufficient available feed because after the leaf is shed only the low quality mature stems remain for consumption. In New Zealand, moisture stress in pastures can be overcome by irrigation during drought periods (summer and autumn). However, this is dependent on several factors including the accumulation of OM and proper management of the field and pasture. Appropriate grazing can improve water retention and infiltration. Greater infiltration means less runoff and soil erosion, thus enhancing the quality and uniformity of both surface water and ground water supplies.

2.3.3. SOIL PH

Soil pH is one of the most indicative measurements of the broad chemical status of the soil. It indicates the *acidity* or *alkalinity* of the soil and it is measured in pH units that range from 0 to 14, with pH 7 as the *neutral* point (Troeh and Thompson, 2005) (Table 2.1). As the amount of H^+ in the soil increases, the soil pH decreases, thus becoming more acidic. Specifically, from pH 7 to 0 soil acidity increases, and any pH from 7.0-14 is alkaline (basic). Knowing the pH of the soil may help answer the following questions:

1) Does lime or sulphur need to be added to the soil?
2) Depending on soil pH, what nutrient problems might affect certain plants, and how might these be corrected?
3) Because some fertilisers will raise (alkalify) soil pH while others lower (acidify) it, which fertilisers should be used?

Brady and Weil (2000) stated that the most productive arable soils in use today have intermediate pH values, being not too acidic and too alkaline. In terms of pH, a range of perhaps 5.5-7.0 is the most suitable for most crop plants.

Table 2.1. Descriptive terms for the range of soil pH (Troeh and Thompson, 2005).

Soil pH and interpretation							
pH —— **5.5**	—— **6.0**	—— **6.5**	—— **7.0**	—— **7.5**	—— 8.0	—— 8.5	—— pH
Strongly acid	Medium acid	Slightly acid	Very slightly alkaline	Very slightly alkaline	Slightly alkaline	Medium alkaline	Strongly alkaline

Troeh and Thompson (2005) stated that the most universal effect of pH on plant growth is nutritional. The soil pH influences the rate at which plant nutrients are released by weathering; the solubility of all materials in the soil; and the amount of nutrient ions stored in the cation-exchange sites. The pH therefore, is a good guide for predicting which plant nutrients are likely to be deficient. Nutrient requirements vary with plant species and so does the optimum pH. The optimum pH for maximum profit and high crop yields is found on soil containing equal concentrations of hydrogen and hydroxyl ions (neutral) (Packer, 2004), because all plant nutrients are reasonably available in that range.

Plants do not grow well in soils that are too acidic, that is, less than pH 5.5 (medium acidic). The major nutrients that plants require (N, P, K and S) are found in limited quantities in acidic soils. Another disadvantage of acidic soil is the presence of the element Al, which is toxic in this situation and hinders pasture growth by restricting the growth and regeneration of roots. Other problems stemming from soils with pH < 5.5 include:

- Mn toxicity
- Ca and Mg deficiency
- a reduction in the availability of P
- reduced N and K efficiency, plus a poor response to N and K fertilisers
- appearance of bark necrosis
- stunted plant growth.

The availability of some micronutrients such as Fe and Zn is lower in alkaline soils and so these micronutrients are not available to plants. Conversely, in acid soils P is very limited and as previously mentioned Al toxicity readily occurs. At pH 6 or higher, there is a very little Al available in solution. Soil pH also affects the abundance of micro-organisms, with bacteria being more prevalent in alkaline soils and fungi dominating acidic soils. This is important because microbes are responsible for nutrient cycling. A pH around 6.3-6.8 is the optimum range preferred by most soil organisms including bacteria, fungi, moulds and anaerobic bacteria. Earthworms, which are highly beneficial to soil health as their feeding and tunnelling aerates the soil and they assist with the breakdown of OM, prefer neutral conditions (Troeh and Thompson, 2005).

As described above, it is important that pasture soil be maintained at the correct pH level; for example, grass-clover pastures prefer conditions of pH 6.2 to 6.5. If the soil pH needs to be raised, pastures should be limed little and often rather than large quantities applied infrequently. Hodgson *et al.* (2002) mentioned that some pastures are naturally deficient in N and P; and other pastures are deficient in macro- and micronutrients. The application of lime will improve the physical properties of the soil and the productivity of acid soils by reducing Al and/or Mn toxicity and increase the availability of P, N and Mo.

Troeh and Thompson (2005) state that the use of liming materials such as dolomitic varieties could raise the pH to near the optimum for crops. The ideal materials should have an action mild enough to cause no harm when an overdose is applied. The pH of alkaline soils can be lowered by adding S, Fe, sulphate or aluminium sulphate, although these products are expensive. Lowering soil pH can be done by using urea, urea phosphate, ammonium nitrate, ammonium phosphate, ammonium sulphate and monopotassium phosphate. Both acid and alkaline soils can be improved by the addition of calcium sulphate (gypsum = $CaSO_4.2H_2O$), which amends acid soil and lightens the structure of heavy clays. Troeh and Thompson (2005) stated that over-liming soil can reduce the availability of Fe, Mn, Bo, Zn and S. It also suppresses the availability of K. Crops are often stunted and turn yellow on high lime spots. In general, the pH of acid soils should not be raised above 7.0.

2.3.4. SOIL AND CLIMATE

In most cases drought alone can destroy even well managed pasture grasses. However, other environmental stressors can also weaken, thin and kill the pasture stands. These stressors include poor fertility, overgrazing (prior to and during drought) and increased pest (insects) pressure. The best way to manage pastures is to be aware of, and prepared for, drought.

Annual variations in seasonal climates affect the CC of the soil due to changes in moisture and temperature. In temperate climates (e.g. New Zealand) there are fewer hours of sunshine per day in winter and temperatures are lower than in summer (Holmes *et al.*, 2002). The rate of evaporative moisture loss is consistently higher in summer, while in the winter months rainfall is greater than the amount of moisture lost through evaporation. As a result, soil is colder and wetter during winter and warmer and drier in summer.

While it is clear that the main limiting factors for pasture growth are due to low soil temperatures in winter and moisture stress in summer, summer growth is slower in areas that receive less rainfall and do not use irrigation (i.e. 10-30 kg DM/day vs. 30-50 kg DM/day) (Holmes *et al.,* 2002). Pasture growth rate (GR) tends to increase when the temperature rises to 20°C for temperate grasses (such as ryegrass, *Lolium perenne* and cocksfoot); and tropical grasses (such as paspalum, *Paspalum dilatatum* and kikuyu, *Pennisetum clandestinum*) require hotter weather conditions (Holmes *et al.*, 2002). Temperate pasture growth, which is inhibited by cold soils in winter, increases by 5-10 kg DM/ha/day for every 1°C increase in soil temperature. In autumn, the GR is limited by moisture stress and increases by only 3-5 kg DM/ha/day for every 1°C increase in soil temperature above the range of 7-14°C (Holmes *et al.*, 2002). During summer, heat warms the soil to 14-18°C and it is mainly moisture loss that limits pasture production. Hence, from September to February GR increases by only 5-8 kg DM/ha/day for every 1 mm of rainfall during this period.

2.4. PLANT PHYSIOLOGY

Grazing animals throughout the world have access to a great diversity of plant species from which to select a diet. Within any sward forage, quality varies not only with genus, species and cultivars, but also with different plant parts, stage of maturity, soil fertility and with local and seasonal conditions. However, the quest for superior species and strains of grasses and legumes has led to a major increase in animal productivity from pasture. However, only about 40 of the 10,000 grass species (*Poaceae*) and 30 of the 11,000 legume species (*Papilionacae*) are widely used as sown pasture species.

This section will describe some of the plant factors that are responsible for differences in quality between legumes and grasses in terms of morphology, anatomy and biochemistry of pasture plants. These will be discussed together with the effects of plant species, stage of maturity and fertiliser on chemical components in the contents and walls of plant cells. These factors are important because they affect the digestibility of voluntary intake (VI) and the efficiency of how absorbed nutrients are utilised. The latter part of this section will discuss the characteristics of specific pasture species and their potential efficiency; and reasons to alter existing species to fit better with the environment to reach optimal forage production will be proposed.

2.4.1. PLANT MORPHOLOGY

Morphological and physiological differences between species, such as growth habit, perenniality, proportions and distribution of leaf and stem and flowering behaviour, have significant effects on both the quantity and quality of forage available to grazing animals (Norton, 1981). An understanding of plant morphology (Figure 2.2) is the key for managing forage quality (ratio of leaf to pseudo stem) and identification of suitable forage for grazing pasture. The morphological traits of plants are closely associated with forage yield (stand height) and experienced farmers can estimate yield based on stand height.

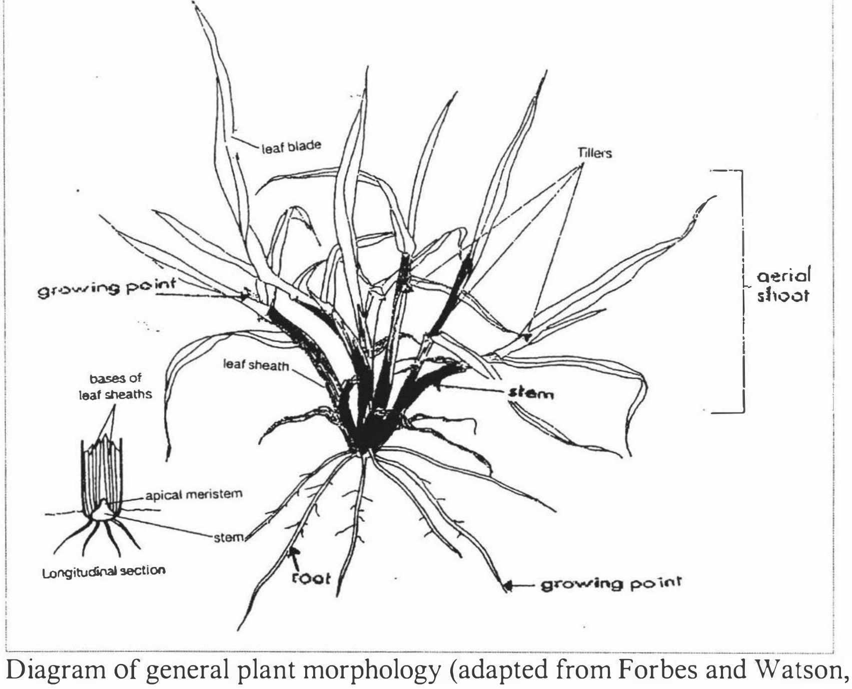

Figure 2.2. Diagram of general plant morphology (adapted from Forbes and Watson, 1992).

The differences between plant morphology and physiology have significant effects on both quality and quantity of forage available to grazing animals. Meristems are the basis of all new growth but can be damaged by tractors or hooves, especially when soils are wet. However, many natural growth characteristics of grazing forage such as rate of tiller formation and growth in tufted grasses, stolon development in prostrate plants, deep rootedness and grown burial in legumes provides selective resistance to the effects of grazing and treading by grazing animals. The superiority of some grass species such as *Lolium spp.* (perennial and Italian ryegrass), *Panicum maximum* and *Brachiaria decumbens* (signal grass) is related to their tolerance of frequent grazing or cutting.

Stobbs (1973) suggested the low level of animal production that occurs when grazing tropical compared to temperate pasture might be caused by the more erect growth habit of most tropical grasses and legumes. The low density (kg DM/ha/cm) of leaf in tropical pastures appears to restrict harvestability and intake of pasture feed. As grasses mature and start producing flowers there is a decline in forage quality caused by the translocation of soluble carbohydrates from the stem and leaves to the inflorescence, an increase in the contents of lignified cell walls and a decrease in leaf to stem ratio. Flowering of legumes does not significantly alter its NV, despite leaf loss through senescence. The initiation of flowering in both grasses and legumes is often determined by day length and temperature regimes. Pasture plants in temperate and Mediterranean environments are maintained in a high quality, vegetative state by environmental variables (vernalisation and day length requirements). The tropical grasses grown in warm environments have a higher GR and fewer environmental restraints to flowering and therefore usually progress to maturity and decline in quality rapidly.

The leafiness of various pasture plant species is commonly associated with forage quality, because there are positive correlations between the percentage of leaf, protein, mineral composition and the dry matter digestibility (DMD) (Fagan and Jones, 1924; Reid *et al.*, 1959). However, differences between species in the proportions of leaf and stem are not necessarily indicative of differences in forage quality. Some species have a higher leaf percentage (e.g. *Dactylis glomelata*) but the leaves are less digestible than other species (e.g. *Lolium perenne*). Tropical grass species vary greatly in leaf percentage, but these differences have no effect on either digestibility or VI of the forage when fed to sheep. Some cultivars of *Panicum* species with a high leaf percentage were consumed in greater quantities than those of similar digestibility but with lower leaf content (Minson, 1971). The differences in intake between leaf and stem were more closely related to the physical properties of the fraction (bulk density, surface area/g) than to differences in CC. For examples, *L. perenne* is degraded more slowly than *L. perenne* x *Multiflorum* in the rumen, despite similar structural carbohydrates contents, and these distinctions are reflected in animal performance. Tropical legumes have larger differences in digestibility of leaves and stems compared to grasses, however, consuming legume stems results in lower animal production (Norton, 1981).

Understanding plant morphology helps in making pasture management decisions by determining grazing potential of ruminant animals and assessing future pasture yield and utilisation. Useful information for the pasture manager includes awareness of the natural growth characteristics of various plant species including the rate of appearance of new organs such as leaves and tillers, rate of expansion, their longevity and fate (intake or senescence) and population densities (number/unit ground area of leaves, tillers). While a lot of descriptive information on plant and pasture morphology is available, it would be intriguing to understand why species differ so substantially and how they modify their morphology, and how this knowledge could be used under different management systems. This area merits further investigation as it would be worthwhile for grass-based dairy production systems in both tropical and temperate conditions to advance their management techniques, expand practice options and improve their plant material.

2.4.2. PLANT ANATOMY

The basic leaf anatomy of plants varies due to differences in biochemistry and physiology (Laetsch, 1969; Walker and Crofts, 1970) and the potential NV for ruminants is dependent on these variations (Wilson and Minson, 1980). Pasture plants produce their energy from the sun (radiant energy) and convert it into carbohydrates (CHO) (chemical energy) through the process of photosynthesis. This procedure involves a complex series of chemical reactions that result in carbon dioxide (CO_2) and H_2O being converted into carbohydrates ($[CH_2O]_n$). Photosynthesis takes place in the leaf in a process called the Calvin cycle. Figure 2.3 shows a cross-sectional view of leaves from a representative tropical and temperate legume and grass, and illustrates the relatively high proportions of bundle sheath and vascular tissue and low proportion of thin walled mesophyll cells in tropical grass compared to temperate grass.

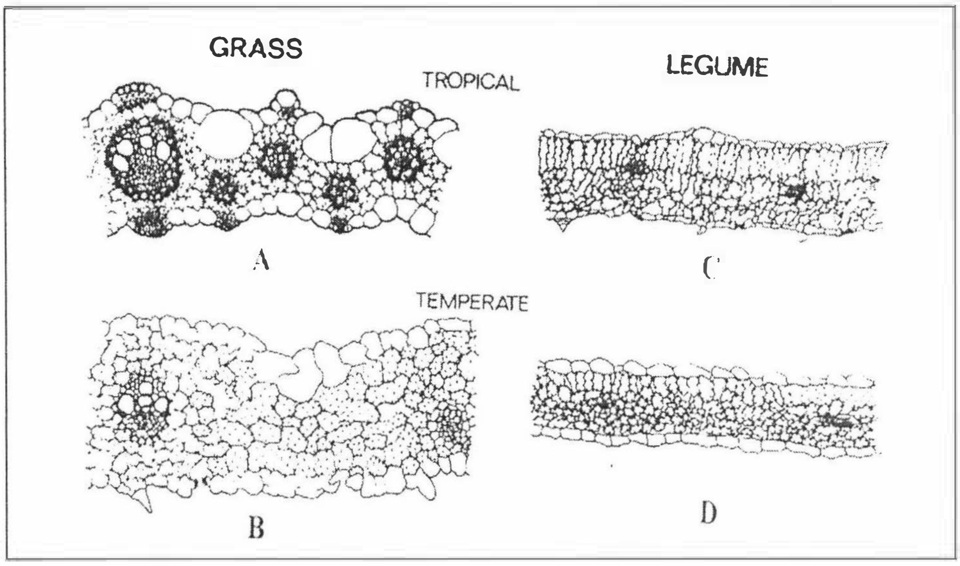

Figure 2.3. A cross-sectional view of the leaves of a tropical and temperate grass and legume. **A**: *Cenchrus ciliaris*; **B**: *Phalaris aquatic*; **C**: *Macroptilium atropurpureum*; **D**: *Trifolium repens* (Wilson and Minson, 1980).

Whiteman (1980) elucidated the Calvin pathway (i.e. C_3); and Hatch and Slack (1966), the pathway in tropical grasses - the C_4 pathway. These are compared in Figure 2.4. The Calvin cycle is common to almost all plants but different pathways are involved in trapping CO_2 from the air. In most temperate plants, described as C_3 plants, CO_2 is trapped by the enzyme ribulose-1, 5-bisphosphate carboxylase/oxygenase (RuBisCO) (Figure 2.4); while many tropical grasses, known as C_4 plants, use an alternative pathway where phosphoenolpyruvate (PEP) is the enzyme that traps CO_2 from the air. Compared to temperate grasses, most of the tropical grasses utilise the C_4 pathway during photosynthesis, which is superior for fixing CO_2 at high temperatures. However, both tropical and temperate legumes use the C_3 Calvin cycle for photosynthesis (Ludlow and Minson, 1971).

Whiteman (1980) explained that the largest group of plants using the C_4 pathway are the tropical grasses in the sub family *Ponicodeae.* The differences between C_4 and C_3 pathway species have important consequences in pasture productivity. The anatomical level of the C_4 leaves (grasses) are characterised by having two types of chloroplast containing cells. These are the mesophyll cells and the bundle sheath cells which are surrounded by the leaves veins (Figure 2.5). The chloroplasts in the palisade cells are much smaller chloroplasts containing very little starch, while the bundle sheath chloroplasts contain abundant starch grains (Laetsch, 1968). These morphological features are interpreted as adaptations for the rapid transport of precursors and end-products of photosynthesis. Whiteman (1980) elucidated that the morphological differences between C_3 and C_4 plants are differences in biochemical and photosynthetic pathways.

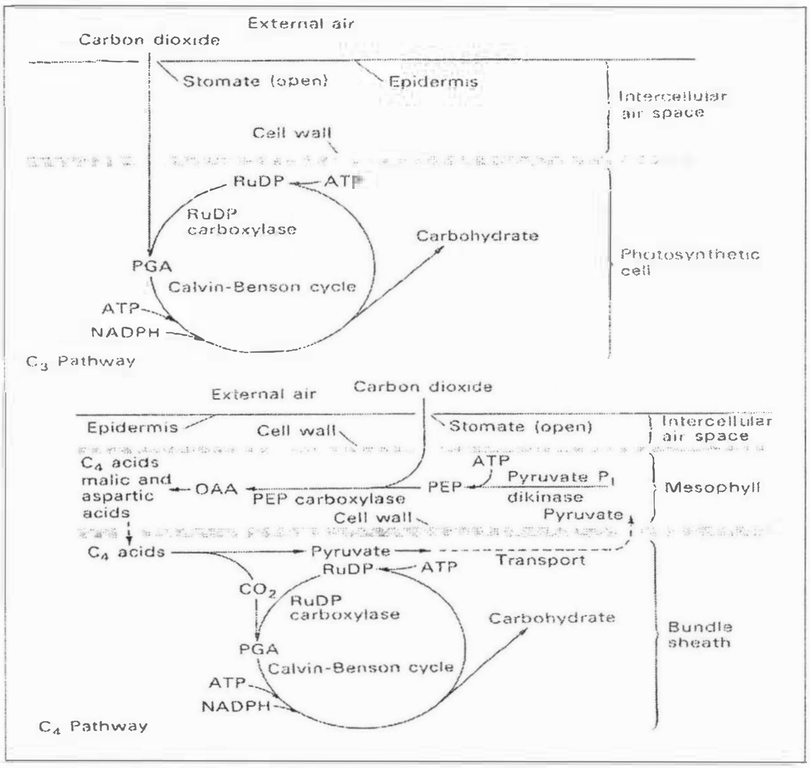

Figure 2.4. Comparison of the C_3 and C_4 biochemical pathways of photosynthesis (Bjorkman and Berry, 1973).

Most tropical grasses are characterised by a specialised leaf anatomy (Kranz anatomy), the major distinguishing features being a radial arrangement of chlorenchyma cells (bundle sheath) around the vascular bundles, structural chloroplasts in the bundle sheath and surrounding mesophyll cells, and more and larger mitochondria in the bundle sheath cells than found in mesophyll cells (Laetsch, 1974). These features are absent in C_3 pathway photosynthetic systems as used by temperate grasses and both tropical and temperate legumes. The stems of tropical grasses also contain more vascular bundles than temperate grasses (Figure 2.5).

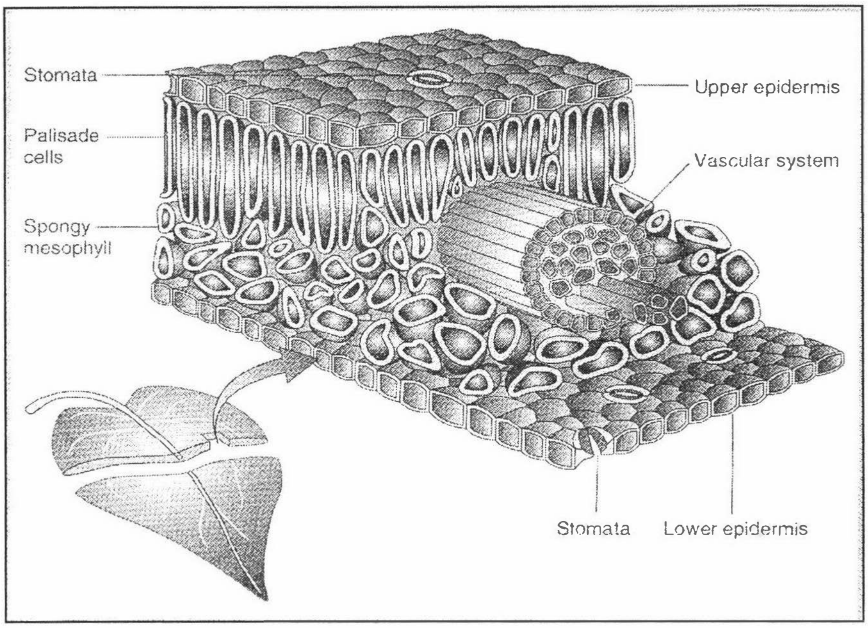

Figure 2.5. The cross section of C_4 plant leaf (Packer, 2004).

The special features of the C_4 pathway used by tropical plants render the leaves or plant structure resistant to mechanical breakdown (Figure 2.5). This higher tensile strength of the leaves of tropical grasses can make it more difficult for grazing cattle to harvest leaf material and requires longer rumination times. The mesophyll cells in tropical grasses are more densely packed (Figure 2.6) than those in temperate grasses; and intercellular air spaces in the former represent only 3-12% of leaf volume compared with 10-35% in temperate species (Caroline *et al.*, 1973). There is a considerable variation in both the numbers and characteristics of vascular bundles in tropical grasses and plant species with high digestibility usually have either fewer vascular bundles in their leaf and stem tissue (Schank *et al.*, 1973) or more rapid digestion of mesophyll and bundle sheath cells (Akin *et al.*, 1974).

The higher resistance of the specialised leaf anatomy of tropical grasses requires longer retention times in the rumen for both mechanical and microbial degradation, resulting in a lower VI (Thomton and Manson, 1973). However, the VI of tropical grasses can be increased if the grasses are ground into finer particles (Minson and Milford, 1968), which indicates that the feed quality is determined by the physical properties of the forage in addition to its CC.

2.4.3. PLANT BIOCHEMISTRY

Tropical grasses have a higher potential yield (35-85 t/ha/year) compared to temperate grasses (20-27 t/ha/year) (Robert and Carbon, 1969; Cooper, 1970). This is related to the influences of the high temperatures in which tropical grasses are grown and the differences in their biochemical pathways. Ludlow and Minson (1971) described several differences between C_4 and C_3 plants and their responses to either tropical or temperate conditions, including the finding that C_4 plants have a greater growth advantage under tropical temperatures than temperate ones. This higher GR enhances CO_2 fixing at higher temperatures due to the C_4 plant's photosynthetic system. The products of photosynthesis for the C_4 plants are oxaloacetic acid, malic acid and aspartic acid, whereas C_3 plants produce phosphoglyceric acid (Norton, 1981). The rate of photosynthesis per unit leaf area in tropical grasses is about double that of temperate C_3 plants. In New Zealand, most C_3 plants favour low temperatures, while C_4 plants can use high light energy to increase their GR to twice that of the C_3 species (Hatch, 1971).

If temperate C_3 plants are grown in the tropics the temperature is too high for optimum photosynthesis and only 30% of the light energy can be utilised. Therefore, most of the plants' energy is 'wasted' in maintaining respiration. Conversely, when C_4 tropical plants are grown in cool temperate conditions photosynthesis is restricted due to lack of light intensity, which does not affect C_3 species.

The cell wall structure of C_4 plants differs from that of C_3 plants. The leaves of C_4 plants contain two interconnected cell types (Figure 2.6), that is, thick walled bundle-sheath cells surrounded by thin walled mesophyll cells. This advantageous structure enables them to consume more CO_2 during high light intensities than C_3 plants. During this process of photosynthesis (see Figure 2.4) (Whiteman, 1980) CO_2 enters the stomata and is converted by the enzyme, carbonic anhydrase, into bicarbonate (HCO_3-). The enzyme PEP-carboxylase converts HCO_3- into the four-carbon compound oxalacetate, which is then reduced into maltate (another four-carbon compound).

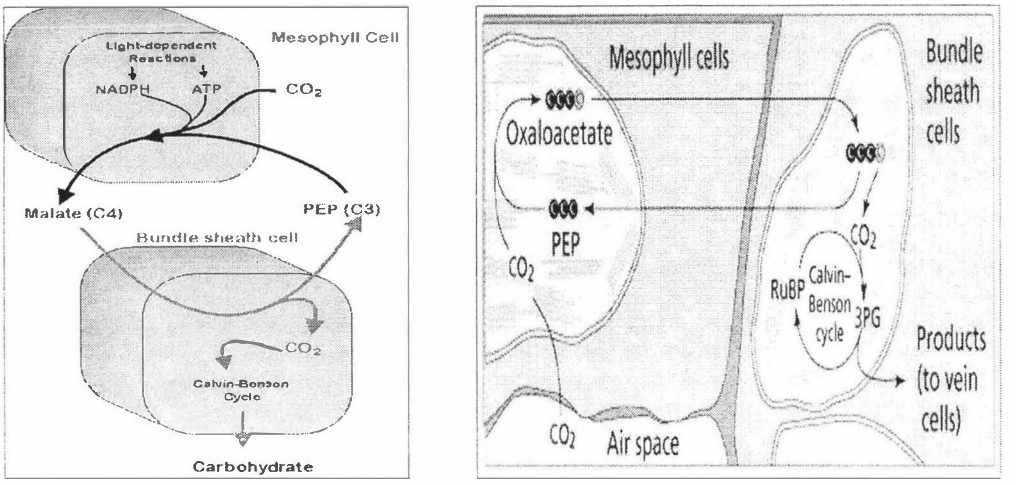

Figure 2.6. The cell wall structures of the C_4 plant (Spilatro, 1998).

In summary, C_4 plants such as sugarcane, maize and sorghum are well adapted to high environmental temperatures, high light intensities (Whiteman,1980) and low levels of soil moisture, and their rate of photosynthesis is faster than C_3 plants under the same tropical conditions for the following reasons:

- C_4 plants have a greater annual yield in tropical conditions because of their ability to sustain CO_2 to enhance rates of photosynthesis (Spilatro, 1998)
- C_4 plants are well adapted to arid conditions because they use water more efficiently
- C_4 plants use water more efficiently, as PEP carboxylase brings CO_2 in faster, resulting in less water lost through transpiration due to the stomata being open for less time
- C_4 plants increase the rate of photosynthesis faster than C_3 plants at higher temperatures and in higher light intensities because CO_2 is delivered directly to RuBisCO and is not able to pick up oxygen and undergo photorespiration
- During hot days, C_4 plants close their stomata, thus conserving water. C_3 plants under the same conditions have less energy to fix CO_2 as they rely on open stomata for their supply of CO_2 because they lack the C_4 plants' ability to use a chemical mechanism to scavenge CO_2.

In addition, C_4 plants are more efficient than C_3 plants at using the application of N fertiliser for improving OM in the soils. Colman and Lazenby (1970) have concluded that C_4 species have inherent, robust metabolic characteristics that can cope with low soil fertility. Thus, C_4 grass species can be clearly recommended for tropical conditions due to the plants' potential capabilities for utilising and coping with these harsh environments.

2.5. PASTURE FORAGE SPECIES

Pastures are mixed communities of plant species adapted to being grazed (Kemp *et al.*, 2002b). However, only a few of the thousands of grasses, legumes and herb species found growing in natural grasslands are considered suitable for managed grazing systems. Grass species provide the majority of the herbage produced by pastures, but the legume species are the keystone of the pastoral system because they supply fixed N and often have greater nutritive value than grasses. Species used in a pasture must complement each other so that the balance between grasses and legumes is maintained and the seasonal supply of herbage meets the requirements of the animals grazing the pasture (Kemp *et al.*, 2002b).

Different genera and species demonstrate different broad adaptations to regional climatic and soil conditions. Within species, plant breeders have selected certain plant types that are better adapted to the particular conditions of the environment and have released these as cultivars (natural species maintained by cultivation). Approved cultivars are distributed worldwide, including tropical countries, based on a strong adaptation to the local environment and the prevailing grazing management system.

2.5.1. GRASS SPECIES

Dairy cattle can be fed a wide variety of feedstuff, but are mainly grass-fed. However, major problems of tropical pasture forage (both legumes and grasses) are that it is bulky, of low quality and unpalatable (Humphreys, 1987). These issues prevent cows from satisfying their nutritional requirements. Apart from the obvious restriction of feed supply, it is crucial to understand what limits the daily VI of cattle.

Tropical pasture species have a lower NV in terms of the efficiency of feed consumed when compared to temperate pasture species (Humphreys, 1987). The NV of pasture is usually assessed in terms of energy availability, PC, minerals and vitamins, and the absence of toxins. Different varieties have different NV and DMD at various growth stages of plant growth (see Chapter 3). Another limitation of tropical pasture species concerns the plants' anatomy. Some species have more organs for digestion, some structures (e.g. thorns) may limit intake and young lamina is superior to leaf sheath and fibrous stem (Humphreys, 1987). Tropical forage grasses and legumes become lignified, and thus less digestible, earlier than their temperate counterparts.

Protein deficiencies of tropical pastures are the main challenge to livestock feeds and production. This problem can be overcome by ensuring the pasture contains a high percentage of a legume species with high PC; and the provision of supplementary feed with a high protein concentration to livestock, such as urea and grasses that respond well to nitrogen. Some legumes produce harmful substances, such as *Leucaena leucocephala*, which has high amounts of toxic amino acids and mimosine which depresses cell division) (Humphreys, 1987).

In general, the FV of tropical pastures depends on the species grown and their management (Chamberlain, 1989). Tropical pastures have higher DM production per hectare than temperate pasture, despite tropical pastures having a lower yield. In this aspect, cows prefer to ingest leaves rather than stems because the top portions are more digestible and higher in N and mineral content. Legumes are eaten in greater quantities than grasses, even though both are of similar digestibility (Chamberlain, 1989).

In conclusion, due to the variation in growth characteristics of tropical pastures and environmental temperature, pasture production is measured in terms of yield (tDM), GR, NV and animal production. The difference in day length between the seasons, amount of rainfall and solar radiation also contribute to the environmental inconsistencies that tropical pastures withstand. Many research and development programs, which aim to improve tropical forage pastures across regions, focus on grasses rather than legumes due to the differences in adaptation to various environmental conditions. The following list describes some of the forage grasses that are recommended for tropical pastures.

1) Signal grass (*Brachiaria decumbens*)

Signal grass is a common member of the *Brachiaria* genus, which are stoloniferous (i.e. runner plants that can develop specialised shoots above ground) and form a dense sward best adapted to the humid tropics with rainfall above 1,000-1,250 mm. It grows well in summer and its annual DM production (33,000 kg/ha) significantly exceeds that of guinea grass (Bamard, 1972; McKay, 1974). Signal grass is persistent, productive, and adapted to the infertile acid soils of the tropical regions; it performs very well both in extensive management and in rotational high input systems (Whiteman, 1980). *Brachiaria* species produce high yields, show excellent response to fertilizer and remain green long into the dry season. Data on nutritive value indicate that forage from *Brachiaria* is highly palatable to stock, leading to high intake, whether fed fresh or grazed in situ.

2) Guinea grass (*Panicum maximum*)

Guinea grass is a vigorous, tufted perennial with deep roots and a high tolerance to drought. This vigorous, summer growing grass is capable of shooting quickly in response to rainfall, and performs well under high temperatures and in regions with more than 1,300 mm rainfall per annum. It is well adapted to fertile and dry conditions, and produces about 80% more leaf DM yield than some other commercial cultivars. It is being increasingly used for dairy cattle in high input, rotational grazing systems (where the carrying capacity is 12 animal units per hectare) (Hacker and Jank, 1998). Guinea grass is suitable for both grazing and cut-and-carry (where the grass is cut and carried to livestock in a different area) systems (Whiteman, 1980). It is associated well with legumes, Centro and Stylo (Mislevy, 1985).

3) Setaria grass (*Splenda setaria*)

Setaria grass was recently introduced to Tonga and is potentially excellent for dairy production. Reports from Vanuatu and Fiji indicated that *S. setaria* gives the highest milk production of any grazing pasture (Lee *et al.*, 1998). This grass competes successfully against weeds and is grown from cuttings or seeds. It grows under temperature conditions lower than most tropical grasses and tolerates only short periods of waterlogged soil. It is well associated with green Desmodium, Siratro, and Glycine legumes and rotation should be four to eight week intervals. Butterworth (1967) indicated that the CP ranged from 4.8-18.4% and crude fibre (CF) ranged from 24-34%. Setaria grass can be grown in quite acid soil, with the pH dropping to 4.8 due to anhydrous oxalic acid. A high concentration of this acid can be toxic to cattle diagnosed as hypocalcemia (Mislevy, 1985).

4) Batiki grass (*Ischaemum aristatum*)

Batiki grass is easy to establish and having a low tolerance to drought, it grows well in areas with high rainfall. This grass thrives in moderate shade, such as under coconut palms. It out-competes weeds and can be propagated by cuttings. The pasture quality is best maintained by utilising a short length, rotational grazing regime.

5) Koronivia grass (*Brachiaria humidicola*)

This stoloniferous, creeping grass is vigorous in high rainfall areas. It is more tolerant to water logging than signal grass and can cope with very acid soils. It grows well under moderate shade conditions (> 70% light) (Hacker and Jank, 1998) and has good drought tolerance. It may be grown from cuttings and is favoured by horses.

6) Elephant grass (*Pennisetum purpureum*)

Elephant grass is a robust, upright growing and deep-rooted grass. It is tolerant to drought and is planted from stem cuttings. It has great potential for enhancing dairy production as it is highly productive (up to 60,000 kg DM/ha/yr), is easily digested and can be cut-and-carried. Young, immature plants are generally quite high in CP, averaging 23 and 12% for plants harvested at four and eights weeks of age respectively (Mislevy, 1985).

7) Para grass (*Brachiaria mutica*)

Brachiaria mutica persists best when grazed at 4-6 cm height and to 7 cm stubble. This is a highly palatable grass and is widely distributed in tropical areas with annual rainfall of about 1,500 mm or more or in swampy areas. Cows favour grazing at the lower, younger stage. It grows well in flooded areas but is very sensitive to frost and cool temperatures. Its NV decreases as leaf-to-stem ratios decrease when reaching 1-2 m in height. Its CP ranges from 10-14% and 3-6% for leaves and stems respectively (Albert *et al.*, 2001), while whole plant digestibility is from about 72% in the leaves and 77% in stems. Para grass has a high leaf-stem ratio, containing twice as much CP as the stems (Mislevy, 1985). It makes poor ensiling due to have a high pH, resulting in a low intake and low milk production (MP). When fed fresh it produces high milk yield (MY) and weight gain in beef cattle.

2.5.2. LEGUME SPECIES

All varieties of legumes found in the tropics have been introduced for exhibiting a strong adaptation to local conditions. In addition, they are perennial and regenerate themselves each year by seeding. Legumes tolerate shade and full sun and combine well with grasses such as Batiki, Signal and Guinea (Mislevy, 1985). In contrast with grasses, legumes have the potential advantage of retaining leaves with high forage quality throughout the growing season (Albert *et al.*, 2001). When combined with tropical grass, legumes can improve the dietary protein of the pasture, increase FI and enhance general animal performance. The primary objective of incorporating legumes with tropical grass pastures is to increase the percentage of CP in the diet, since CP concentration of tropical grasses is often lower than that required for animal maintenance (Albert *et al.*, 2001).

Growing legumes to increase total VI can overcome the deficiency of CP in the diet of sheep. In addition, the rate of weight gain of young cattle is improved due to increased PC in the diet and higher digestibility. Legumes also supply supplementary N to the pasture through the nutrient cycle, thus increasing forage yields and animal carrying capacity (Albert *et al.*, 2001). However, legumes can also cause problems for livestock, the most serious of which is bloat. Bloat is caused by the formation of stable foam in the rumen which prevents the eructation of gasses (e.g. methane) that are the products of microbial fermentation in the rumen (Bray, 1982). Soluble leaf protein is the principle foaming agent in legumes (Jones *et al.*, 1970; Kendall, 1996). When the diet contains high levels of the legume *Leucaena* (*L. leucocephala*), it causes problems such as inappetence, weight loss and enlargement of the thyroid gland (Jones, 1979). These clinical signs are effects of the presence of the substance mimosine, which was mentioned in the previous section. This non-essential amino acid degrades in the rumen to dihydroxypyridine which can be goiterogenic (Hegarty *et al.*, 1976).

Hill and Barnes (1977) suggested that the selection of pasture legume species should be based on both leafiness and chemical analysis. Chemical composition of fibre is measured as acid detergent fibre (ADF), consisting mainly of cellulose and lignin, and neutral detergent fibre (NDF), which, in addition to the components that make up ADF, includes hemicellulose. As per Hills and Barnes (1977) recommendations, PC should be high, ADF and NDF should be low (and hence lignin levels are minimised), as opposed to selecting for greater digestibility. Legumes should be well adapted to the environmental (climatic, soil and grazing) conditions. Climatic adaptations include winter hardiness in subtropical zones, the ability to withstand prolonged droughts or floods and alteration in photoperiod response to improve seed production. The following list describes some of the forage legumes that are recommended for tropical pastures.

1) Greenleaf desmodium (*Desmodium intortum*)

Whiteman (1980) explained Greenleaf desmodium, is a deep-rooted legume with a trailing growth habit up to 5 m long containing many short, brownish, hooked hairs and is grown from seed. It grows well in areas with low soil fertility and tolerates wet conditions. Regarding FV, it provides an excellent source of protein as it can fix more than 300 kg N ha/yr, riboflavin and vitamin A, and is useful for chicken feed. Greenleaf desmodium competes well with Setaria and Guinea grasses, but grows well with Siratro and Glycine which are described below. Although vulnerable to extended dry periods, the green leaves persist well under rotational grazing systems and it is marked to be one of the best pasture legumes in coconut plantations. The optimum growth temperature for this plant is 25-30°C (Whiteman, 1968).

2) Centro (*Centrosema pubescens*)

Centro is a perennial creeper of vigorous growth which is capable of persisting in grass-dominated pastures, however, it can easily invade other desirable species because it can climb over trees, roadsides and riverbanks (Smith, 2002). It is quite resistant to disease, tolerant of drought and moderately tolerant of shade. Centro is good quality forage and has 18 to 24% CP which remains high for long periods (6-12 weeks) of time (Mislevy, 1985). It can extract nutrients from low-mineral-content soils and tolerates considerable Mn.

3) Siratro (*Macroptilium atropurpureum*)

Siratro is a deep-rooted perennial legume with a trailing, pubescent stem. It thrives in many varieties of soil (with the exception of heavy clays), but prefers podzolic and alluvial soils of pH 4.8-8.0. Optimum GR is in mid-summer to autumn. This plant can withstand drought, but does not tolerate very wet conditions. Siratro is compatible with grasses (Whiteman, 1980) such as Rhodes grass (*Chloris gayana*), Buffel grass (*Pennisetum ciliare*), Green panic grass (*Stipa viridula*), Guinea grass and Setaria, and can fix around

100-175 kg of N ha/year and increase the CP level of other grasses. It should be harvested at a 60 day interval for 60% digestibility and 10% CP content (Mislevy *et al.*, 1981). It is known to have excellent palatability (Mislevy, 1985).

4) Perennial soybean (*Neonotonia wightii*; *Glucine wightii*)

Glycine is a perennial, warm season, woody and twining habit shrub. It has a deep taproot which provides good drought resistance, but it does best on well-drained soils. Glycine can tolerate soils that are acidic and of low fertility. It can be established together with perennial grasses that have slow established vigor. It is best grown together with Guinea, Pangola and Setaria grasses, however, grazing frequency of 5-6 weeks is recommended. Plants average about 15% CP and 65% digestibility at their flowering stage and can used for making hay (Mislevy, 1985).

5) Leucaena (*Leucaena leucocephala*)

Leucaena has proven to grow well in areas with an annual rainfall of around 3,500 mm; however, it would probably excel in drought prone areas due to its ability to thrive in dry conditions. It is strong growing and combines well with tall grasses but can smother fences if left ungrazed. Both leaves and stem have high protein and can remain green as a good protein source during drought. Plants can be cut for silage when they attain height of 90-15 cm and average 16-22% CP. Their DM yields range from 3-20 Mg ha^{-1} (Mislevy, 1985).

The negative aspects of legumes species can be improved by careful selection of desirable species. Desired traits include general adaptability, high yield and high NV; resistance to pests and diseases are also valuable. Most of the improved legumes for pasture production are being used in tropical regions. Many of the examples described above are well adapted to the environment, high yielding, persistent, palatable for livestock to consume and compatible to grow with grasses. These legumes are recommended by Mislevy (1985) and Lees *et al.* (1998) for having the following advantages:

- they are adaptable to tropical characteristics including heat stress, drought conditions and temperature variations
- to enhance pasture production, these legumes should be companion planted with grass forages to enable fixing of atmospheric nitrogen, conversion of N into a form that is available to the plants, increase CP content, etc.

- legumes are the best replacers of inorganic fertiliser that is required for grass forages
- all legume parts have high PC and can remain green under drought stress
- legume seeds can be easily established even under adverse conditions
- most grow well over a wide range of soil pH, even in acid soils as low as pH 4.0.

2.6. CHEMICAL COMPOSITION OF PASTURE SPECIES

The CC of the pasture forage is responsible for the physiological function of the plants and that of the grazing animals. The CC is expressed as: CP, fat or ether extracts, CF, ash and nitrogen-free extract (NFE). The NV of the forage is dependent on the CC. Formally, the fraction of CF was believed to represent the indigestible portion of the CHO content, but it is now considered that forage with a low amount of CF has a high NV, although this varies between forage species. In addition to the CC, the NV of the forage depends on its digestibility and the characteristics of the digested products (Crowder and Chheda, 1982). However, the amount of forage an animal can eat will depends on forage NV, palatability, presence of undesirable substances, rate of digestion through digestive tract and availability of desirable forage.

Van Soest (1966) considered that the basic dietary fraction of the forage was made up of two basic components: cell content and cell wall content. The cell content is made up of lipid, sugar, starch, non-protein nitrogen, soluble protein, pectin, organic acid and water-soluble matter. These elements are soluble in neutral detergents and therefore they are almost completely degraded by digestive enzymes in the gastrointestinal tract and the rumen through microbial activity. The rate of this breakdown depends on the proportion of different constituents such as lignin, hemicellulose, cellulose and silica. The cell wall content is the fibre fraction of the plant which comprises the insoluble portion (or NDF), which as previously discussed, contains hemicellulose, cellulose and lignin (which form the plants' cell walls) and ADF, which contains only cellulose and lignin (Van Soest, 1966).

2.6.1. SOIL AND CLIMATIC CONDITIONS

Different forage species have different NV in terms of their CC (Crowder and Chheda, 1982). These variations occur in particular in tropical forages, which tend to have a poorer NV and CC and thus lower productivity of the pasture system. The CC of any forage is affected by soil, climate, stage of plant growth and plant genotype. Sometimes there is a long wet or dry season that can cause a seasonal fluctuation in CC (Denium, 1966; Mohamed, 1972). In addition, the rate at which nutrients are absorbed by the plant is affected by moisture stress and high heat intensity, which results in early maturation and formation of lignin (French, 1957). The yield of green plant material, DM, percent of CP, silica, free ash and NFE are directly related to the amount of precipitation a plant receives during the year (Oyenuga, 1960).

Crowder and Chheda (1982) suggested that the chemical, physical and biological properties of soil and the rate that nutrients return to the soil could affect the CC of pasture forage. Despite tropical soil being generally low in N and other important nutrients, the ramifications of this depend on the management of the pasture. Consistent addition of N fertiliser and other essential elements to nourish the soil will increase yield and improve the CC of the herbage (Crowder and Chheda, 1982).

2.6.2. DIGESTIBILITY AND GENOTYPE

As herbage becomes mature, CC of pasture species declines, resulting in lower voluntary feed intake (VFI) and digestibility. When animals consume forage with low digestibility, the food remains in the rumen longer compared to highly digestible forage (Crowder and Chheda, 1982). Animals tend to eat less digestible DM when their nutritional requirements are not met, as opposed to products that are more digestible. According to Conrad *et al.* (1964), Milford and Minson (1966) and Raymond (1969), there are differences in the digestibility of the various legumes, although they are not apparent if the digestibility is above 65-70%. Digestibility is highly correlated with the inherent differences among varieties, families and species in relation to VFI. However, animals may consume considerable larger amounts of legumes than grasses when both have similar digestibility. For example, the legume Glycine spends shorter time in the rumen than Crabgrass, Setaria and Rhodes grass. Van Soest (1965) found that this trend was due to legumes having higher proportions of cell contents and lower proportions of cell wall constituents than grasses of the same digestibility.

To recap, high quality forages should provide protein, minerals and energy in proportion to an animal's requirements. Forage CC is often used as an index of pasture quality, which can be expressed as CHO, CP and mineral content. Forage CC is affected by environmental factors including the amount of light, temperature and moisture stress. Plant species have been grouped into tropical and temperate grasses and legumes, which differ in nature and concentrations of protein, minerals, non-structural carbohydrates (cell content) and cell walls as indicted in Tables 1.2, 1.3 and 1.4.

2.6.3. MINERAL CONTENT

The balance, concentration and nature of minerals in herbage vary with plant species, stage of growth and availability of minerals in the soil. Fertilisers are used to increase plant GR and mineral content, but species differences are still evident when optimal fertiliser requirements for growth are provided. Various factors affect the mineral composition of herbage in tropical pastures and the deficiency of any one of the 17 elements that are essential for animals will limit digestion, absorption and utilisation by the animal of all the dietary components of grazing pasture (Norton, 1981).

The low content of minerals in plants may be caused by low availability in the soil, low genetic capacity for accumulation or by low requirements for growth. Alternatively, high and/or toxic levels may be the result of excessive availability of minerals in the soil, genetic or physiological capacity, and high rates of accumulation or be indicative of elevated requirements for growth. The wide range of mineral contents found in different plant species suggests that all these factors are operative. However, the forage quality will only be affected if the mineral requirement and content of the forage falls outside the range required for optimal animal growth (Norton, 1981). The mean values for mineral content of tropical and temperate legumes and grasses are shown in Table 2.2. This represents values from forage grown under a wide range of environmental conditions.

Table 2.2. Mean value for mineral content in the dry matter of tropical and temperate grasses and legumes. Values in parenthesis are the number of samples (adapted from Norton, 1981).

	Temperate		Tropical	
Minerals	**Grass**	**Legume**	**Grass**	**Legume**
Phosphorus (%)	0.33 (400)	0.36 (320)	0.22 (586)	0.26 (165)
Calcium (%)	0.59 (428)	1.86 (291)	0.40 (390)	1.21 (154)
Magnesium (%)	0.18 (335)	0.29 (193)	0.36 (280)	0.40 (48)
Sodium (%)	0.23 (318)	0.19 (121)	0.26 (192)	0.07 (40)
Copper (ppm)	6 (127)	12 (93)	15 (94)	10 (17)
Zinc (ppm)	32 (31)	55 (34)	36 (119)	10 (17)
Cobalt (ppm)	0.20 (111)	0.42 (21)	0.16 (45)	0.07 (3)

2.6.4. PROTEIN CONTENT

Grasses usually contain less protein than legumes. Figure 2.7 (Norton, 1981) indicates that the relative frequency of CP is in the range of 6-9% for grasses and 12-18% for legumes. Temperate and tropical legumes have a similar range of CP content with few values falling below 9%, which is considered minimal for ruminant requirements; whereas around 53% of the tropical grasses contain less than 9% CP compared with 32% of the temperate grasses. A minimum of 15% CP is required for ruminant lactation and growth and most legumes and temperate grasses satisfy this requirement; however, less than 20% of the tropical grasses have CP content above 15%. The fact that tropical grasses have lower PC than temperate grasses is a major limitation of animal production in the tropics. Nevertheless, the inclusion of legumes in tropical pastures improves animal production by increasing protein availability for grazing stock. The CP content of both grasses and legumes is significantly affected by the environmental conditions under which they are grown (Lyttleton, 1973).

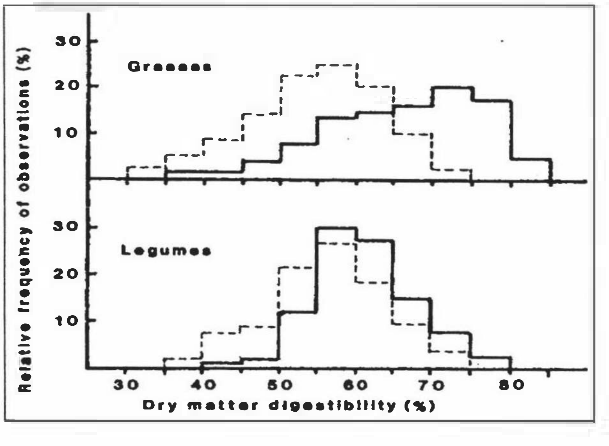

Figure 2.7. The distribution of crude protein in tropical (solid line) and temperate (broken line) grasses and legumes (Wilson and Minson, 1980).

Nitrogen in forage consists of soluble and insoluble amino acids and proteins, amides, ureides, nitrates and ammonia. About 25% of the non-protein constituent of the total N component of forage depends on the application of N fertiliser and the nutrient status of the plant (Hegarty and Peterson, 1973). Table 2.3 shows the distribution of protein in the leaves of temperate grasses and it is clear that chloroplast protein is the major protein found in plants' cells. Distribution of protein fractions in tropical grasses are different for leaf anatomy and biochemical activity, however, a lower concentration of protein is found in the bundle sheath cell of the tropical grasses than in mesophyll cells of temperate grasses.

Table 2.3. The distribution of protein in the leaves of temperate grasses (adapted from Brady, 1976).

Intercellular	Location	% of total protein
Cloroplast	Membrane	30 – 45
	Soluble	25 – 30
Mitochondria	Membrane	3 – 4
	Soluble	2 –3
Cytoplasm	Membrane	5 – 13
	Soluble	15 – 20
Nucleus cell wall	Membrane	1 – 2
	Soluble	1 – 2

2.6.4.1. Protein solubility

Significant differences in protein solubility are also found between grass and legume species and between different plant parts (Aii and Stobbs, 1980). The differences in the leaves and stems of some tropical grasses and legumes are summarised in Table 2.4. The amount of fibre in forage and its physical composition can limit VI if protein, vitamins and minerals are available in sufficient quantity. If the CP content of the pasture falls below 6-8%, animals' appetite and VI will be reduced due to depressed activity of rumen microbes. Providing supplementary protein or urea to cattle that are fed N deficient silage can increase VI by 16-82% (Morris, 1958, 1966). The effect of protein deficiency depressing appetite appears to be caused by factors other than rumen retention. It is likely that the problem is due to a deficiency of circulating amino acids, because the VI of a protein deficient diet is increased if casein (but not urea) is infused into the duodenum (Egan, 1965). Both grasses and legumes have higher proportions of soluble protein in their young leaves; and stem proteins are more soluble than leaf proteins in both types of plants.

Table 2.4. The solubility of protein in the leaves and stems of some tropical grasses and legumes (adapted from Aii and Stobbs, 1980).

Species	Protein solubility (% total nitrogen)	
	Leaf	**Stem**
Grasses:		
Staria spp. and cv	19.3	29.0
Digiteria decumbens cv *Pangola*	24.4	22.7
Pennisetum clandestium	24.0	66.0
Chloris gayana	29.7	48.2
Brachiaria mutica	33.5	53.0
Legumes:		
Desmodium uncinatum	5.3	36.3
Desmodium introtum	7.6	15.9
Macroptilium at: cv *Siratro*	40.8	52.9

As previously stated, tropical grasses generally contain less PC than temperate grasses (Minson, 1976) and the insufficient supply of protein, minerals and vitamins of the tropical species limits the VI of animals grazing the pasture. The lower VI and DMD of the tropical grasses are also due to an increase in fibre content associated with tropical climatic conditions. Plant breeding programs and selection of varieties with a high FV can alleviate some of the deficiencies in the CC of tropical forage. However, the cheapest way to overcome nutrient deficiencies is to include the higher performing leguminous species in the pasture (Minson, 1981) and apply an N-based fertiliser.

2.6.4.2. Phosphorus deficiency

The element phosphorus (P) is an essential mineral required for bone development, growth, reproduction and energy transfer (Minson, 1990) and its deficiency is a widespread problem in tropical pasture. This deficiency is more prevalent in certain areas and as the plant matures P and PC diminish species (Minson, 1982). Feeding cows mature forage decreases P content because CHO is translocated from the leaves to the seeds and roots. Grain feeds are generally higher in P. According to Norton (1981) both tropical grasses and legumes are somewhat lower in P than temperate species, although the range is similar. The clinical signs of P deficiency in cattle are unthriftiness (failure of the young animals to thrive), fragile bones and botulism because of bone chewing (as an attempt to increase P in the diet) (Underwood, 1981). Most (75-80%) of the body's P is found in the skeleton (Beever *et al.*, 1965) and less than 0.4% in blood serum. Inadequate levels of P affects fertility in that weaning weight, calving rate and conception rate are all reduced. A lack of Ca, P and/or vitamin D can result in rickets in young animals and osteomalacia in adults.

2.6.4.3. Sulphur deficiency

The element sulphur (S) is an essential mineral required for protein formation. The depression of animals' appetite due to eating low S feed, is because of a protein deficiency. However, when animals are fed supplementary S, VI can increase by 28% (Minson, 1981). The problems associated with S deficiency can be alleviated by the application of S fertiliser to the pasture, which can increase DM yield and the leaf percentage.

2.6.5. PLANT MATURITY

As plants mature, the CC of the pasture varies and productivity is affected (Holmes, 1980) (Figure 2.8). The advancing maturity of tropical forage is accompanied with an increase in DM content, which reflects the increase in cell wall contents and a decrease in cell contents. Levels of CF and NFE of most tropical grasses rise as plants age, however the amount of CF starts to climb during the first month of growth while NFE increases later (Crowder and Cheda, 1982).

Although cell contents increase with plant maturity this does not mean that nutrient absorption ceases, because DM is yielded simultaneously through photosynthetic activity rather than mineral absorption. However, this causes a dilution of mineral content in proportion to increased bulk, resulting in a lower percentage of CP, P and K (Crowder and Chheda, 1982). In this situation, the grass can be grazed frequently for short intervals to provide animals with high levels of digestible nutrients. Coward-Lord *et al.* (1974) suggested that notable changes in CC which occur after extensive tissue differentiation take place between 30 and 60 days of growth. The overall quality of the pasture forage may depend on the relative proportions of high quality fractions. Normally the leaves and stems have equal nutritional value at the beginning of growth, but later decline at different rates depending on maturity, although the growth rate of the cell walls of stems usually increases faster than leaves (Reid *et al.*, 1973).

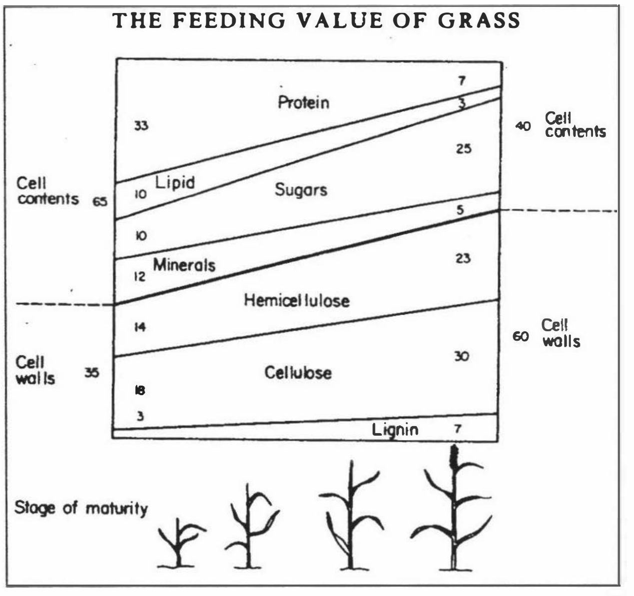

Figure 2.8. A schematic representation of the changes in the chemical composition of grasses which accompany advancing maturity (Holmes, 1980).

Advancing maturity of tropical grasses adversely affects its NV and the VI of grazing cattle. Investigations carried out on several tropical forages at various stages of growth in Australia by Milford and Minson (1966) and Minson (1971) found that the intake of grasses decline as plants age. The percent of PC of both tropical and temperate grasses is usually high at the vegetative stage of growth and decreases as the grasses mature, thus posing a major limitation to forage quality for grazing animals. The decline in PC is less significant in the leaf than in the stem.

In grasses, the percent of CP at plant maturity is determined by the differences in initial protein levels in the vegetative tissue, the rate and extent of decline and the final proportion of leaves and stem in the mature plants. However, the inherently lower PC of tropical grass C_4 plants means that CP decreases to lower levels at maturity than those found in mature temperate grasses, and the level in tropical grass falls even lower if the plants are water stressed (Lyttleton, 1973). On the other hand, the percent of CP in legumes declines slowly with maturation and is greatest in older leaves. The higher amounts of CP and the maintenance of soluble protein in the mature plants are associated with the continuous supply of nitrogen being fixed by rhizobium bacteria. The amount of available CP varies between different legume species, which reflects their effectiveness under different environmental conditions.

2.7. THE NUTRIENT CYCLE

The nutrient cycle can be defined as the uptake, utilisation, release and reutilisation of a nutrient by various processes in a plant's system (Till, 1981). This complex process involves many combinations of physical, chemical and biological processes. There are at least 16 chemical elements essential for growth. The bulk of a plant's DM is comprised from the products of photosynthesis, which uses C, H and O_2 from the air. As discussed in section 1.2, the minerals N, P, K, Ca, Mg and S are obtained from soil and known as macronutrients. All the essential nutrients are equally important for healthy plant growth. Micronutrients (Fe, Mn, Zn, Cu, B, Mo and Cl) are only required in very small amounts (White, 2006).

Good pasture management practice should include paying attention to the recycling of soil nutrients, in particular N, P, K and Ca, and of course water. It is crucial that the nutrient cycle functions efficiently and continuously to improve pasture production, livestock growth, soil health and water quality (Till, 1981). The inputs and outputs of the nutrient cycle are illustrated in Figure 2.9.

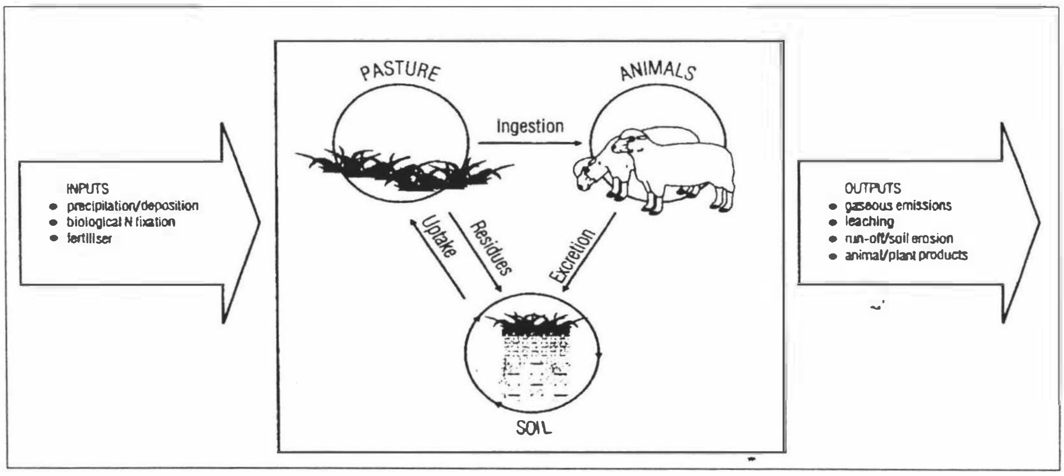

Figure 2.9. The soil nutrient pools and the nutrient cycle indicating the flow of nutrients in the grazing pasture system (Kemp *et al.*, 2002a).

Each pool of nutrient resources plays an important role in the growth and productivity of both pasture forage and livestock. These pools are limited by the environmental factors that control the productivity of pasture and the flow rates of nutrients. The main limitations to nutrient cycling in tropical pastures are poor management practices, lack of improved forage species, no fertiliser application, a slow rate of mineralisation and lack of rainfall. Therefore, some form of 'physical input' must be carried out to maintain the cycle such as planting legumes, fertilising the soil, practising rotational grazing systems and other techniques (Kemp *et al.*, 2002b).

Another factor that compromises the nutrient cycle is having a large amount of plants with a low NV per unit area of grazing pasture. The NV of tropical grasses is low in general, which is especially true in humid regions where rate of growth and lignification are high. In addition, NV of pastures decline as they become mature mainly due to unimproved pastures (Humphreys, 1987).

Climate is an important influence on the process of nutrient cycling. The tropical climate is mainly drying and the cycle depends on retaining soil moisture. Soil organisms, pasture plants and grazing livestock are also of importance as they continually cycle nutrients within the pasture system. Livestock remove very small portions of the minerals they ingest from forage, but most of it is excreted in dung and urine which will become part of water cycle again. In general, urine contains most of the N (60-70%) and K wastes and dung contains mostly P. Urea and K in the urine are soluble and therefore are readily available for the plant to use immediately.

This chapter has shown that legume species are of great importance for pasture productivity and health. They achieve this by enhancing and maintaining soil fertility, especially when inorganic fertilisers are not used. As discussed, a main reason for low productivity is the reliance on grass species alone which often results in soil infertility and hinders the nutrient cycle. Both OM and legume plants are responsible for providing and fixing N and converting it into an available form (nitrate or ammonia) for ready uptake. It is vital to understand that N can be lost from the soil through leaching, run off, erosion and by chemical (volatilisation) and biological (denitrification) processes (Brady and Weil, 2000).

2.7.1. WATER IN THE NUTRIENT CYCLE

Water is critical for pasture productivity. The water cycle is of paramount importance in the nutrient cycle because it facilitates numerous biological activities such as transporting nutrients and carrying energy (Packer, 2004). Soil nutrients dissolve in water, which moves them close to plants' roots. Inside the plants, water supports cell growth and photosynthesis; in the soil, water supports the growth and reproduction of all microorganisms. However, water also can degrade pastures through runoff, erosion and leaching, which causes nutrient loss and water pollution. Good pastures are able to absorb and use water more effectively for plant growth than poor pastures. Sound pasture management practices promote water absorption by maintaining forage cover over the entire soil surface and minimising soil compaction by animals or equipment.

The OM in soil absorbs water and nutrients, reduces compaction and increases soil porosity. Despite being easily compacted, clay soils absorb more water and nutrients than sandy soils, which leach water more easily and do not hold onto water and nutrients well (Bellows, 2001). Figure 2.10 shows how water is precipitated and recycled in the ecosystem/pasture system.

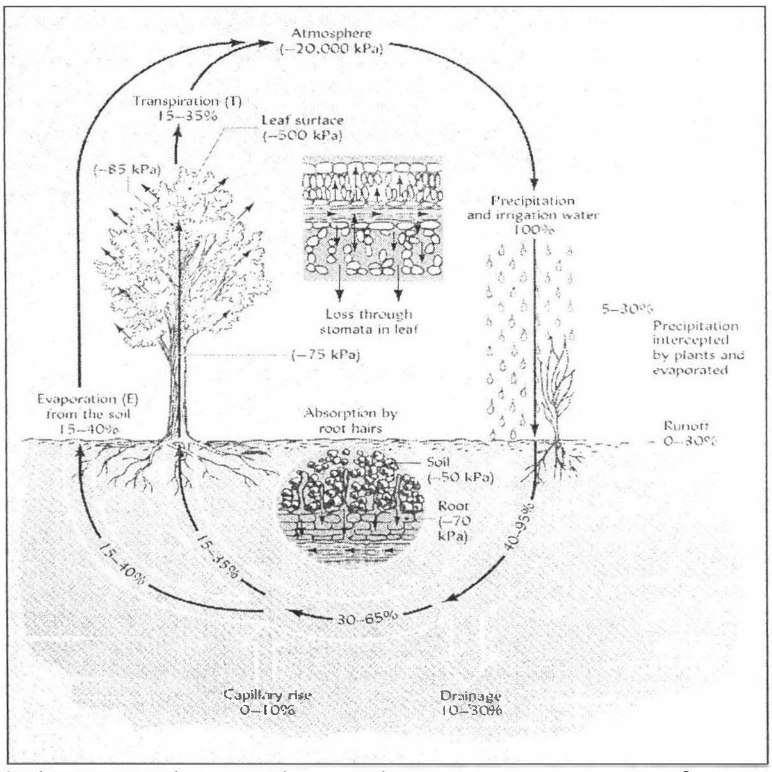

Figure 2.10. Soil-plant-atmosphere continuum, showing water movement from soil to plants to the atmosphere and back to the soil, in humid to sub-humid regions (Brady and Weil, 2000).

When soil is deprived of water, many problems concerning both livestock and pasture forage become apparent. Signs and symptoms of water stress include:

- plants exhibiting dehydration by becoming weak, less turgid and finally wilting

- insufficient process of photosynthesis
- plants' leaves changing colour, shape (rolling, curling) and fall off
- plant growth becoming slower/stunted and malformation of leaves, fruits and flowers
- inactivity of soil microorganisms due to a slowing of the mineralization process
- an increase in plants' fibrous content and a decrease in digestibility, leading to poor digestion in the grazing animal.

All living organisms in the soil need water for their chemical and biological activities and to aid the nutrient cycle within the pasture ecosystem. Nutrient balance and nutrient availability both determine the fate of nutrients in the system. Nutrients can be lost from the soil by runoff, leaching (Bellows, 2001) and livestock consumption, while animal-deposited manure returns nutrients to the soil. However, unless OM and fertiliser are applied to replenish nutrients, the continuous removal depletes soil fertility and slows the nutrient cycle (Vitousek *et al.*, 1979).

2.7.2. NUTRIENT AVAILABILITY AND MANAGEMENT PRACTICES

Chemical and biological interactions determine the availability of the nutrients that plants use for the nutrient cycle and management practices can affect these interactions. The type of soil organisms, nutrients in the OM, soil moisture and temperature determine the rate of the nutrient cycle and the amount of nutrient mineralisation released. While it is clear that nutrient depleted soils produce unhealthy growth, low yielding forages and unproductive forages, an excess of nutrients may contaminate wells, springs, rivers and streams and be dangerous for animal health (Vitousek *et al.*, 1979).

It is now apparent that human intervention has altered the ecosystem and the rate of the nutrient cycle. The key components of the pasture system can be controlled through expert management techniques to enhance the nutrient cycle at various levels (Vitousek *et al.*, 1979). In order to maintain the nutrient cycle, soil moisture must be of an appropriate level and the requirements for recycling C, N and P must be met. The nutrient cycle can be maintained consistently by practising the following management techniques:

- good pasture management should be practiced throughout the year. This includes maintaining a productive, high quality soil by cycling nutrients, increasing OM content, rotating grazing and ensuring that moisture and pH levels are within the optimum range
- maintaining ground cover to prevent the soil from drying and protect it from intense rainfall
- increase the use of legume species as companions to grasses to improve PC and soil fertility
- minimise soil compaction and disturbance of soil by minimising grazing during wet conditions
- till and cultivate the soil to promote the process of microbial mineralization
- avoid burning pasture and overgrazing by using suitable stocking rates
- plant a diversity of pasture species (grasses and legumes) with a variety of root systems that are capable of holding nutrients and water
- apply the correct type of fertiliser and manure on pasture at the right rate.

It is implicitly understood that these management practices will enhance the nutrient cycle in the pasture ecosystem. The collapse of key functioning components is marked by a low yield of DM, poor pasture growth, water pollution and infertile soil to name just a few. A sufficient period of rest enables plants to re-grow enough leaf area for photosynthesis, thus allowing both plants and soil organisms to rebuild soil nutrients through the mineralisation process (Vickery, 1981).

2.8. CONCLUSION

The geographical origin of individual plants species is very useful in identifying and comparing the differences between temperate and tropical pasture species, mainly their nutritive value and management techniques (Norton, 1981). The degree of lower performance of pastoral productivity may be blamed on the inextricable high temperatures of tropical regions. Soil and climates mainly promote plant growth and many other environmental resources affect the promotion of normal growth including soil nutrients, pH, wind, altitude and management factors (McKenzie *et al.*, 2002). Normally, severe droughts and water deficits are detrimental to pasture quality and lower the NV of grasses and animals' performance. In general, legume species have higher NV than grasses which are not influenced by environmental factors (Wilson, 1981).

Soils and its components play an important role in providing the mineral requirements for plants. In addition, the productivity of the pasture generally depends on management, particularly of soil pH (ideally pH should be 6.5 to 7.5); pH normally increases in continuously used pastures. The effects of regional variation in soil and soil fertility have indicated limitations do occur on pasture species. Reid and Harvath (1980) and McDowell (1985) stated that there is considerable evidence that mineral limitations or imbalances occurring in herbage limits animal productivity in both temperate and tropical environments.

Pastoral productivity can be improved by maintenance of soil fertility, inclusion of legume species together with grasses and proper pasture management, despite the fact that tropical pastures have lower NV than temperate pastures. Mannatje (1981) stated that the productivity of tropical pastures also depends on individual species which can adapt to tropical conditions. However, a high input of research resources directed towards the improvement of pasture is still required and will have even greater effects on pasture production.

Plant morphology, anatomy and chemistry are also considered important for pastoral productivity because of how they may influence the quality and quantity of forage available for grazing animals (Stobbs, 1973). These plant characteristics (e.g. erect growth and plant density) are blamed for the lower animal production on tropical pastures in comparison to temperate pastures. Leafy species are also considered desirable for improving forage quality and quantity, mainly because they produce more protein, minerals and DMD (Fang and Jones, 1924; Reid *et al.*, 1959).

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CHAPTER 3:

EFFECTS OF FEEDING AND ENVIRONMENT ON PERFORMANCE OF DAIRY CATTLE

3.1. ABSTRACT

Feeds and reproduction have had substantial effects on the productivity, health and production of ruminant animals and high feed quality and reliability of reproduction activities are required. Both feeds and environmental factors affect annual productivity and fertility. The effects of a hot environment have significant immediate and ongoing effects on animal reproduction and fertility, and farmers can use a range of management techniques to minimise these.

Pastures in tropical and temperate systems have different feeding values. In general, the tropical pastures have lower levels of productivity than temperate pastures. Therefore, levels of production and fertility are very much dependent on the influence of various factors, including climate, soil nutrients, pasture species, animal factors (genetics) and management factors. Deleterious pasture production and fertility effects can be alleviated through use of the high quality pasture species and skilful management. The used of improved cattle breeds and pasture species with appropriate management can add value to animal production.

This chapter initially outlines general principles involving feeding value, the various influences of environmental factors and reproductive efficiency dairy cattle. Each important principle is highlighted with explanations, definitions and the way they are being affected by environmental factors. These represent only the most important problems existing in our dairy farming system in Tonga. This paper also uses publications from temperate pastures to compare with tropical data and information. Similarities and differences are discussed together with evidence adapted from other sources to justify the main principles. This section is also aimed at promoting further research in this area in the future and to be a useful teaching resource.

Keywords: Feed; feeding value (FV); nutritional value (NV); digestibility; temperature; fertility; reproduction; tropical; heat stress; temperatures; season; energy; breed; cattle; reproduction; voluntary feed intake (VFI).

3.2. INTRODUCTION

Farming in Tonga is based on cattle feeding on pastures and forage all year round. The performance of cattle is mainly affected by the feeding and nutritional value of pastures and the availability of digestible supplementary feeds. Quality and availability are influenced by a range of factors, including plant species, maturity, climate (high temperatures) and seasonal variations.

Feeds and the nutritional value of feeds determine the animal production (e.g. milk) within our system (Tonga). Cattle do not meet their energy requirements from the dominant pasture species because of a lack of legume species. Animal production is a function of FV, defined as NV x intake (Waghorn and Clark, 2004). A high FV can only be attained during the wet season in Tonga (January-April); it then declines during the remaining season. The NV affects the animals' intake, and legumes have higher NV than grasses because they contain lower concentrations of fibre and higher concentrations of protein and readily fermentable components (e.g. sugar, organic acids) than grasses. The NV of forages is often indicated by the ME (metabolisable energy) content, however, animal production is influenced mainly by the efficiency with which the ME is used and the presence of toxins (Forbes, 1995; Lambert *et al*., 2004).

Tropical pasture species are well recognised as having a high potential for dry matter production (Humphreys, 1981). In general, animals and pastures in tropical conditions have consistently low levels of performance per animal and feeding value of the herbage on offer (Hardy *et al*., 1997; Sollenberger and Burns, 2001). Pasture management is central to feeding cattle generously and to maintaining forage quality (Clark and Kanneganti, 1998; Lambert *et al.*, 2004) because high feed availability (lax grazing) will maximise animals' performance (Holmes, 1987) but will usually lead to a future decrease in pasture quality.

The objective of this chapter is to present evidence about pasture feeding value and animal fertility relevant mainly to tropical climates (e.g. Tonga). Only certain aspects of ruminant feeds and fertility are outlined and discussed. The overall aim is to provide a basic understanding of the effects of environmental and other factors on both ruminant feeds and reproductive efficiency in cattle.

3.3. FEED INTAKE

Farmed animals are provided with a certain amount of daily feed either below their capacity (i.e. under-fed), or having free access to food supply (i.e. fed ad libitum) (Barry and McWilliam, 2005). Feed intake (FI) is one of the most limiting factors affecting dairy production in tropical conditions. Several factors affect DMI such as some dietary and environmental factors including:

- dry matter density (< 18% DM will depressed intake)
- energy density (excessive > 12 MJ per kg causing adicosis)
- forage digestibility and protein content in feed (less digestible)
- elevated temperatures (> 30°C) humidity and/or solar radiation dramatically (Holmes *et al.,* 1980; Lean, 1987).

The FI of different breeds shows different responses to the above factors. For example, the FI of temperate breeds (e.g. Holstein Friesian (HF)) declined at 23°C, while Brahman and Friesian cross-bred cattle maintained their level of FI (Colditz and Kellaway, 1972). Holmes *et al.* (1980) did observe a lower FI at 34°C than at 17°C. The effects of increasing ambient temperature (AT) are pronounced with FI and rumination ceasing at 40°C in *Bos taurus*. An increase in air temperature (TA) can depress both appetite and FI, consequently decreasing metabolic activities. Therefore the animals need to maintain their internal heat balance (Roy *et al.,* 1963; Johnson, 1967; Yousef *et al.,* 1968).

3.3.1. VOLUNTARY FEED INTAKE AND TEMPERATURE

The VFI is expressed as kg of fresh DM or dry feed/day/animal (Barry and McWilliam, 2005) and it is commonly related to *'metabolic live weight'* (i.e. $LW^{0.75}$, where metabolic weight is the body weight in kilograms to the power of 0.75 (Minson, 1981). The VFI of tropical cattle is generally depressed by elevated temperatures, solar radiation and relative humidity (RH), but increased when the AT is colder like in temperate countries (Holmes, 1979). Several factors affect VFI apart from live weight such as breed, sex, age, physiological state in relation to food factors such as bulkiness, taste and the presence of toxic compounds (Barry and McWilliam, 2005).

Barry and McWilliam (2005) have stated that VFI is the key determining factor for production efficiency and it depends on the cows' ability to eat as a major factor in determining the energy intake for high producing cows (Lean, 1987). However, body condition also determines VFI, for example extreme fatness can depress VFI up to 25%, and an even greater decline for very thin cows (Holmes and Minson, 1984; Lean, 1987). The rumen size, distension and flow rates are also influenced VFI. Feed intake during the early stage of lactation (8-20 weeks) is also depressed by temperatures of 25-27°C, with further decreases above 30°C (Holmes *et al.*, 2002).

The VFI of tropical grasses is generally limited at all stages of growth which is associated with increases of fibre content (Figure 3.1), lower DMD (%) and a larger quantity of indigestible fibre which takes longer time to digest in the reticulo-rumen (Minson, 1981). The difference between the fibre content and its distribution between tropical and temperate grasses is shown in Figure 3.1.

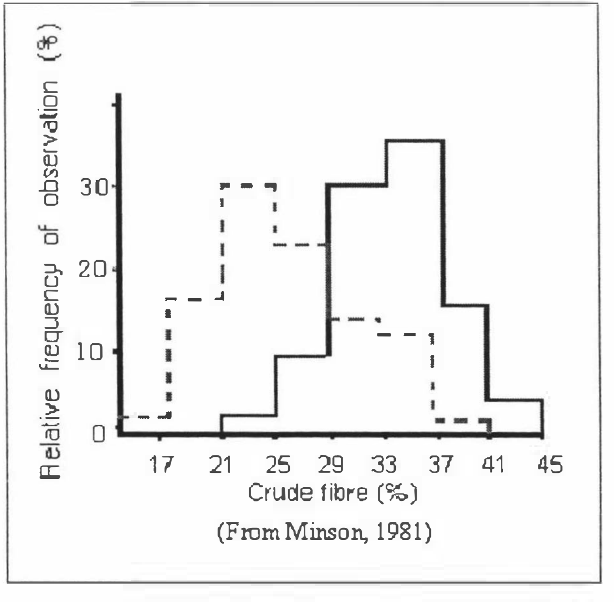

Figure 3.1. The frequency distribution of fibre contents in a wider range of tropical (—) and temperate (---) grasses cut at many stages of growth.

Mount (1979) mentioned that the reduction in FI is the first response by cows to hot conditions. Feed intake in HF cattle falls by 20% at 32°C, and rumination declines or ceases at 40°C. The cows might change their eating behaviour by eating smaller amounts more often at high temperatures (Holmes *et al.,* 1980). The decline of VFI that occurs near or above the upper critical temperature of animals is a major negative influence on productivity (Collier and Beede, 1985). The general principle of feed consumption relative to a range of constant environmental temperatures is shown in Figure 3.2. It indicates that a decrease in VFI occurs when the temperature rises above 25°C.

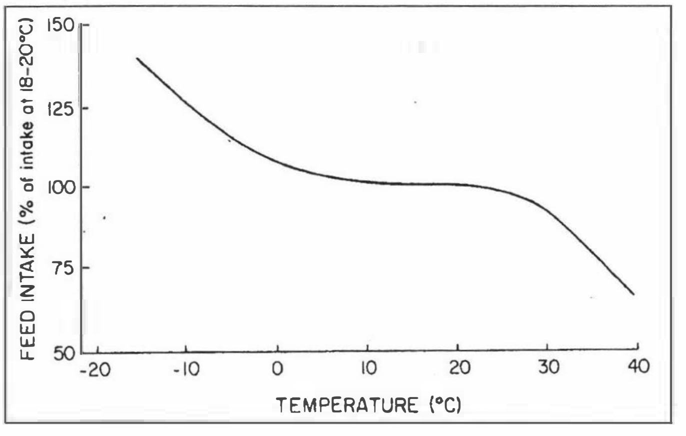

Figure 3.2. The effect of environmental temperature on feed consumption of cattle maintained in an environmental chamber (NRC, 1981).

Feed intakes were lower at 34°C than at 17°C in *B. taurus* breeds (HF), while *Bos indicus* (Brahman and Brahman x Friesian) continued to eat at the higher temperatures (Holmes *et al.,* 1980). In addition, *B. taurus* cease rumination activity at 40°C (Williamson and Payne, 1978). Grazing behaviour changes in hot temperatures during the day: cows spend less time grazing and more time in the shade to reduce heat production and gain. For example, the *B. taurus* breeds reduced their grazing time from 35% to 11% of their total grazing time when AT increased from 27-30°C (McDowell, 1972).

In tropical conditions, FI begins to decline when temperatures rise above 24-26°C for HF cattle, 26-29°C for Jerseys, above 29.5°C for Brown Swiss and 32-35°C for Brahmans. The side effects of decreasing FI are lower milk yield and growth (Mount, 1979). Generally, lower VFI is the major cause of low animal productivity in tropical regions. Tropical pastures generally do not meet cattle's nutritional requirements for their maximum production, due to lack of green feeds for almost half of the year, particularly the dry season and lower NV in the pastures even during the period of active pasture growth (Mannetje, 1982).

In contrast to temperate pastures, the primary factor that limits FI in tropical conditions is the low digestible nutrient concentration per kg DM in tropical forages; whereas in temperate pastures, FI is affected mainly by the amount of pasture made available to the cattle each day, which affects the rate at which they can harvest the pasture. The quantity of feed that a grazing animal can eat in 24 hours (kg DM/day) depends on:

1) rate of ingestion through the mouth and throat (harvesting)
2) rate of passage through the digestive system (digestion)
3) rate at which absorbed nutrients are utilised by tissue or demand (metabolism) (Holmes and Burke, 2006).

This written equation expresses the amount of pasture a cow can eat per day (g DM/24 hours):

Daily grazing time (minute of grazing/day)	x	Biting rate (Bite/min of grazing)	x	Bite size (g DM/grazing bite)	=	g DM eaten per day

3.3.2. MECHANISMS OF INTAKE CONTROL

In trying to satisfy the feed and energy requirements of tropical dairy cattle, it is crucial to understand what governs or regulates FI. This is because the production performance of animal grazing pastures is based on *animal* and *feed factors*. Ruminant production in tropical regions (e.g. Tonga) is largely dependent on unimproved pasture that contains inadequate energy and protein contents.

Many factors can influence VFI, which may be determined by cattle's dietary requirements or by feed constraints (e.g. bulk) (Barry and McWilliam, 2005). Generally, there are three important feed characteristics which are correlated with controlled FI, including *appetite, satiety* and *hunger* (Holmes, 1980). Appetite can be defined as the desire of an animal to eat; satiety as the lack of desire to eat; and hunger as a physiological state resulting from the deprivation of food, rectified by the ingestion of food. These factors influencing FI are controlled in the brain by the hypothalamus, including both hunger and satiety centres. The brain has a hunger centre (lateral hypothalamus) which normally initiates the feed requirement and signals the animal to eat until it is inhibited by the satiety centre (ventromedial hypothalamus) (Brookes *et al.,* 2003; Barry and McWilliam, 2005). The potential intake capacity and limiting factors which influence the actual FI by grazing cows are illustrated in Figure 3.3.

Factors which limit the intake to levels below the potential intakes.

Examples:
1) a full digestive tract from low digestive feed
2) inadequate supply or grazability of pasture (small average bite size)

Factors which drive the potential intake up higher level.

1) high genetic merit for milk yield
2) poor body condition

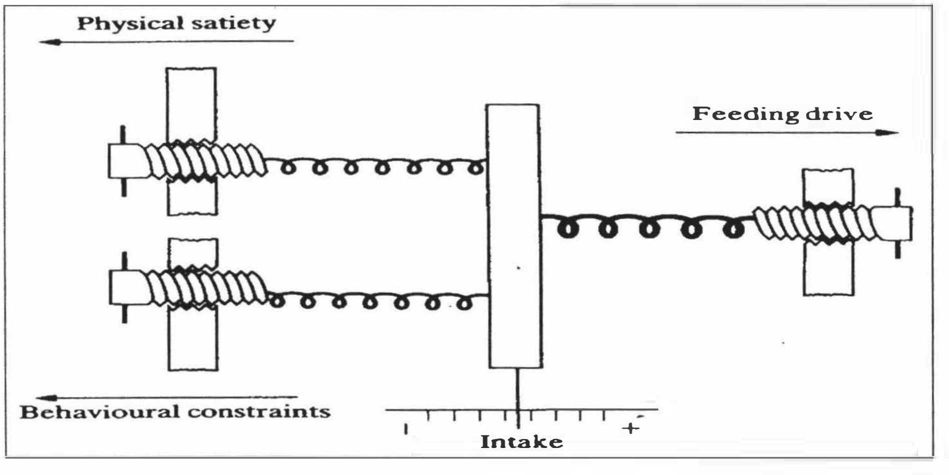

Figure 3.3. Factors that influence the actual feed intake of grazing cows (Hodgson, 1990).

According to Holmes (1980) there are similarities within these three groups of factors (appetite, satiety and hunger) which affect feed intake, including:

1) factors affecting the animals' appetite
2) factors influencing the ingestibility of the diet
3) the manner in which the food is presented to the animal.

3.3.3. FACTORS AFFECTING FEED INTAKE

Individual animals differ in their genetic make-up and metabolic states, therefore the potential feed demand is likely to vary within groups of similar animals. Therefore, the level of energy demand and feed intake may depend on factors such as live weight and body composition; the digestive system; lactation; pregnancy; activity and climate; and genetic factors.

3.3.3.1. Live weight and body composition

Larger animals (e.g. Friesian cows) generally have a higher energy demand than smaller animals (e.g. Jersey cows). The VFI increases with live weight in a curvilinear manner. Intake is generally expressed per unit live weight or $LW^{0.75}$, so this value is higher in young animals than older ones. Thin cows have been shown to consume more feed than fat cows of the same body weight. This is not only because of the desire to reach a particular level of body fatness, but also because excess internal fat may inhibit the fat cows' capacity to accommodate extra feed.

In comparing the relative intakes of different animal live weights (LW), intake can be expressed per unit of LW. For example, the FI of a dry, non-pregnant sheep would be:

2 kg DM/100 kg LW (2% of LW)

Thus, a 50 kg sheep would consume:

50 kg x 0.02 = 1.0 kg DM

A 60 kg sheep would consume:

60 kg x 0.02 = 1.2 kg DM

Therefore, the FI per unit LW is likely to be higher in younger animals because their energy requirements for growth, maintenance and reproduction are higher than older animals' requirements. Similarly, thin cows have been shown to consume more feed that fat cows of the same body weight. Holmes (1980) has stated that this factor is related to appetite. It is a change occurring in animals' physical state as a response to the change in climate, especially in growing animals. For example, a 100 kg calf may eat 2.9 kg DM/day, while a 600 kg finished steer can eat 11.6 kg DM per day (MAFF, 1975).

3.3.3.2. Capacity of the digestive system

Larger animals have larger digestive tracts and so can accommodate more feed. However, the capacity of the tract can be modified by:

- metabolic state e.g. digestive tract capacity is greater in lactating animals than dry animals of similar weight
- reduced abdominal cavity volume due to fat deposition or pregnancy, thus restricting the ability of the digestive tract to expand.

3.3.3.3. Lactation

Milking cows eat more feed than dry cows due to the increased demand imposed by lactation. Peak intake normally occurs somewhat later than peak milk yield and cows tend to loose body weight in early lactation in order to maintain nutrient supply to the udder. The maximum energy demanded for milk production occurs at peak milk yield, generally five to eight weeks after parturition (Figure 3.4), while VFI peak may occur later (Bines, 1979).

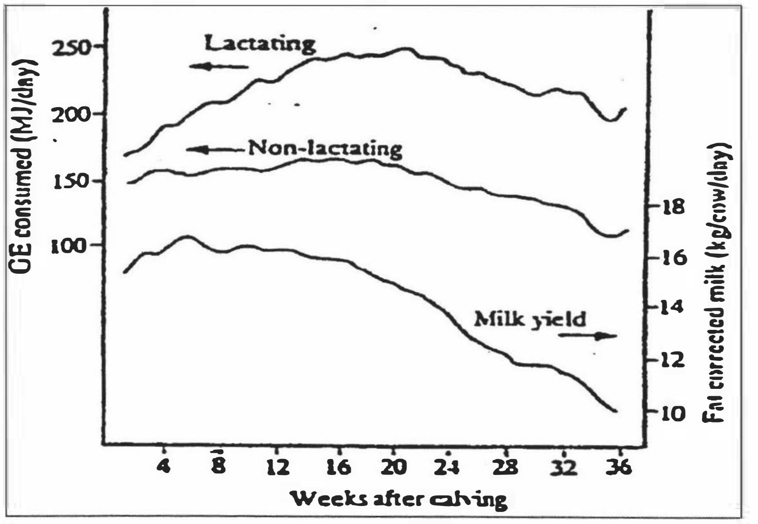

Figure 3.4. The intake of gross energy and changes in milk production in lactating and non-lactating cows (Hutton, 1963).

The reasons stated for the lag in intake are unclear, but may include:

- slow metabolic adaptation to increase nutrient demand
- time required for extension in the capacity of the digestive tract

- slow recovery from the effects of endocrine changes in late pregnancy (Brookes and Morel, 2003).

Under tropical conditions, FI declines due to heat stresses. These are attributable to the increase in heat production caused by intake of food, and the difficulties of heat dissipation under conditions of high temperature and humidity. For example, HF cows stop eating at temperatures greater than 40°C due to dehydration (Chamberlain, 1989).

3.3.3.4. Pregnancy

Energy demand is increased as pregnancy progresses and the growing foetus has increasing nutrient requirements. However, FI decreases in late pregnancy, mainly in the last few days of pregnancy (Reid and Hinks, 1962; Holmes *et al.*, 2002). The possible reasons for this decline may include:

- compression of the rumen by the growing foetus
- the effects of increasing oestrogen secretion
- discomfort and preoccupation with seeking a suitable birth site.

In a tropical environment, FI during pregnancy requires extra demands for energy but this maybe restricted by hormonal changes as a result of the effects of heat stress if cattle are exposed to hot conditions (Holmes, 1979).

3.3.3.5. Activity and climate

Activity affects energy requirements, e.g. cows walking longer distances have increased energy demands; and grazing animals will require more feed than housed ones (Holmes *et al.*, 2002; Brookes *et al.*, 2003). Heat is produced during metabolism and so FI tends to increase in cold conditions and decrease at high temperatures (see Figures 2.3 and 2.14). The combined effects of high AT and relative humidity (RH) (71-81°F) result in a declining milk yield, FI (25-30°C) and water intake of tropical cattle (Johnson *et al.*, 1963). The elevation of AT is an emotional factor, which signals to the hypothalamus and central nervous system to alter FI, hormonal functions and heat production.

3.3.3.6. Genetic factors

Animals with higher genetic potential and ability for production are likely to have a higher FI and greater digestible feed conversion efficiency (FCE) when compared to animals that have a lower genetic potential for production (Hodgson, 1990). Individual breeds have different VFI due to the variation in terms of size, age, physiological state and favoured temperatures (Holmes *et al.*, 2002). High producing breeds have higher VFI than lower producing breeds (e.g. Holstein Friesian cattle have higher VFI than Jersey cattle).

3.3.4. PHYSICAL FACTORS OF FEEDS

When feed contains a low concentration of energy in the DM, the animal eats more units of DM to meet its energy demand. The bulky nature of the feed is a limiting factor for FI (Minson, 1981). In general, the effectiveness of eating to reduce feed particle size is greater for leaves than for stems, for legumes than for grasses and for fresh forage than for hay (Black, 1990). Leaves are eaten in larger quantities than stem due to the shorter time that the leaf is retained in the reticulo-rumen. This shorter retention time is associated with a larger surface area, lower grinding energy and lower density (Minson, 1981).

One method of reducing bulk is to chop the feed into smaller sized particles that take up less space (Figure 3.5). By doing this the feed may pass through the rumen more rapidly leading to increased intake for both tropical and temperate grasses (Minson, 1981). The following photograph shows the volume occupied by 1 kg DM of:

A)	Fresh pasture	20% DM
B)	Lucerne hay	85% DM
C)	Chopped lucern chaff	85% DM
D)	Concentrate meal	85% DM

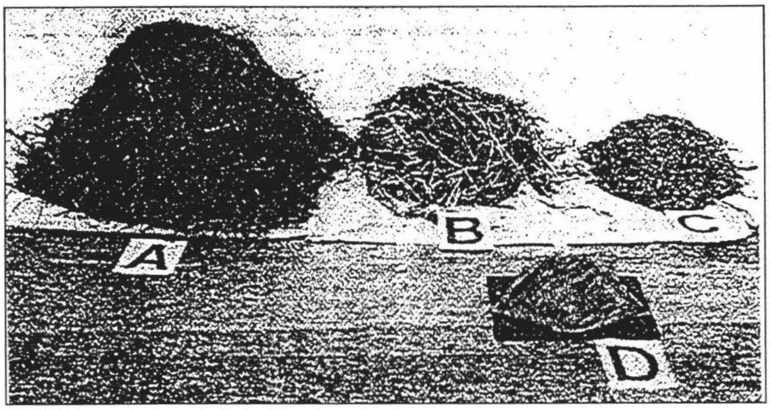

Figure 3.5. The various particle sizes of feed (grasses) ready for consumption (Brookes *et al.*, 2003).

In order to increase FI of low quality diets, the bulkier feeds should be ground or pelleted. The difference between leaves and stems is not restricted to tropical grasses, but also found within temperate grasses, although the difference is smaller. Ruminants in tropical conditions consume lower quality feeds (roughages) just to satisfy their nutrient requirements, but their FI is restricted by physical factors of the feed (Holmes *et al.*, 2002; Brookes and Morel, 2003). Their VFI is determined by the high proportion of indigestible residues in tropical forages, the size of rumen-reticulum and the transit time of the food residues from the rumen (Balch and Cambling, 1969; Holmes, 1980).

3.3.4.1. Seasonal factors

Dairy cattle can change their feed intake to meet their mineral requirements when seasonal changes occur. In tropical situations, the major factor reducing forage intake is the low protein content and the high degree of lignifications in most forages; these also reduce the total minerals consumed (McDowell, 1985). Since tropical forages contain low concentration of minerals during the dry seasons, consequently most cattle are likely to suffer from mineral inadequacies during these times.

In the wet season the pasture growth rate increases and mineral requirements are also higher. The general response of cattle FI and digestibility in most sub-tropical and temperate regions is expected to be highest in spring, then fall in mid-late summer, and increase in autumn and decrease again in winter (Hacker and Minson, 1972; Strickland, 1973; Laglands and Holmes, 1978).

3.4. FEEDING VALUE AND NUTRITIONAL VALUE OF PASTURE GRASSES

Feeding and nutritional value of the feed represents the level of production obtained per unit of food consumed and is a function of:

- apparent digestibility
- utilisation of digested nutrients (Brookes and Morel, 2003).

The FV and NV measure the availability of nutrients in the diet (grasses and legumes) that are required by the animal (Waghorn and Clark, 2004). The following are the nutrients representing the FV and NV of the diets: N often expressed as CP (nitrogen concentration x 6.25); lipids; fat-soluble vitamins; *macro-elements* including Na, Ca, K, P, S, Mg and Cl; the *micro-elements* including Cu, Co, Se, I, Fe, Zn and Mn; and energy (ME). The ME in feed is derived from microbial digestion, intestinal digestion and absorption. This is an essential component of the NV of feed which is commonly used as indicator of forage NV in New Zealand farm systems.

3.4.1. FEEDING VALUE OF GRAZING FORAGES

The FV of a feed refers to its capacity to promote production and depends upon its ability to supply nutrients to the animals. Minson and Wilson (1980) stated three main elements of FV of a feed:

- the amount of forage that animals will eat (voluntary intake)
- the content of nutrients in the forage (nutrient contents)
- the ability of the animals to absorb and utilise the nutrients.

The level of animal production (e.g. meat, milk yield, wool and growth rates) expresses the degree of nutrients concentrated in a particular feed stuff which is used to define the FV, i.e. the animal production as response to a specific feed (Holmes, 1980; Brookes and Morel, 2003).

Feeding value is not a feed characteristic, but it depends on a complex three-way interaction between the ruminant animal, its feed and the microbial population in the rumen (Minson and Wilson, 1980). The extraction of nutrients from the diet depends on the ability of the digestive process and microbes. However, the FV between forage species (e.g. legumes is higher than grasses) and their combined effects will be reflected in live weight gain and performance of livestock. Table 3.1 illustrates the differences in FV between grasses and legumes for sheep live weight gain in New Zealand.

The FV is different between plant species, for example legumes have superior NV than grasses in terms of their digestibility and nutrient concentration for the following reasons:

- rapid breakdown in the rumen, causing faster outflows and higher FI
- increased flow of undegraded dietary protein to small intestine
- more efficient utilisation of ME, perhaps due to different patterns of volatile fatty acids (VFA) produced during rumen fermentation and greater protein absorption/unit of energy.

Table 3.1. The comparative live weight gains of sheep grazing some pasture species grown in New Zealand (all values relative to Ruanui perennial ryegrass = 100) (Ulyatt, 1981).

	Comparative Feeding Value
Grasses:	
Perennial ryegrass	100-111
Hybrid ryegrass	148
Itakian ryegrass	160
Timothy	129
Browntop	83-100
Legumes:	
White clover	192
Lucerne	157
Red clover	124-136
Lotus pedunculatus	162

The FV of the tropical grasses is consistently lower than that of temperate plants and varies between 17.2 and 18.4 KJ/g DM (Minson and Milford, 1966), while temperate pastures have 18 and 19.1 KJ/g of DM (Hutton, 1961; Holmes *et al.,* 2002). The variation in the gross energy content of grasses is usually associated with differences in the proportion of protein or ash in the feeds.

The ME is higher (11-12 MJ/kg ME) when forage is younger and highly digestible (75-80%) but falls to very low values (< 1% N) when grasses progress to maturation (Norton, 1982; Hardison, 1996). This high NV in forage expressing a lower NDF (30-35% DM) content occurs during spring and autumn grazing in New Zealand (Norton, 1982; Hardison, 1996). The ME value of tropical grasses ranges from 7-11.0 MJ/kg DM when grazed between two to eight weeks of growth. The PC of tropical pastures decrease rapidly as growth progresses. The higher NV of temperate pastures in New Zealand is due to having mixed grass-legume (e.g. perennial ryegrass and white clover).

3.4.2. CHANGES IN NUTRITIONAL VALUE WITH SEASONAL CHANGES

The nutritional quality of the forage species normally change when seasons change during the year (e.g. temperate pastures in New Zealand). The FV of mixed pasture sward depends upon the varying proportion of different pasture species and various stages of maturity at any particular time (Holmes *et al.,* 2002). Grasses grow well during the spring and autumn, whereas legumes grow best in the late spring and summer period. There are also changes in both digestibility and nutrient concentrations for New Zealand dairy pastures (Holmes *et al.,* 2002).

The highest feed quality occurs in the cooler early spring and autumn months, but become lower with increases in reproductive growth in late spring and early summer (Holmes *et al.,* 2002) (Figure 3.6). The main factors limiting pasture growth were temperature in winter and moisture in summer. The Northland area receives its lowest pastures growth during the dry summer.

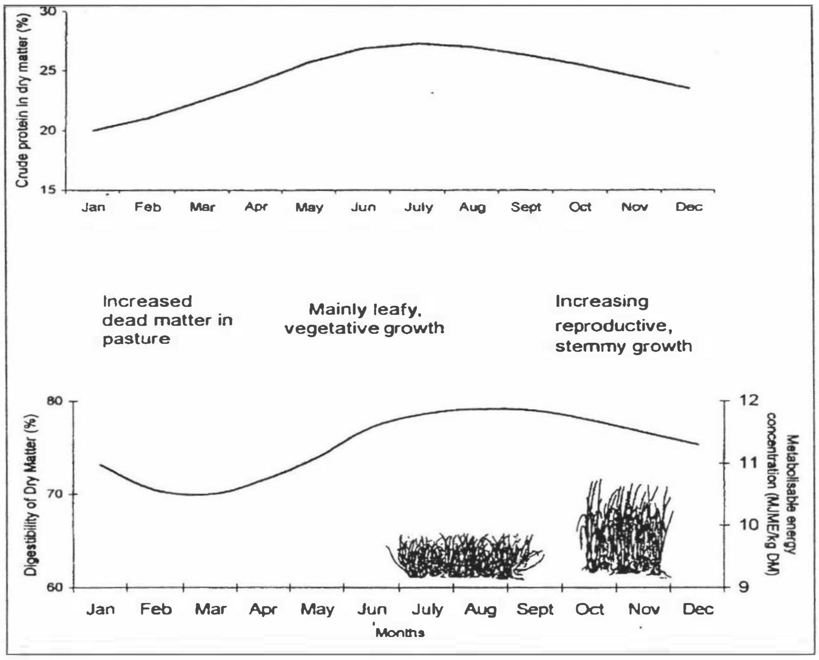

Figure 3.6. Seasonal changes in the feeding value of well-managed ryegrass/clover pastures in New Zealand (Holmes *et al.*, 2002).

The ME concentration in forage is highest at the early stage of pasture growth (11-12 MJ/kg DM) and digestibility is as high as 75-80%. This high digestibility is associated with the low NDF (30-35% DM) content of pasture during the spring and autumn grazing (Hodgson and Brookes, 2002).

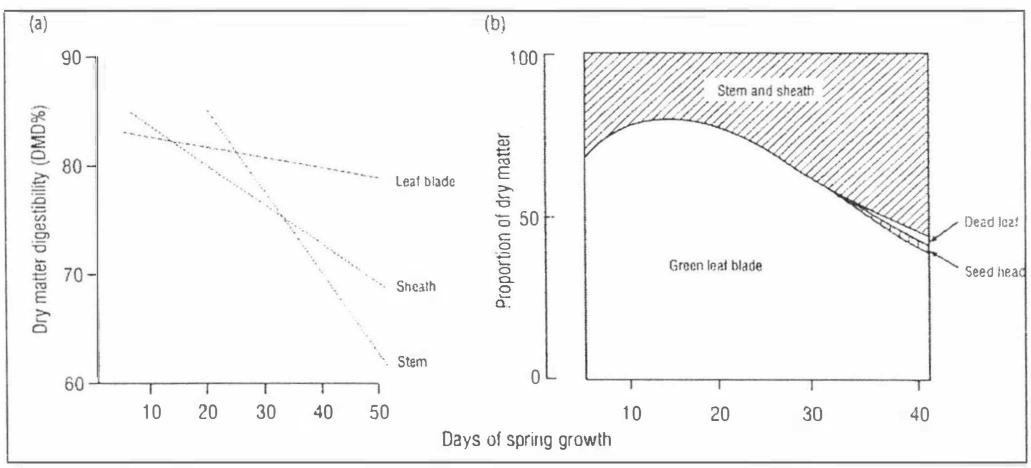

Figure 3.7. (a) Changes in digestibility of leaf blade, leaf sheath and flowering stem of perennial ryegrass; **(b)** changes in the relative proportions of these components in the sward, with increasing maturity during growth in spring (Hodgson, 1990).

The changes in forage ages are associated with progressive declines in the concentration of N and soluble CHO in plant tissue. So, as the plant matures, both the fibre content and lignification of the plant cells increase with the development of flowering stems. Therefore the proportion of readily digestible cell content declines (Figure 3.7) while the content of cell walls increases. There is a substantial reduction in herbage NV as the plant matures. Hodgson and Brookes (2000) determined that the proportion of dead material in the sward can easily reach 50% of the DM in summer.

3.4.3. DRY MATTER DIGESTIBILITY

The digestibility of the DM eaten is a measure of the NV of a feed given to animals. It is one of the most important factors affecting intake. Although apparent digestibility measures only the differences between FI and faeces output, it is an important component of NV (Minson, 1971 cited by Ulyatt, 1973; Ulyatt, 1981b). There is a positive relationship between digestibility of herbage DM and level of VI (Figure 3.8). Even though digestibility is generally highly correlated with intake for herbage, particularly below 70% digestibility, this relationship doesn't always hold, particularly when the herbage availability is limited (Minson, 1971 cited by Ulyatt, 1973; Poppi *et al.*, 1987).

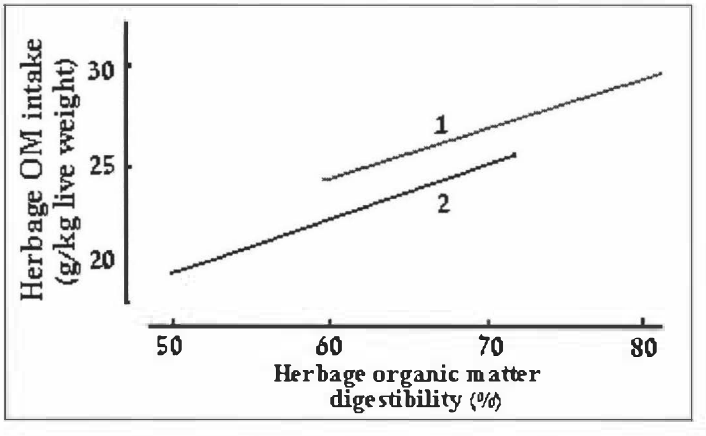

Figure 3.8. The relationship between the digestibility of grazed herbage and the amount eaten (Hodgson, 1990).

Minson and Milford (1966) have stated that the DMD of tropical grasses is lower and ranged from 30-75% with mean of 54%, compared to temperate pastures that ranged from 45-80% DMD (Minson and McLeod, 1970) (Figure 3.9). The lower digestibility of tropical grasses is associated with the higher temperatures at which they are grown and anatomical structures associated with different photosynthetic pathways (Laetsch, 1974).

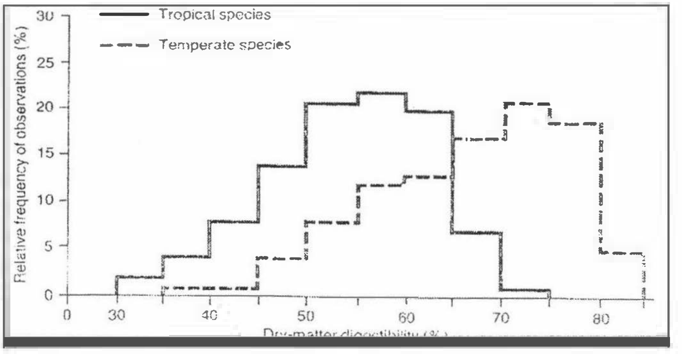

Figure 3.9. The frequency distribution of digestibility for 543 cuts of tropical grasses and 592 cuts of temperate grasses (Minson and McLeod, 1970).

Tropical grasses generally contain more fibre than temperate species, so a lower DMD is expected. Even if grown under irrigation or in very fertile soil, its DMD rarely exceeds 65%, due to having more lignin (Minson and Wilson, 1980).

The apparent digestibility coefficient (%) of the feed is defined as:

$$\frac{\text{The digestible portion of the feed}}{\text{Total amount of feed eaten}} \times \frac{100}{1} \quad \text{OR} = \frac{\text{DM consumed - DM defecated}}{\text{DM consumed}} \times 100$$

(Holmes, 1980).

The difference between the amounts consumed that are absorbed into the body is termed the coefficient of DMD. The values for forage vary between 50% and 80% and are usually expressed as decimals i.e. 0.5 (50%) and 0.8 (80%) (Holmes, 1980).

Similar coefficients of digestibility are used to determine the organic matter digestibility (OMD) (i.e. cell walls, cell contents, or CP of the DM consumed). There is also a D-value (digestible organic matter in the dry matter (DOMD)) which is usually lower than OMD, but it depends on the ash or mineral content of the consumed herbage. This is used particularly for forage feed like silage that is often contaminated with minerals from the soil (Holmes, 1980). Figure 3.10, clearly shows the relationships between the major measures of digestibility, DMD, OMD and D-value.

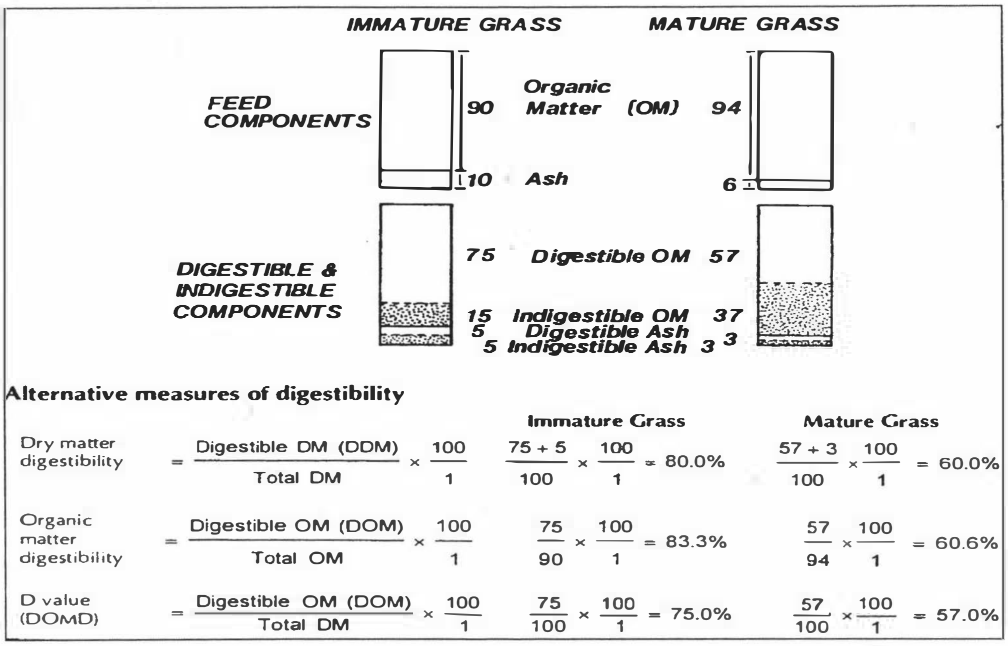

Figure 3.10. The relationship between digestible and indigestible constituents of grass at two stages of growth (as percentage of dry matter) (Holmes *et al.*, 2002).

The level of digestibility is useful in predicting NV of grazing pasture and the livestock products. It expresses the amount of the DMI used by the animal for its own nutritional requirements (Andrew *et al.,* 1998). For example, if the digestibility of a pasture is said to be 70%, that means 70% of the consumed DM basis is digested, absorbed and used by the animal for its own nutritional requirements, while 30% is passed as faeces (Figure 3.11).

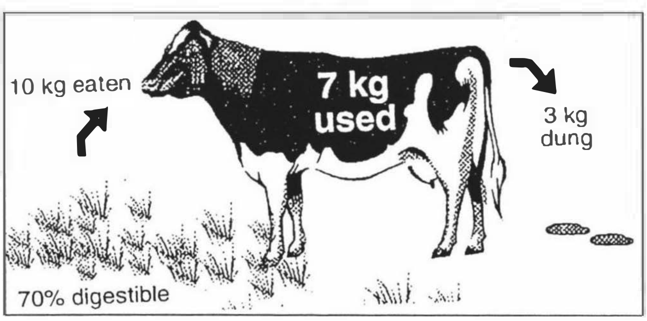

Figure 3.11. Digestibility is a measure of the amount of pasture used by the animal (Andrew *et al.*, 1998).

Therefore, digestibility is a useful measurement of the forage quality due to several reasons (Andrew e*t al.*, 1998).

It is directly related to the usable energy content of the pasture, assessed as MJ metabolisable energy per kg of DM. The approximate energy (MJ ME) value corresponding to various levels of expected digestibility are shown in Table 3.2.

Table 3.2. The megajoules of metabolisable energy per kg dry matter (Andrew *et al.*, 1998).

Digestibility (%)	Energy content (MJ ME/kg DM)
40	4.8
50	5.7
60	8.2
70	9.9
80	11.6

Digestibility is positively related to the protein content (PC), i.e. when digestibility is high the PC is also high. In addition, the PC varies between different species (e.g. it is generally higher in legumes than in grasses) (Figure 3.12).

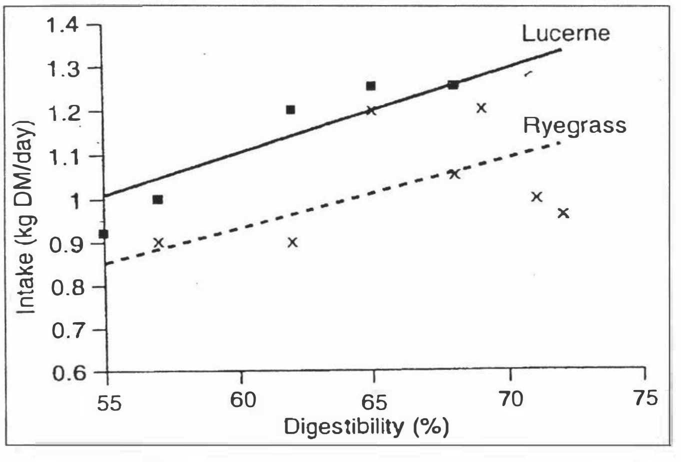

Figure 3.12. The intake of legumes is higher than the grasses at the same digestibility (Greenhalgh, 1979).

Digestibility is directly related to the speed of digestion and therefore the rate of movement of feed through the animal (e.g. young forages and legumes).

3.4.4. ENERGY AND NUTRIENT REQUIREMENTS

The energy value of feed is measured by the number of megajoules of ME available in one kilogram of dry feed (100% DM). Metabolisable energy is the amount of energy in a feed which animals can use to meet their own requirements (Andrew *et* *al*., 1998). Figure 3.13 shows the partition of food energy during digestion and metabolism including energy losses.

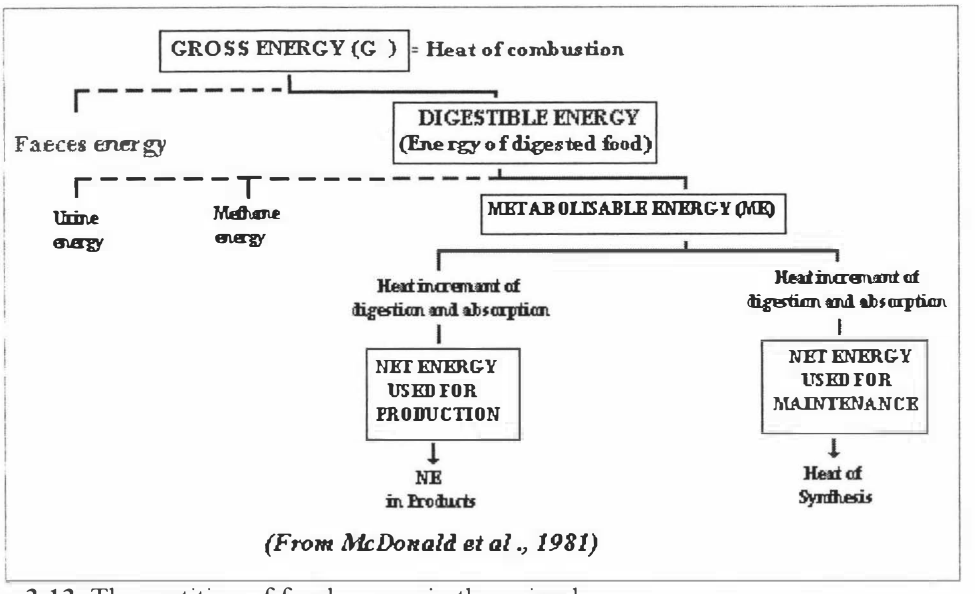

Figure 3.13. The partition of food energy in the animal.

The definition and explanation of each of the energy categories are described in the following paragraphs.

1) Gross Energy (GE): the total quantity of chemical energy contained in feeds (eaten) and animal tissues. The GE concentration for the main feed constituents is: Lipid 39 MJ/kg DM; Protein 24 MJ/kg DM; CHO 16 MJ/kg DM. Most feeds consist predominantly of CHO some protein are approximately 18.4 MJ/kg DM.

2) Digestible Energy (DE): DE = GE - faecal energy output. Undigested feed components that contain some energy and are lost in faeces (GE), minus the energy in faeces, represents apparently digestible energy. The apparent DE% can be calculated as:

$$\frac{\text{Feed energy consumed (g/d)} - \text{feed energy excreted in faeces (g/d)}}{\text{Feed Energy Consumed (g/d)}} \times \frac{100}{1}$$

(The DE value is termed "*apparent*" because some of the faecal matter is of body rather than dietary origin and gases produced during microbial fermentation (methane and hydrogen) have not been taken into account.)

3) Metabolisable Energy (ME): ME = DE - (urine energy + methane energy). Further loss of energy (from DE) occurs in the urine (in urea) and energy in the fermentation gas mainly in the form of CH_4. Metabolisable energy is the energy that reaches animal tissues in the form of absorbed nutrients from the digestive tract (Hodgson and Brookes, 2002; Holmes *et al.,* 2002). Metabolisable energy is used for the process of maintenance and for synthesis of products (milk).

Maintenance: Metabolisable energy is needed for vital processes of circulation, excretion, respiration and muscular activity and for living cells. Maintenance is considered the state in which the animal is neither gaining nor losing live weight (Hodgson and Brookes, 2002). For example: the estimated ME required for maintenance is 0.55 MJ per $kg^{0.75}$ per day; a ME requirement for a 500 kg cow is 0.55 x $500^{0.75}$ = 0.55 x 105.7 = 58.2 MJ ME per day.

4) Net Energy (NE): NE = ME - heat increment (HI) or heat loss. (Heat increment is all heat energy that is lost during some reaction such as mastication, propulsion of feed in the digestive tract, metabolism of nutrients by micro-organisms). However, the energy remaining after HI has been subtracted is termed net energy (NE). Net energy is used by the body tissues for maintenance and production (Holmes *et al.,* 2002; Brookes *et al.*, 2003).

The efficiency with which ME is used to produce NE is termed the K value:

$$K = \frac{NE}{ME}$$

3.5. ENVIRONMENTAL EFFECTS ON ANIMAL PRODUCTIVITY

Dairy cattle are of great importance in providing meat and producing milk in Tonga. However, they were mainly developed in cold climates, so are predominantly cold-tolerant. Cattle can only sweat to a certain degree in hot conditions in order to maximise evaporative heat loss through sweating and the respiratory tract (Mount, 1979). They also have high rates of water turnover because they are highly sensitive to lack of water. However, different breeds of cattle have distinct differences with regard to adaptation to high temperatures (Mount, 1979). Basically, when food is digested its energy is converted into heat as a result of metabolic process, digestion and absorption. Therefore the intake of food is associated with production of heat in the body. When animals get cold, their intake increases as they are forced to produce heat to cope with coldness by having shivering or non-shivering thermogenesis. The additional heat produced is used to substitute the heat used in shivering and extra energy will be used as a fuel for the metabolic process of thermoregulatory heat production.

On the other hand, under hot conditions animals will find it difficult to dissipate heat. If they eat more, more heat is produced and consequently they are more stressed, with an increased rectal temperature and respiration rate (Robinson and Lee, 1947). Animals exposed to hot conditions tend to decrease their FI in order to reduce heat production during metabolic processes, consequently body temperature can be maintained within the zone of thermoregulatory. Figure 3.14 illustrates the corresponding pig FI to air temperatures. The data in this graph show FI declining as TA is increasing; and the rate of intake declines faster when TA is greater than 25°C to 30°C. Rectal temperatures and respiration rate also increase rapidly after AT is over 25°C (Hamilton, 1976).

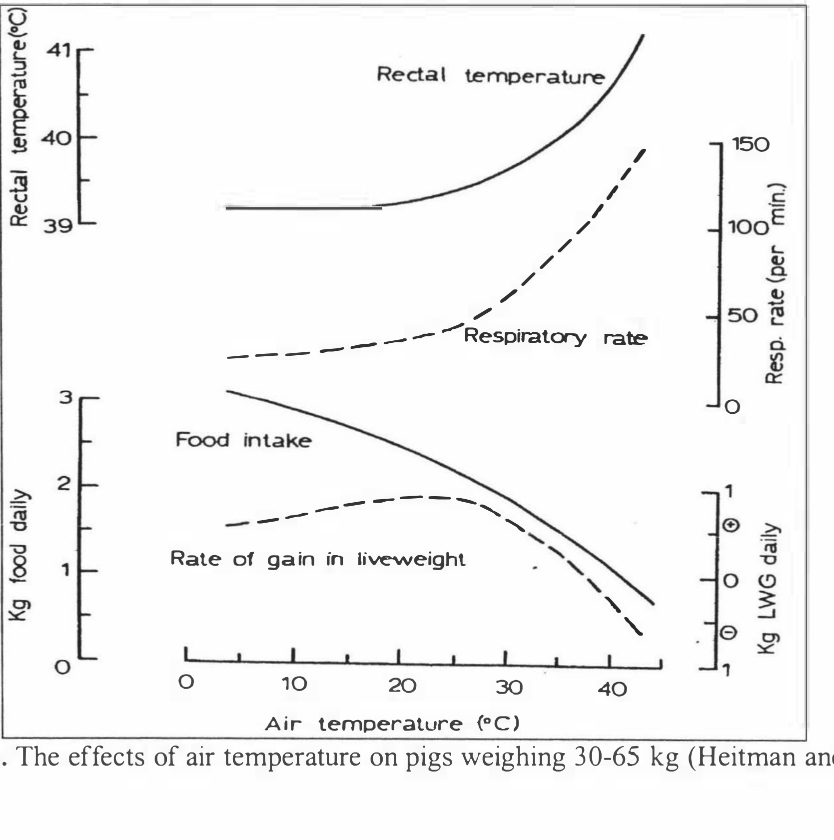

Figure 3.14. The effects of air temperature on pigs weighing 30-65 kg (Heitman and Hughes, 1959).

However, some recently reported data suggests that FI showed no further increase once the temperature decreased below 25°C (Holmes, 1979). Nevertheless, McDonald and Bell (1958a) found that the quantity of food eaten by lactating cows was increased by 0.1 kg of food for each degree Celsius decrease in average TA in the range 5°C to -16°C. Furthermore, Kellaway and Colditz (1975) reported that the FI of young cattle increased consistently as temperature decreased from 38°C to 30°C to 20°C.

3.5.1. DAIRY BREEDS AND MILK PRODUCTION

There are hundreds of different breeds of cattle in the world but only some are classified as '*dairy*' breeds (e.g. Jersey, Holstein, Friesian, Ayrshire) because they were genetically selected mainly for dairy characteristics over the last 200 years (Holmes *et al.*, 2002). Dairy breeds are different in size, coat-colour, appearance, milk yields and milk composition. Each breed made considerable genetic improvements regarding yields of fat, protein and milk. Today, the differences between the dairy breeds are relatively small on average, except for milk volume (see Table 3.3).

Table 3.3. Average yields of milk fat and protein; concentrations of fat and protein; and live weights of four dairy cattle breed groups in New Zealand (NZ Dairy Statistics, 1999/2000; Livestock Improvement; Holmes *et al.*, 2002).

Breed group	Yields			Concentration (%)		Live weight (kg)
	Milk	Fat	Protein	Fat	Protein	
Jersey	2,791	161	113	5.77	4.06	355
HF	3,803	166	131	4.39	3.46	450
J x HF	3,445	170	127	4.96	3.71	420
Ayrshire	3,452	151	122	4.39	3.55	417

Crossing any of the three main breeds could produce slightly larger gains in yield (production) and live weight. For example, crossbred J x HF cows produce 279 kg milksolids (MS) per cow, which is more than the average of the two purebreds (285 kg MS/cow). This 'extra' 12 kg MJ represents the effects of hybrid vigour or hetrosis. In general, cattle are categorised into two breed varieties: *B. taurus,* including European breeds and *B. indicus*, the Indian and tropical breeds (Swan and Broster, 1976; Mount, 1979; Webster, 1987).

3.5.2. TEMPERATE BREEDS, CLIMATE AND MILK PRODUCTION

The *B. taurus* breeds can tolerate very cold conditions and include Friesian and HF (the main breeds in New Zealand, comprising about 58% of all dairy cows in New Zealand), Jersey (16% of NZ cows) and crossbred HF x J (19%) (Table 3.4).

Table 3.4. The breed composition of the New Zealand dairy herd from 1921 to 1999 (each breed as a percentage of the whole herd) (Holmes *et al.*, 2003).

Breeds	1921	1949	1962	1979	1999
Ayrshire					1
HF	11	12	12	36	57
HF x J				28	19
Jersey	30	86	81	36	16
Shorthorn	50	5	3		

HF cows have rapidly increased in numbers in New Zealand since the 1970s, although there is no real evidence to show that HF cows are more productive or profitable in New Zealand (Holmes *et al.*, 2002).

The thermal neutrality temperature of HF ranges between -20°C and 25°C and they begin to show signs of heat stress above 25°C. When the TA exceeds 25°C to 40°C they will be unable to dissipate heat or maintain homeothermy. Furthermore, *B. taurus* shows decreases in milk yield below -5°C (Webster, 1987). The levels of heat and cold tolerance for temperate and tropical cattle are indicated in Table 3.5.

Table 3.5. Heat and cold tolerance of temperate and tropical cattle acclimatised as appropriate to hot or cold conditions (adapted from Webster, 1987).

	Temperate (*B. taurus*)		Tropical (*B. indicus*)
	Friesian	Hereford	
Heat production (thermoneutral, KJ/kg$^{0.75}$/d)			
- maintenance	500	450	400
- peak lactation	900	700	620
LCT (°C)			
- maintenance	-15	-15	+10
- peak lactation	-30	-25	-5
Limit of optimal productivity (°C)			
- lower	-5	-10	+10
- upper	+25	+20	+32

In looking at this table, the lower critical temperature (LCT: the air temperature below which food is oxidised to produce extra heat to maintain body temperature) for temperate breeds is -15°C and +10°C for tropical breeds. Conversely their temperature level for optimal productivity is different (e.g. by 7-12°C in their upper critical temperature (UCT)). McDonald and Bell (1958) found that the milk yields of HF drops at -5°C in a curvilinear fashion. Their FI, appetite and milk yield start decline above 25°C, even if energy intake is controlled (Johnson *et al.*, 1962).

Maximum performance of *B. taurus* breeds occur between -5-25°C compared to 10-32°C in tropical breeds (see Table 3.5). Holstein Friesian cows raised in Tonga normally produce 7-14 L of milk per cow per day at various temperatures throughout the year (Fisiihoi, 2006). European breeds normally produce at least 12 L/cow/day during April to May and 18-24 L/cow/day during August to October in New Zealand dairy farm systems (Holmes *et al.*, 2002). European breeds are more sensitive to heat than tropical cattle and the HF fails to produce more than tropical cattle in the tropics due to other factors including diseases, insufficient feed supply, poor husbandry management and quality of feed being too low to sustain high yields (Webster, 1987). For lactating cows exposed to cold stress, their lactation will be depressed by the following mechanisms:

- energy is channelled to increase heat production due to increased heat losses caused by the cold environment
- there is a reduction in blood flow to the milk gland
- milk production is directly affected when the udder is exposed to cold wind (Holmes, 1971).

3.5.3. TROPICAL BREEDS, CLIMATE AND MILK PRODUCTION

Bos indicus breeds (e.g. Brahman, Sahiwal, Jersey and Guernsey) originated and thrive at higher environmental temperatures ranging from 10-32°C. They have a genetic tolerance for hot conditions and they can cope with temperatures between their LCT and UCT. *Bos indicus* breeds have lower levels of milk production and FI, but these levels do not fall off as rapidly as temperate breeds in hotter conditions (Mount, 1979).

Heat stress markedly reduces milk yield, particularly in mid lactation (Figure 3.15), and the yield can be reduced by 1 kg for each degree Celsius increase above UCT

(Mount, 1979). Generally, *B. indicus* cows have lower milk yields than European breeds, but when the environmental temperature increases, it does not affect yield produced by Brahman cattle until it reaches 35°C, whereas milk yield by European cattle falls off at 27°C (Mount, 1979).

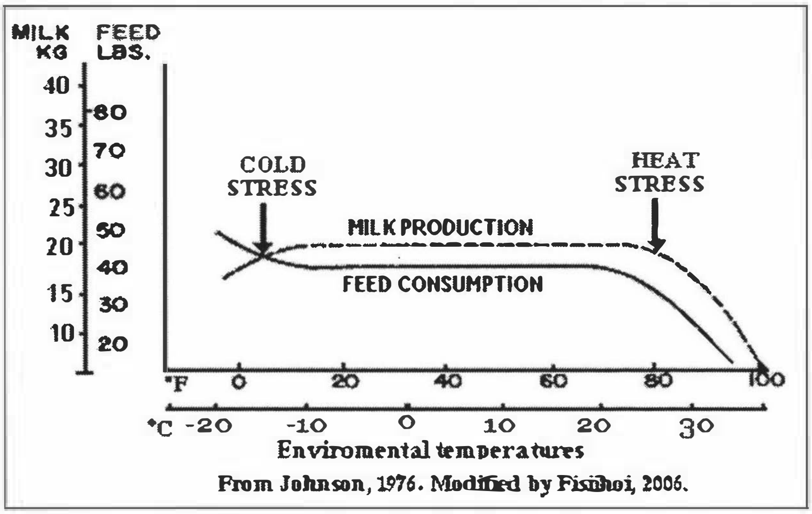

Figure 3.15. The effect of environmental temperature on milk production and feed consumption in dairy cattle.

In addition, the optimum environmental temperature (ET) for lactation is dependent on the species, breed and degree of tolerance to either heat or cold (Hafez, 1968). There are also breed differences in their maximal and minimal critical temperature (CT), outside which their productivity starts decrease rapidly. For example, the milk yield declines in HF cattle at about 21°C, Brahman at 32°C and Brown Swiss and Jersey at 24-27°C (Figure 3.16); but yields are much lower in Brahman than in HF.

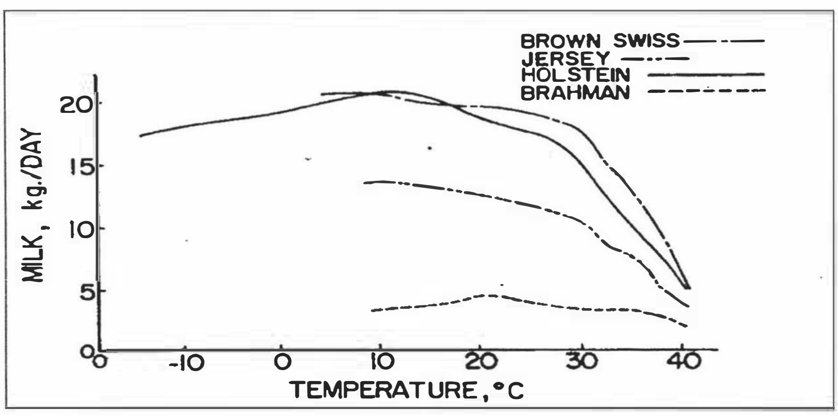

Figure 3.16. The effect of environmental temperature on milk yield in different breeds of cattle in a temperature-controlled laboratory at a relative humidity of 40-60% (Johnson, 1976).

The minimal CT for Jersey cattle is around 2°C, whereas HF are not greatly affected at even -13°C (Hafez, 1986). Hafez (1986) stated that the reduction in milk production when cows are exposed to heat or during summer cannot be blamed on either low FI or forage quality. It is correlated with physiological mechanisms which relate to lactation, particularly to low levels of thyroxine during the summer. It is difficult to predict milk production from grazed pastures, even when the nutrient content is known, due to variations in grazing behaviour, and pasture species, but especially forage growth. Highest yields of milk are produced in the warm, wet growth season, with reduced milk yield and body condition in the dry season when there is less forage growth (Chamberlain, 1989).

Table 3.6 shows the possible milk production from a range of pasture feed types. The HF cows can produce up to 12-14 L of milk/cow/day (or 3,600-4,200 L per lactation) in tropical pastures. On the same feed, Jerseys were producing a maximum of 9-10 L of milk daily (or 2,700-3,000 L per lactation) (Chamberlain, 1989).

Table 3.6. Possible HF milk production per cow (500 kg live weight) from a range of pasture types (Chamberlain, 1989).

Pasture type	Example	Maximum digestibility (%)	Maximum intake/day (kg DM)	Proportion used for maintenance (%)	Possible milk/cow/ day (L)	Possible milk/cow/ lactation (L)
Excellent	Temperate: ryegrass/clovers	80	15	42	21	6,300
Average	Tropicals: grass/legume, nitrogen	65	12.5	63	12-14	3,600-4,200
Poor	Native pastures, unfertilised and unimproved	50	10	90	2	600

Table 3.6 shows that higher milk production per cow was obtained from tropical legumes than from tropical grasses. The cows seem to use their nutrients for maintenance but less for milk production, thus the lactation period will become shorter. However, it is uneconomical to keep cattle in the tropical pasture if their average milk per day is less than 12 L (Chamberlain, 1989).

There are seven improved dairy breeds recommended for Tonga (see Chapter 4 in this document), including one temperate breed (HF). They have been identified as the best performing milking breeds in many tropical sites around the world with climates similar to Tonga's, for reasons such as high adaptability, ease of management, heat tolerance and high feed conversion efficiency (Chamberlain, 1989).

3.6. REPRODUCTION AND FERTILITY

Reproduction and fertility are key components of livestock production systems. For the dairy herd, efficient reproductive performance is an essential requirement for sustainable and profitable farming (Holmes *et al.*, 2002). The reasons for this include:

- the calving pattern is controllable as part of effective farm management. Its objective is mainly to match the feed requirements of the herd with that of pasture growth curve where maximum economic return can be achieved (Figure 3.17)
- pregnancy and parturition are the most effective ways of initiating mammary gland growth and milk secretion
- replacement animals have to be selectively bred in order to produce a genetically improved herd (Holmes *et al.*, 2002).

In New Zealand dairy production systems about 95% of farms calve their herd in spring. This is based on the seasonal pattern of pasture growth rates with all cows being mated and conceiving in spring or early summer in order to calve in the following spring (Figure 3.17). It is important to understand the causes of the reproductive failures and infertility in dairy cattle. This is one of the major problems in the dairy production system in tropical conditions (e.g. Tonga), mainly due to the effects of higher temperatures, lower feed value and infectious diseases. Normally the cows are expected to deliver one calf per year after nine months of pregnancy (Webster, 1987). The next oestrous cycle should be recommenced in less than two months after calving so that the cows can have a calving interval of 365 days (Webster, 1987).

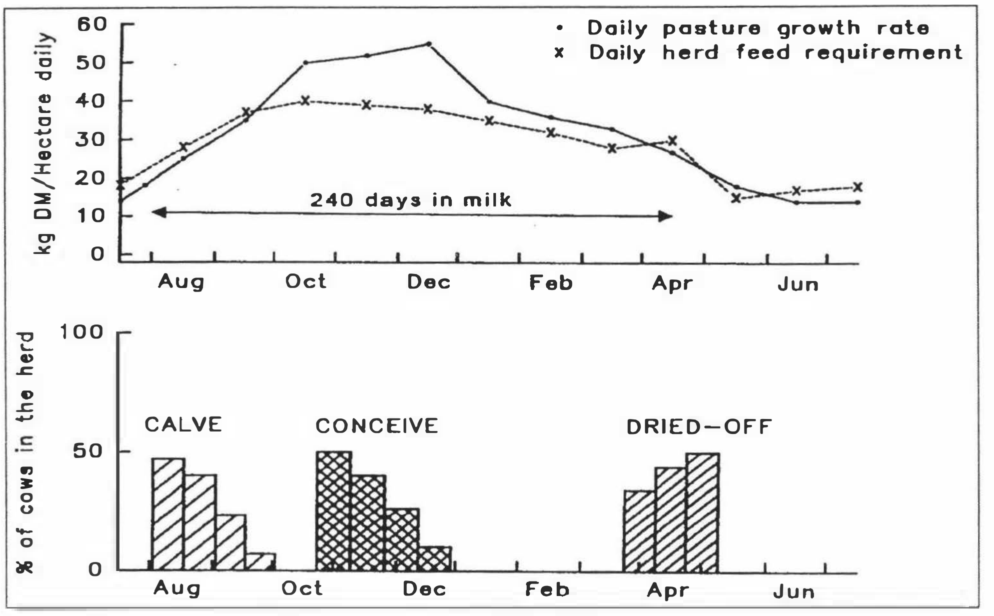

Figure 3.17. The seasonal pattern of calving, breeding and drying-off and the synchrony between feed requirements and pasture growth (Homes *et al.*, 2002).

As shown in Figure 3.17, the cows are expected to calve in August (spring time) to coincide with availability of the daily feed requirements which occur at the start of lactation (Holmes, 2002). In the case of Tonga, the best time to calve is December-February. This is when the pasture growth production is increased (Figure 3.18), with higher feeding value and higher digestibility (Fisi'ihoi, 2006). The AT is cool because it is the rainy season, but it becomes hotter and drier after April. Figure 3.19 shows the annual temperature and rainfall of Tonga over 50 years, indicating the months where pasture production increased.

Figure 3.18. Mixed grass-legume pasture in Tonga (photo taken by Fisi'ihoi in May 2005 at Tupou College).

Figure 3.19 shows the normal average rainfall, maximum temperatures (Tmax) and minimum temperatures (Tmin) recorded over 50 years in Tonga. This figure indicates the highest DM production occurs from December to March when Tmin is lower (below 25°C) and there is higher rainfall. The FV of pastures is also highest during these months and slowly decreases afterwards.

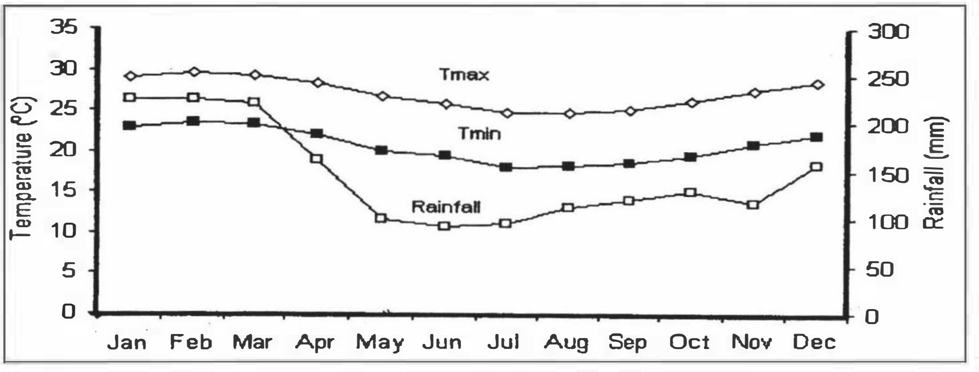

Figure 3.19. The annual average temperatures and rainfall of Tonga over 50 years (Meteorology Department of Tonga, 2006).

3.6.1. FERTILITY IN THE DAIRY HERD

In nature *'lactation'* is an ideal component of the reproductive cycle which is designed to produce milk to feed the newborn (Holmes, 2002). The production of a calf is a culmination of events involving follicle development, growth of a good quality oocyte, ovulation, fertilization, implantation and embryo survival. As a consequence, the ultimate goal of the dairy industry to operate an economical and efficient production system is dependent on high reproductive efficiency and hence, on fertility (Holmes, 2002).

Fertility is one of the major factors influencing the profitability of dairy herds because it can be measured as the number of calves produced per unit time. Therefore, a cow must produce milk after she has produced her first calf, when she is about two years old (Holmes *et al.*, 1987). In temperate conditions, dairy cows are bred to calve at the required time of the year, e.g. in New Zealand this is in early spring. This means:

- cows must become pregnant again in late October/November if they are to calve in late June/July of the following year. Their gestation period is about 282 days, with 365-day interval between successive calving

- all heifers must become pregnant at about 15 months of age in order to calve for the first time at about 24 months of age
- the cows used must produce genetically superior heifer calves for herd replacement (Holmes, 2002).

Fertility and mating depend on the biological and physiological reproductive events of individual heifers and cows. A biological event is an ideal lifecycle for a heifer/cow. It must work within a tight timetable with these major components:

- **Puberty:** all cows and heifers must reach sexual maturity (puberty) about 10-14 months and begin oestrus cycles with regular ovulations
- **Pregnancy:** their gestation period is 282 days (range 270-290) and there are only 83 'non-pregnant' days available to productive cows that calve every year.

i.e.	Age at puberty	360 days (approximately)
	Pregnancy	- 280 days
	Total	640 days (21 months)

  Therefore, the heifers must conceive within 90 days of her puberty time (i.e. 730 days - 640 days = 90 days).
- **Post partum anoestrus interval**: (time after calving until the next oestrus activity is 20-40 days). The cows and heifers must continue with the next post partum anoestrus activity 20-40 days after calving. It is slightly longer for two year old cows.

i.e.	Pregnancy	- 282 days (approximately)
	Post partum anoestrus	30-60 days (approximately)
	Total	312 - 342 days

This tight schedule for cows' reproduction can be disrupted by any problems, for example poor nutrition, disease and climate (Holmes, 2002).

3.6.2. PUBERTY, AGE AND WEIGHT

All heifers must reach puberty and conceive before 15 months of age. The successful mating should conceive six to eight weeks after mating and consequently calve nine months later. To ensure mating at puberty, all heifers must be above certain minimum weights by a certain age. The following minimum weights are suggested as reasonable targets at the ages of 15 months which allow for some safety margin:

- Friesians: 300 kg
- Jerseys: 230 kg (Holmes, 2002).

If all heifers in a group are heavier than these targets then there is a high probability of conception in the first six to eight weeks of mating. When reaching the age for puberty, the oestrous cycles should begin. This cyclic event (heat) normally occurs at about 21 days (average cyclic length) in cattle and is a sign of sexual maturity (Chamberlain, 1989). Mated heifers are expected to conceive at 15 months of age but this does not always occur. Failure to conceive is most common in the lightest heifers (e.g. 15% failure rate) and is lower in heavier animals such as HF (e.g. 10% failure) (Macmillian, 1994).

3.6.3. DETECTION OF OESTRUS

Figure 3.20 shows the characteristics and visible signs of cows in oestrus (heat). For artificial insemination (AI) oestrus must be detected by the herd manager, as it is the most important cause of failure in reproduction efficiency. The identification of the oestrous ensures that mating or insemination takes place at the most appropriate time in relation to ovulation process. Successful mating by AI depends on reliable and accurate detection of oestrus signs and it is absolutely essential (Holmes, 2002).

Regular observations can be made in late morning, mid afternoon, before dark and both milking times (Chamberlain, 1989). Detection is sometimes difficult when there are only a small number of cows on heat at any time, because the riding and standing behaviour will be less obvious. Therefore, extra care is needed after the mating period when most of the cows are pregnant. Oestrus detection is also difficult in those herds with spread-out calving and mating patterns because only one or two cows may be on heat each day (in larger herds) or each week in very small herds such as in Tonga (Fisi'ihoi, 2006).

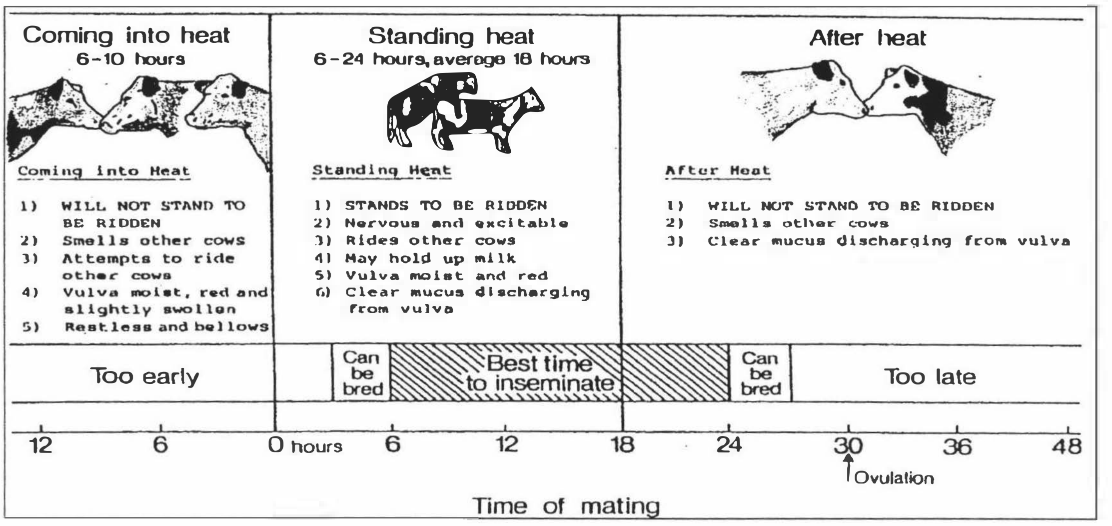

Figure 3.20. The sequences in stages of oestrus (heat) in relation to the ideal time for insemination (Holmes *et al.*, 2002).

Bulls and cows may favour each other's company for two or three days, but the period of oestrus for mating is only about 16 hours (range 8-24 hrs) (Webster, 1987).

3.6.4. CONCEPTION RATE

Conception rate (CR) is the proportion of individual matings which result in conception (measured as a percentage) (i.e. the non-return rate (NRR) to oestrus at normal interval). For example, if 100 cows are mated once and 65 of them conceived (or do not return to oestrus within 49 days) then the NRR is 65% for their first mating (Holmes, 2002). Therefore, 35 cows have not conceived and they are to be returned for mating in the next oestrus cycle.

Webster *et al.* (1977) indicated that failures in CR are mediated by biological or external factors. It may occur during the releasing of adrenal corticosteroids, after the synthesis and secretion of gonadotrophines which may depress fertility. The following factors contribute to failure in CR:

- the length of previous dry period
- the level of body condition during the dry period
- calving problems and retained placenta
- condition and reproductive health post-partum
- climate: temperature, humidity and clean air

- the detection of oestrus and management at breeding, including quality of semen or bull fertility and the timing and replacement of semen (Whitaker *et al.*, 1993).

Today, the problems with CR in New Zealand are lower than previous years, but reproductive problems are now caused by anoestrus at the start of the breeding season (Burton *et al.*, 1999; Verkerk *et al.*, 2000).

3.7. MISMANAGEMENT CAUSING REPRODUCTIVE FAILURES

Reproductive failures and low fertility are sometimes caused by mismanagement of dairy cows. The confirmation of optimum fertility depends on proper recognition of oestrus, but also on other factors including age, weight, climate and nutritional levels of the cows and heifers. In addition, inexperienced dairymen and lack of knowledge of livestock fertility and reproductive problems can lead to more problems.

3.7.1. NUTRITIONAL PROBLEMS

Inadequate nutrition is the major cause of poor fertility in tropical cattle, particularly for heifers at the early stage of lactation (Holmes, 1979; Johnson, 1987; Webster, 1987; Chamberlain, 1989). Cows are very sensitive to nutritional stress in early lactation, which may result in lower CR, infertility and submission rate (Chamberlain, 1989; Holmes *et al.*, 1999). Energy is a crucial nutrient for attainment of fertility. Heifers that are under-fed during their first six months of life grow slowly and reach puberty at older ages (Holmes *et al.,* 2002). Heifers should reach 60% of their adult body weight a month before the mating season starts (e.g. HF - 240 kg LW) (Penno, 1997) to maximise the probability that they will conceive early in the mating period.

Most cows lose condition in the first 60-90 days of milking (due to lack of appetite and low FI). Inadequate nutrients are related to body condition score (CS) (see Figure 3.21). Cows that calve with thin CS will probably have smaller and less active ovaries and a prolonged anoestrous period, lower CS and finally fail to conceive during the short mating period (Chamberlain, 1989; Webster, 1987). The CS expresses the visual estimation of the cows' body fat reverse, which in turn provides useful information about cows:

- future feed requirements
- future productivity (milk and fertility)
- previous level of feeding (Holmes *et al*., 2002).

The CS is based on the appearance of tailhead from 0-5 (Figure 3.21).

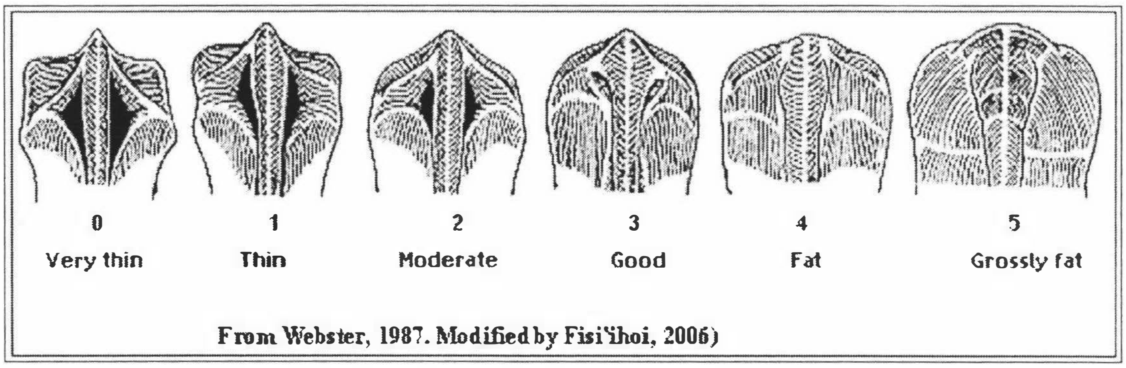

Figure 3.21. The condition scores of dairy cows from the appearance of the tailhead.

The New Zealand system scores range from 0 (very thin) to 10 (very fat), with CS 5 being a widely accepted target for cows at calving, equivalent to CS 2.5 in Figure 3.21. A thin CS at calving (< 2) means fewer cows will return to oestrus, with 50% lower CR (Webster, 1987). Feeds that have lower concentration of protein, Cu and selenium could result in delaying and shortening oestrus and causing lower fertility. Andrew *et al.* (1998) stated that cows' fertility is very sensitive to inadequate nutrition around calving through to mating; this may result in heifers having undeveloped ovaries and delayed puberty. Stunted heifers may result in having lower fertility throughout their life. On the other hand, excess fat can impair reproduction and increase calving difficulties. Exposure to hot conditions can reduce fertility through the effect of reduced FI.

3.7.2. SEASONAL EFFECTS

Reproductive performance varies between herds and locations as seasons change. This factor has caused abnormal physiological functions of the cow which depends on the environment in which they live, such as AT, feed supply and photoperiod (day length) (Tucker, 1982). Cattle normally show oestrus cycles throughout the year. At northern and southern latitudes their reproductive efficiency is lowest in winter, whereas in areas around the equator it is lowest during summer - possibly because of the effects of hotter conditions and reduced FI (Poston *et al.*, 1962.; Tucker, 1982).

Seasonal differences also cause longer intervals of post partum oestrus and ovulation in spring than in autumn calving cows. On the other hand, the anoestrus interval is shorter for cows calving in early summer than in late winter calving cows (Poston *et al.*, 1962; Montgomery *et al.,* 1985; Sharpe *et al.,* 1986). Cows that are fed low energy diets around calving time in winter might have a longer interval of oestrus than cows calving in spring due to feed restriction (Montgomery *et al.*, 1985; Xu and Burton, 1996). Randel (1984) stated that *B. indicus* may alter their reproductive function in winter resulting in lower a CR and pregnancy rate due to fewer fertilised eggs.

3.7.3. IMPROPER HEAT DETECTION AND MATING

Inadequate heat detection is a major worldwide cause of poor reproductive performance in dairy herds. Most of it is due to lack of knowledge and time and having too many cows (Chamberlain, 1989). Sometimes heat stress is difficult to observe because some cows show few heat signs and in very short period of time (e.g. Zebu) especially in hot, humid climates (e.g. 10-11 hours). Timing of mating during oestrus is critical. The oestrus cycle occurs every 21-24 days from puberty onwards (Websters, 1987), but poor handling of it will result in failure to achieve reproduction efficiency (Chamberlain, 1989). Mating too early or too late in the oestrus period will reduce the chance of conception.

The use of bulls that are immature or too old, or insufficient numbers of bulls, can reduce herd fertility. The working bull should be older than two years and in good, vigorous condition. One bull can serve 35 cows, or 1:16-18, depending on the number of cows.

3.7.4. EFFECTS OF HOT CONDITIONS ON FERTILITY

Hot conditions can reduce fertility in both male and female animals. In many cases the problem with reproduction can be reduced by skilful management. Persistent high temperatures (< 27°C) could depress fertility by depressing the concentrations of spermatogenesis, causing death of ova and damaging the early embryo (Edwards, 1978). This does not affect *B. indicus* bulls' semen quality, while *B. taurus* bulls may be affected when exposed to 40°C for 12 hours (Van and Free, 1970). The severity of this effect depends on the extent to which the animals' body temperature, or testicular temperature, is elevated above its normal temperature.

Mount (1979) stated that hot conditions affect the sperm and its mobility in young bulls exposed to 30°C (85°F) for more than five weeks. The internal scrotal temperature can vary between -3-31°C, but at 40°C spermatogenesis decreases and the number of abnormal spermatozoa and damage to seminiferous tubules increases (Ulberg, 1967; Mount, 1979). High environmental temperature (HET) also delays the age of puberty in heifers and bulls (Barnett, 1962), e.g. Brahman and Shorthorn cows can delay puberty for up to five months as a consequence of HET, in association with slow growth caused by reduced FI.

3.7.5. EFFECTS OF HEAT STRESS IN COWS

The worst effects of HET on cows' fertility appear in their oestrus cycle. Both temperate and tropical breeds have shorter oestrus periods and weak signs of coming into heat in hot conditions. Ovulation is depressed and abnormal ova are produced, with an increased number of services required before conception (Chamberlain, 1989). Embryonic mortality in cows is increased soon after mating under hot conditions (Bamett, 1962; Johnson 1987).

The gestation time will become shorter (by one month), with a lower birth weight and chances of survival of the calf. Dunlap and Vincent (1971) found there was severe infertility when cows were exposed to 32°C for 72 hours immediately after breeding. Mount (1979) mentioned that pregnant HF cows exposed to HET may produce smaller calves and temporarily stop the oestrus cycle. The concentration of sex hormones, such as lutenising hormones (LH), is reduced at the peak of oestrus (and sometimes this peak will not occur). Generally, to maintain maximum profitability, herd fertility should achieve the following goals:

- < 83 days calving to conception interval
- < 5% cull due to infertility
- < 1.5 total serves per conception.

Many of these adverse effects on fertility are due to either reduced food intake or increased body temperatures, or possibly a combination of both.

3.8. CONCLUSION

Central to profitable dairy farming is the concept of FV, which combines the quality components of the forage eaten with the amount of feed eaten. High voluntary feed intake cannot be achieved under restricted feed availability and with lower FV. Good pasture management is crucial for maintaining NV, by minimising stem development and preventing senescent material accumulating, so animals are able to achieve intake near *ad libitum*. It is crucial to have a good knowledge of nutritional concepts including the digestibility of feeds and the impact of high CP concentration.

Further research is needed to improve our understanding of the constraints of the forage digestion and environmental effects on both pasture and reproductive efficiency. The limitations imposed by climate, soil and suitable forage will become apparent for each situation and the focus will move towards the factors limiting feed utilisation. Animal fertility and the presence of deleterious substances in pastures will remain as a target for further research. There will be a more attention paid to issues such as forage quality, appropriate management and breed genetics, with the potential for improving feed quality and fertility in general.

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CHAPTER 4:

PASTORAL DAIRY PRODUCTION FOR TONGA

4.1. INTRODUCTION

The effects of high environmental temperatures, poor pasture production and poor management pose serious problems to dairy systems; all have prevented increases in milk production in Tonga. Milk yield has recently become the major focus due to a rapid increase in demand for local milk rather than imported produce. The main objectives of this chapter are to provide reasonable management strategies and suitable techniques to further improve milk production in Tonga.

The interaction between the environment, pastures, livestock and production are considered in this chapter. The management techniques recommended here will depend upon the response of these factors. In order to improve the level of milk production, dairy breeds are a key factor together with the effects of environmental temperatures. *Bos indicus* breeds and crossbreeds are planned for this new improvement program, because they suit the harsh tropical conditions in Tonga. Improvement in animal production depends on using tropical hybrid breeds in conjunction with high quality pasture types and species.

Tropical pastures contain high fibre contents, lower FV and NV and result in lower animal production. This chapter provides feasible management techniques that can be used to achieve better quality pastures in Tonga. These methods aim to increase FI during hot days when cows are under heat stress and should increase milk yield and live weight gain.

The influence of heat stress on livestock production provides the basis for the types of feeding and grazing management suitable for cows during hot conditions. In addition, improvement in pastures will maintain their productivity and replenish soil minerals from companion pasture species. Cows' reproductive efficiency can be improved through these judicious management techniques and health problems can also be minimized. Finally, total pastoral production will be of a higher standard (pastures, soil, cows and income), including management skills and a more profitable farm.

4.2. DAIRY BREEDS FOR TONGA

There are hundreds of different breeds of cattle in the world but only few are classified as *dairy breeds* (e.g. Jersey, Holstein, Friesian and Ayrshire). These breeds have been selected over the past 200 years, with the focus mainly on their dairy characteristics (Holmes *et al.*, 2002). *Bos indicus* breeds are renowned as tropical dairy breeds, and include Brahman, Jersey, Australian Friesian Sahiwal (AFS), Australian Milking Zebu (AMZ) and Brown Swiss. They have been genetically selected based on heat tolerance (the ability to produce milk under hot condition), tick resistance and foraging ability.

The following dairy breeds have been proven in many tropical countries, including Australia, Thailand, Indonesian, Malaysia, Singapore, India, Pakistan and central and Latin America; mainly for milk production, heat and tick resistance. Consequently, they are now internationally recommended as the best dairy breeds for tropical regions.

4.2.1. AUSTRALIAN FRIESIAN SAHIWAL

The AFS breed (Figure 4.1) has been proved to be the best dairy breed for tropical conditions (Alexander, 1984). It was produced by the Queensland Department of Primary Industry (QDPI) in Australia in early 1961. This breed is a result of crossing between Sahiwal bull (**a**) with HF breed (**c**) during a selective breeding program for milk production and tick resistance (Alexander, 1984). The AFS breed (**b**) is now a pure breed of cattle in its own right.

a) **b)** **c)**

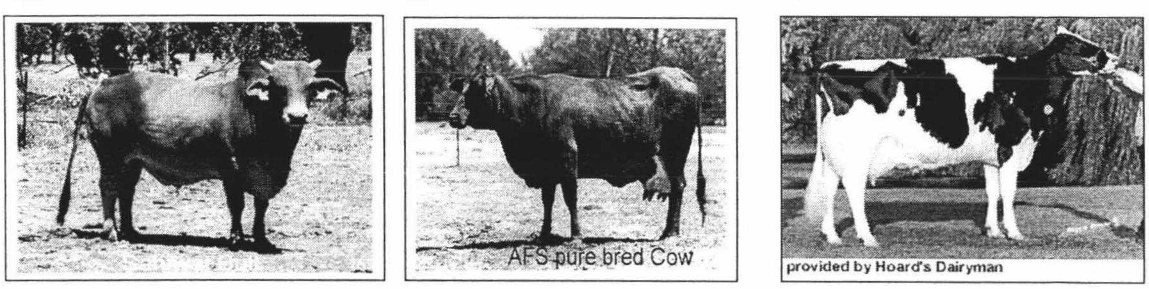

Figure 4.1. a) A pure Sahiwal breed bull; **b)** a pure Australian Friesian Sahiwal cow, consisting of 50% x 50% crossed between a and c; **c)** a pure Holstein Friesian cow (Alexander *et al.*, 1984; Hoards, 2004).

The AFS breed is a unique combination of 50% HF and 50% Sahiwal breeds and is now known as the pure AFS breed (100%). The AFS breed has reportedly outperformed other breeds in the tropical conditions (Alexander *et al.*, 1984). They have combined the tick and parasite resistance, heat tolerance and foraging ability of the Sahiwal with the high milk production of the HF (Alexander *et al.*, 1984).

The following features describe the unique features of AFS breed under in tropical conditions:

- 12 month-interval calving, easy calving and milk let down
- good temperament and easy to manage
- high milk quality (3.4% butter fat and 4% protein content; 27% higher than HF)
- high resistance to ticks and other parasites
- low maintenance requirements
- good foraging ability
- good body conformation
- 12.6% shorter dry period length compared with other breeds.

These characteristics enable AFS cattle to outperform European breeds in tropical regions. Their average milk yield reaches 3,750 L in 300 days lactation and 3,000 L for mature cows; and they have been recognised internationally as the most suitable breed for tropical regions (Alexander *et al.*, 1984).

4.2.2. JERSEY

The Jersey breed originated from the Island of Jersey (Figure 4.2), a small island in the English Channel off the coast of France. They are the smallest of the dairy breeds, weighting up to 450 kg when mature.

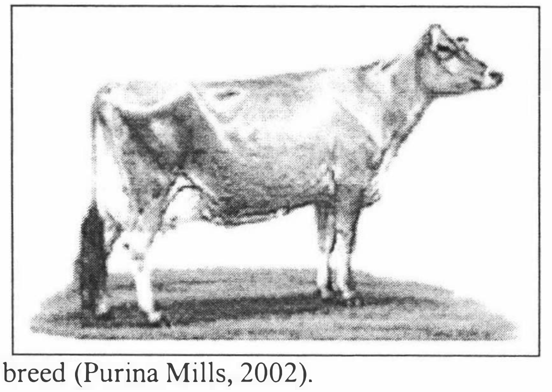

Figure 4.2. The Jersey breed (Purina Mills, 2002).

They are adaptable to a wide range of climates and geographical conditions. Jersey cows are excellent grazers in intensive grazing programs and require less energy for body maintenance due to being lighter in weight. For example, an 'average' 355 kg Jersey requires about 1.8 t DM/year for maintenance, while a HF cow (450 kg) requires 2.1 t DM/year. Therefore higher stocking rates (SR) per hectare are preferred (Holmes *et al.*, 2002).

Jerseys are lighter than other breeds. They have a smaller volume of milk but higher concentrations of fat (5.77%) and protein (4.6 %) than HF (Holmes *et al.*, 2002) (see Chapter 3, Table 3.3). They produce similar or slighter lower yields of MS, but per hectare they produce slightly larger yields of MS (Briggs and Briggs, 1980).

The advantages of the Jersey breeds are claimed to be:

- ease of management: e.g. better health, reduced herd turnover, economical level of feed demand (i.e. 20% lower feed costs compared to larger breeds)
- high feed conversion efficiency: a higher proportion of FI goes to milk production rather than body maintenance
- adaptability: superior foraging ability; thrives better in heat and high humidity
- longevity: productive lifespan is about 10% longer than other dairy breeds
- higher reproductive efficiency: e.g. easy calving, earlier maturation, shorter calving intervals with few calving problems

4.2.3. AUSTRALIAN MILKING ZEBU

The AMZ was developed in the mid 1950s by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia (Figure 4.3). They were developed to overcome the problems dairy breeds encounter under high temperatures, high humidity and tick-infestation, as well as to achieve high milk production.

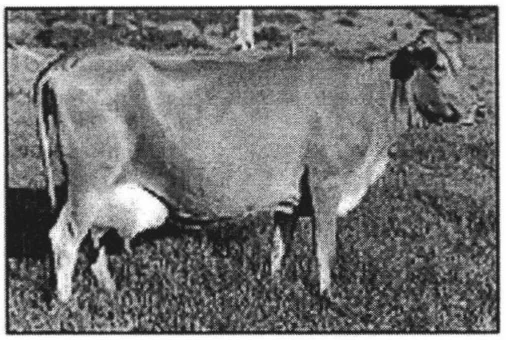

Figure 4.3. The Australian Milking Zebu (Anon, 1996).

Mature purebred AMZ cows produce an average of 2,700 L of milk over a 12 month period; while AMZ x Friesian cows produce more than this amount, the milk of AMZ contains approximately 3.5-4 % protein.

The AMZ carries the colour markings and general shape of the Jersey, but also shows the tropical influence of the Sahiwal and Red Sindhi breeds through the ability to sweat and discard ticks from a highly mobile, loose skin (Hoards and Atkinson, 1996).

4.2.4. GUERNSEY

Guernsey is a dairy breed developed on the Island of Guernsey in the English Channel from cattle brought to the island by monks from France about 980 A.D. (Figure 4.4).

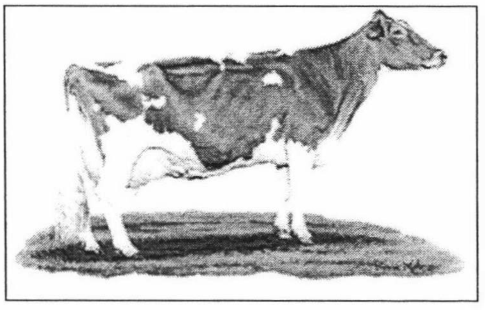

Figure 4.4. The Guernsey breed (Purina Mills, 2002).

The Guernsey cow is well known for its ability to produce high yields of butterfat and protein, with high concentrations of betacarotene (Hoards and Atkinson, 1996). Being of intermediate size, Guernseys require 20-30% less feed per kg of milk produced than larger dairy breeds. They reach productive maturity at an early age and can calve at 22 months of age, earlier than the larger breeds (Bredenkamp, 2001). They are known to lack undesirable genetic recessives and to have better adaptability to warmer climates.

The Guernsey is also an excellent grazer because of its genetic merit for pasture based-milk production (Hoards and Atkinson, 1996). Because of their grazing abilities, gentle disposition, easy calving and ability to produce milk efficiently with less feed than other breeds, they are an ideal breed for intensive grazing. Dairy producers can realise their potential profitability with minimum cost management. Guernseys are very adaptable and do well under close confinement, such as zero grazing. This breed produces an average of 23 L of milk per day with a high fat content (4.57%) (Purina Mills, 2002).

4.2.5. HOLSTEIN FRIESIAN

The HF breed (Figure 4.5) originated in Europe and was bred strictly to obtain animals that would make best use of grasses in abundant areas of pasture.

a) b)

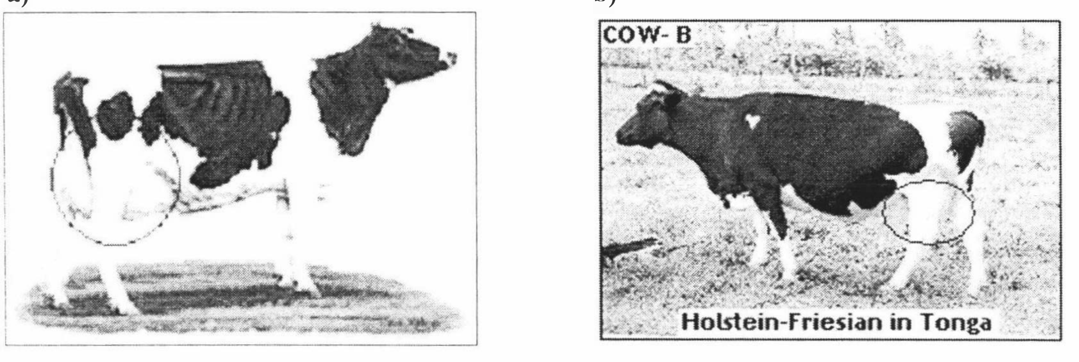

Figure 4.5. The Holstein Friesian breed **a)** in a temperate region; **b)** in a tropical region (Tonga) (Purina Mills, 2002; photo b) by Fisi'ihoi, 2006).

The HF breed is renowned for having higher milk yields than other breeds (see Table 3.3 in Chapter 3). Holstein Friesian cows raised in Tonga produce only 10-14 L/c/d at their highest yield; despite having a larger body size, they have smaller udders. Figure 4.5b illustrates the difference between HF raised in temperate and tropical regions. This is the ultimate indicator of the effects of the warmer conditions in tropical regions. They are strongly built, with large feeding capacity and udders. Holstein Friesian cows require high quality feed in order to achieve their genetic potential for milk production;

if their feed requirements are not adequately met, their condition, reproductive performance and milk yield deteriorates (Hoards and Atkinson, 2000).

They are good grazers, especially in good pastures, but do not thrive well in poor pastures. Holstein Friesians are large, stylish animals, with colour patterns of black and white or red and white. A healthy HF calf weighs 40 kg or more at birth. A mature HF cow weighs approximately 680 kg and heifers can be bred at 15 months of age when they weigh about 362 kg. The heifers can be mated for the first time between 24 and 27 months of age with a gestation period of approximately nine months. Their normal productive life span is six years. They produce much larger volumes of milk per cow per hectare than other breeds (Holmes *et al.,* 2002).

These dairy breeds (AFS, Jersey, AMZ and Guernsey) are recommended for the new renovation program in Tonga mainly because of their production potential and inherent ability to withstand all kinds of harsh tropical conditions. They have the potential to improve milk production through their ability to graze on low quality pastures in hot weather. The HF breed requires extra care and management due to their sensitivity to higher temperatures.

4.3. MANAGEMENT STRATEGIES FOR PASTURE PRODUCTIVITY

Most native pasture in the tropics is dominated by grasses (eg. in Tonga: *Panicum maximum*, *Brachiria decumben* and *Brachiaria mutica*), which have a short growing period or mature very quickly when compared to temperate pasture species. Protein deficiency is very common in tropical grasses (Humphreys, 1972) and CP of pasture is usually below 3%, particularly during the dry season. However, when CP levels fall below 7-8% milk production seems to be limited by protein deficiency (Evans, 1968). In addition, most tropical pastures have a lower feeding value and are invaded by non-palatable species which dominate areas of increased grazing pressure.

Several pasture management techniques have been proven in numerous tropical regions to improve livestock production (milk yield and live weight gain). The following management practices are appropriate for the environmental conditions and resources available in Tonga and could be successfully applied there.

4.3.1. LEGUMES IN THE PASTURE

The inclusion of legume species in pasture systems is likely to increase both pasture and livestock productivity, as shows by several studies (Holmes, 1980; Crowder and Chheda, 1982; Webster, 1987). The inclusion of legume species is the only feasible management practice that could be used to improve the condition of the pastures in Tonga. Aminah and Chen (2006) stated that this practice is far better than reliance on nitrogen fertiliser for the following reasons:

- legumes can improve soil conditions with the nitrogen build up in the soil from their accumulated organic matter
- legumes fix nitrogen through their rhizobium symbiosis in the soil and for the companion grasses
- they increase both pasture quality and animal performance (Sheath *et al.*, 1987) due to the higher NV of legumes and faster digestion in the gut, and consequent increase in VFI
- legume species have higher FV than grasses
- legumes are eaten in greater quantities than grasses due to having lower resistance to breakdown during chewing (Minson, 1990) and digestion in the stomach
- forage production will be varied in its stability, in particular, total yields will be increased when compared with either legumes or grasses alone (Crowder and Chheda, 1982) because the grasses will benefit from the nitrogen fixed by legumes.

The CP content of the whole pasture could be increased and the grazing period can be further extended with the inclusion of legume species. Legumes can remain green throughout the dry season and a high NV can be maintained when they become brown or even die (Crowder and Chheda, 1982). Usually, the CP content of legumes (25%) is higher than that of grasses at similar ages and stages of growth and shows little fluctuation during the growth process. Apart from a higher nitrogen content, tropical legumes generally maintain higher S (0.07-0.21%) and Ca (1.13-1.93%) in the plant tops than grasses (0.09-0.15% and 0.17-0.41%, respectively) (Andrew and Robbins, 1969). The value of P in legumes is also higher than in grasses, despite a greater variability between species and plant ages. It is crucial to understand that legume variability and persistence are always problematic on acid soils (Aminah and Chen, 2006).

Legumes are the basis of the New Zealand pastoral farming system, because of their ability to fix N; without legumes, N fertiliser needs to be added. The quantity of N fixed ranges from 0-350 kg N/ha/year depending on the percentage of clover in the pasture, clover growth rate, the nutrient level in the soil, soil temperatures and moisture (Table 4.1). However, the main objective of pasture management is to maintain sufficient legumes in the pasture for adequate N fixation.

Table 4.1. White clover yields, percentage of total pasture yield and N fixation per year for a range of environments in New Zealand (Hoglund *et al.*, 1979).

Site (environment)	Clover yield (kg DM/ha/year)	Clover (%)	N fixation (kg N/ha/year)
Kairanga (mild winters and summer)	3040	22	211
Gore (cold winters, wet summer)	2910	26	265
Kaikohe (warm, high, rainfall)	3750	34	342
Masterton (dry summers)	1500	15	152
Kirwee (dry)	3910	39	120
Kirwee (irrigated)	5040	38	192
Woodville (low fertility hills)	150	2	34

White clover based pasture should contain 25-35% of its total herbage yield accumulated in the pasture. As Table 4.1 shows, this percentage is often achieved on high fertility farms (Kemp *et al.*, 2002).

The qualities of tree legumes, including providing a good source of protein and their ability to withstand drought and remain as the main source of forage during the dry season in several tropical countries, all contribute to their ability to help maintain high livestock production (i.e. milk yield) (Moog, 2006). Some tree legumes have multiple uses, they are easy to establish and well associated with tropical grasses. *Leucaena* is the most popular of the tree legumes, while *Gliricidia maculate* is now being recognised as an excellent source of fodder. Moog (2006) reported that feeding Sahiwal-HF with 5-19 kg of fresh *Leucaena* leaves combined with fresh grasses produced 4-7 kg milk/c/d.

Therefore, *Leucaena* and *Gliricidia* should be planted along the fence (e.g. 1-2 m apart) in a pasture/ cattle/coconut integrated system.

Mixed pasture compromises of five or more species of various grasses or legumes. In general, animal performance in the tropics will be increased with about 40% of the pasture being legumes (Figure 4.6), which is about the same as for the temperate zone (Crowder, 1985).

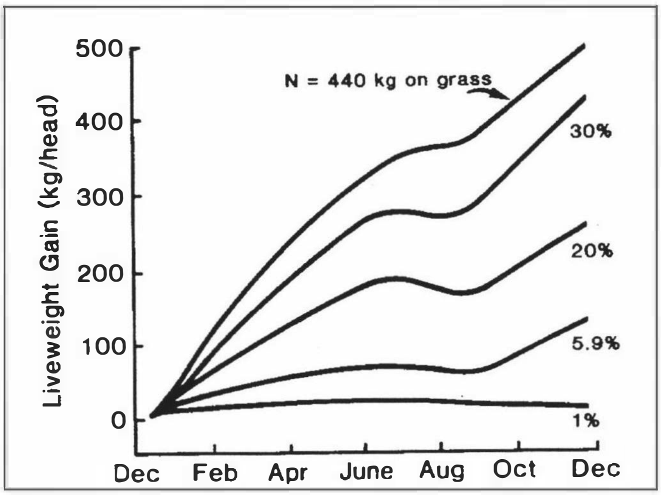

Figure 4.6. Animal performance as influenced by percentage legumes (shown by lines 1-30%) in grass-legume pastures and N-fertilised grass (Evans, 1968).

As illustrated in Figure 4.6, LW gain and growth rates increase in grass-legume pastures. Maintenance of legumes in pastures needs judicious grazing management, especially if they have high SR. The general aim of including legumes as part of the pasture management is to utilise the herbage more economically and to maintain a balanced pasture composition with higher quality (Charlton and Stewar, 2000). Cowan (1968) summarised the levels of milk production that have been obtained from three different types of tropical pastures (Table 4.2).

Table 4.2. A summary of milk production per cow and per hectare from cows grazing tropical pastures (Moog, 2006).

Types of pasture	Breed	Stocking rate (cows/ha)	Milk yield (kg/cow/day)	Milk yield (kg/ha/yr)
Unimproved pasture	Jersey	1.1	6.8	2660
	Guernsey	1.5	6.9	2670
	Friesian/Criollo	1.0	6.9	2660
Improved grass-legume pasture	Jersey	1.0	8.5	-
	Guernsey	1.8	9.3	4700
	Friesian	1.6	12.4	5350
	Friesian/Zebu	1.7	7.3	3720
	AFS	1.6	8.0	3840
Improved pasture with nitrogen fertiliser	Jersey	2.5	6.8	5250
	Guernsey	2.5	7.8	5350
	Friesian	2.5	11.0	8250
	Friesian/Zebu	2.2	8.7	5200
	Jersey/Criollo	2.6	6.7	4100
	A.F.S	2.5	7.0	4800

The grass and legumes mixed pastures have higher production per cow than N fertilised grass pastures. However, they cannot carry such high SR as nitrogen fertilised grasses and production per hectare is lower. Grass and legume systems have produced up to 8,000 kg/ha/year, but loss of legumes was observed at high SR (Cowan *et al.*, 1975).

4.3.2. CRITERIA FOR PASTURE SPECIES

Management of pastures will depend on a thorough knowledge of many components in a complex system, in particular plants, their structure and lifecycle. Plant breeders have released the most widely used pasture species and cultivars which are suitable and adaptable for different environments (Kemp *et al.*, 2002). The improvement and development of the pasture should start with pasture management, better use of existing pasture resources and replacement of existing native species with improved pasture species. The other method is to introduce species by over-sowing into the existing pasture species (Whiteman, 1980). The basic philosophy is that the existing species in the region are well adapted to the existing environment. Therefore the management approach should be to increase or at least maintain the most productive species for animal production.

All introduced pasture species should be evaluated for the characteristics described in the following sections.

1) Forage yield

The total DM yield of a species is a crucial characteristic for determining the animal carrying capacity for a pasture. All selected species should be able to provide the maximum DM yield in harsh environments. Some high yield grasses with vigorous growth characteristics can limit the ability of legumes to grow. However, selection of grasses should be based on yield and their associative ability with other pasture species. For legumes, however, selection for yield is important since N fixation and N yields are related to total DM yield. Some important characteristics that will contribute to the yielding ability of the pastures include:

- rapid establishment and seedling vigour
- tolerance of stressful conditions
- ability to remove and utilise soil nutrients
- ability to compete with other companion species and weeds (Whitman, 1980).

2) Persistence

Pastures in general are permanent and require long term survival under fluctuating climatic conditions and regular defoliation by grazing animals. Therefore, the following characteristics are associated with pasture persistence:

- tolerance of grazing
- ability to survive water stress or water logging
- ability to withstand low and higher temperatures
- resistance to disease and insect infestation
- ability to regenerate from stolons, rhizomes or seed (Whitman, 1980).

3) Associative ability

The best pasture species are those that have the ability to survive in harsh conditions and still be productive. Productive pasture refers to mixed swards which have the following advantages:

- a combination of different species with different seasons of growth
- different species providing different nutrients

- legume species contribute the most CP in the feed and provide nitrogen (N-fixation) input into the pasture system.

In this situation the pasture can establish competitive growth behaviour with the influence of light, water and nutrients (Donald, 1963; Hall, 1971). They can be modified by the growth form of the various species, seasonal growth, palatability, selective grazing and rate of growth (Jones, 1974).

4) Ease of propagation

Establishment of a pasture from seeds or vegetative cuttings is crucial to consider in large-scale pastures. The availability of seed and its production are also important for pasture persistence, particularly for annual and perennial species. High seed producing species can ensure regeneration following some natural catastrophes, e.g. drought, excessive frost, fire and overgrazing. However, it is crucial to evaluate all pasture species with their potential characteristics and yields before utilising them in pasture production.

5) Adaptation

The best cultivars and species are those that are generally adaptable to the local environment and conditions (e.g. heat stress, drought and low fertility soil).

6) Species or cultivar characteristics

The best pasture species and cultivars often have the following characteristics which suit tropical environments:

- ease of establishment
- ability to tolerate drought spells
- palatability and high yield (DM)
- persistency and competitive growth
- ability to maintain and improve soil nutrients and OM of the pasture (Crowder and Chheda, 1982).

Management of grazing pasture involves the manipulation of available resources to meet the plant and animal requirements, in order to sustain a stable system of production. The improvement options/factors of forage and fodder resources include:

- selection of adaptable grass species and higher yields (grasses and legume species)
- seasonal distribution and quality of species
- manipulation of fertiliser input
- control of grazing time, with the correct SR (frequency and intensity of grazing)
- effective methods of grazing system
- different types of grazing animals to control of herbage quality and NV
- pasture maintenance (fertilisation, weed control and herbage accumulation)
- use of available supplementary feeds (Crowder, and Chheda, 1982).

In order to improve animal productivity (meat, milk, wool and reproduction) and herbage yields (DM and feed unit) skilful management is required (Evans, 1981). The successful husbandry manager can judiciously manipulate these factors to optimise pasture and animal production (Cowder and Chheda, 1982).

4.3.3. FERTILISER USE ON PASTURE

Using artificial fertilisers can undoubtedly increase both pasture productivity and soil fertility. Tropical soils are known for their infertility, which constrains plant growth in about 60% of tropical soils (Beinoth, 1985). Some major and minor elements are deficient in some places and it is difficult to predict the availability of particular nutrients due to insufficient soil information. Different varieties of grasses require different nutrients for persistence. The use of inorganic fertiliser on pasture in Tonga is uncommon due to the high cost. If fertiliser is needed, such factors as economic return, pasture species, soil nutrients and nutrient quality and loss should be considered before using them (Crowder and Chheda, 1982).

1) Economic return

In intensive management systems, fertiliser use aims to optimise pasture and animal outputs. These points should be considered:

- types and quality of the cattle (breeds), their ability to eat and utilise extra pasture
- price of the animal product (e.g. $1.00-1.50 per L in Tonga)
- cost of fertiliser ($/kg of fertiliser nutrients)
- credit and return from investment (fertiliser)
- level of technology
- managerial skills of the farm manager/operator.

2) Pasture species and their botanical composition

Pasture species differ in their fertiliser requirements. Some have higher extraction and utilisation of soil nutrients than others. Grasses generally respond well to N-fertiliser, while legumes respond well to P. When there is a high percentage of legumes in the pastures, P fertiliser can be applied at regular intervals.

3) Soil nutrient and their availability

The quantity and availability of soil nutrients vary with soil type, moisture, temperature, microbial activity and previous land use. The availability of individual soil nutrients varies because some are released by mineralization, while others are fixed within the soil fraction and may be released over time.

4) Quantity of nutrient removed

The extraction of nutrients from the soil is related to the yield and CC of the herbage. For example, a grass species that yields 10 t/DM per hectare and contains 1.5% of N, can extract 150 kg of N from the soil including what is in the roots and stubble; a legume that yields 10 t DM/ha can extract about 200 kg of N (part of which is fixed by the associated rhizobium), 25 kg of P and 200 kg of K, plus minor elements (Crowder and Chheda, 1982).

5) Loss of nutrients from the soil

The mineralisation of soil OM occurs when rains begin after the dry season (Tonga i.e. December to January), resulting in a flush of available nutrients (especially N); however, the heavy rainfall can often result in the leaching of about 50-60% of the N and 20-40% of the K from the rooting zones. The remaining nutrients found in the lower soil profiles will be recycled by deep rooted pasture.

However, the decision to apply fertiliser is ultimately an economic one. The rate and regularity of applying fertiliser will depend on the above factors, including the level of pasture utilisation, which will depend on SR and grazing management (Kemp *et al.*, 2002). The application of NPK fertiliser will boost pasture growth and enable fast establishment of growth, with the P maintaining legume growth and therefore N fixation (Kemp *et al.*, 2002). Application of fertiliser can increase pasture production and overcome nutrient deficiencies in both soil and livestock via nutrients in pastures. Fertilising pastures with essential elements generally boots pasture yields until they are limited by another nutrient deficiency (Figure 4.7).

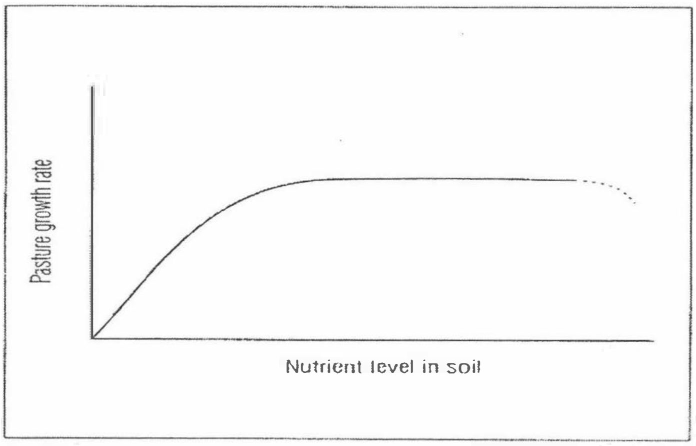

Figure 4.7. The general response of pasture growth to the level of mineral nutrients in the soil. The dotted line shows the toxic effects of excessive application of some nutrients (Kemp *et al.*, 2002).

In addition, excessive application of fertiliser can result in decreased growth and toxicity, e.g. due to micro-nutrients such as Bo (Kemp *et al.*, 2002).

4.3.4. MAINTAINING NUTRIENT CYCLING IN PASTURE

Farmers are strongly advised to rebuild nutrient availability through an expert nutrient cycling system in pasture paddocks. Paddocks which have been in pasture continuously for more than 15-20 years should be rotated with cultivation of a crop (Figure 4.8). The main components of pasture ecosystems are animals, plants (pasture) and soil with nutrients (Kemp *et al.,* 2002). The nutrient pathways in grazing pasture are: from the soil or air, to the plant, returned to the soil in plant residue or through the grazing animals (Crowder, 1985). Figure 2.9 in Chapter 2 illustrates the component and major pathways associated with nutrient cycles in grazing pasture. Kemp *et al.* (2002) stated that 30-95% of plant nutrients obtained from soil by grazing animals and 65-95% of nutrient uptake by plants, are returned to the soil in the form of litter, root residues or animal excreta (urine and faeces).

The fertility of the soil can be maintained by executing judicious pasture management. Apart from urine and faeces, inclusion of legume species in pasture undoubtedly boosts pasture yield and replenishes soil minerals. Another alternative to improve pasture productivity is rotating permanent pasture with cultivating crops (Figure 4.8), which is more economical than regular application of expensive fertiliser.

a) **b)**

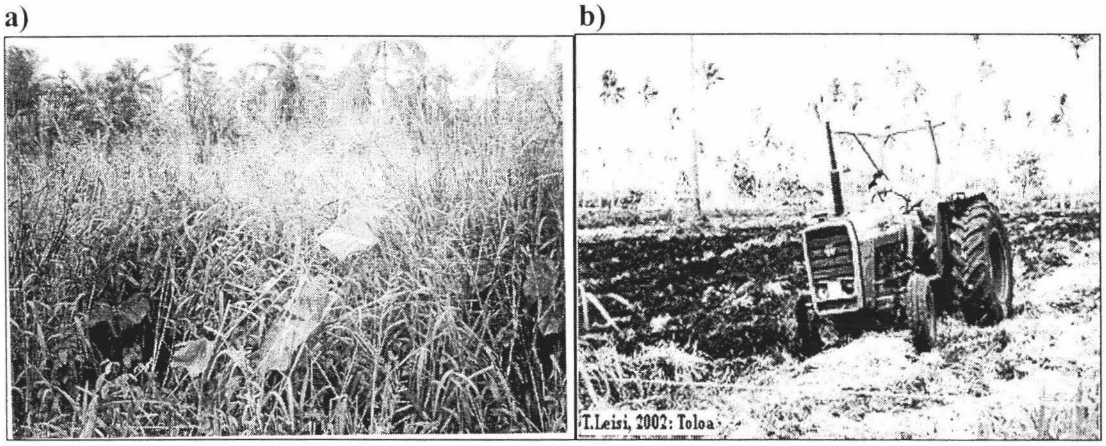

Figure 4.8. a) Forage re-growth on a fallowing cultivated paddock; **b)** the same paddock re-ploughed for cultivation on its third rotation (Fisi'ihoi, 2006).

In Figure 4.8, the physical properties of the soil become normal and minerals have been replenished to make it more fertile than it was before. The benefits of using this technique in Tonga have been observed on both crop yields and pasture growth. Based on these observations, this method is advised due to the following reasons:

- the physical properties of the soil could be renewed and minerals replenished
- more OM collected from crop residues and extra minerals added from fertiliser applied to crops
- improvement of aeration, pH, soil temperatures and moisture content
- establishment of new pastures can be quicker.

Maintaining the soil nutrient cycle is very important for upholding pasture productivity in Tonga.

4.3.5. TOPPING, MOWING PASTURES OR SLASHING

This style of grazing management has been used profitably in developed countries such as New Zealand and Australia. This technique is suggested for Tonga because of its advantages to both pastures and dairy production. Holmes *et al.* (1987) cited that mowing in early summer could stimulate re-growth of new vegetative tillers and increase the FV of re-growth. Irregular topping can be done if rain occurs regularly and during the wet season. Theoretically, there should be advantages to topping grass inflorescences in their early development to avoid apical dominance and to stimulate the growth of existing and new vegetative tillers (McDonald, 1986).

McDonald (1986) showed that topping at various stages of flowering during summer improved herbage quality when seed head density on pasture ranges from 1,200-2,000 m^2, reducing pasture dead matter levels and improving herbage N and digestibility, despite the fact that total herbage accumulation may temporally reduce after topping. Pasture should be topped or mown either before or after grazing to achieve high quality pasture and increase MS during summer, even though the total DM production will be reduced (Kolver *et al.,* 1999). The MS production will be increased by 4.0% on topped pasture compared to non-topped pastures (Bryant, 1982 cited by Holmes and Hoogendoorn, 1983). In addition to MS, LW also increases by 0.76 kg/cow/day after either mowing before grazing or topping after grazing, as a response associated with an increase in the ME content of summer pastures, of 0.2 and 0.6 MJ ME/kg DM respectively. In conclusion, it is suggested that pasture should be mown after cows have grazed it, especially during late spring and early summer.

Slashing is one management technique used to reduce bulk and increase leaf percentage of sward (Chacon and Stobbs, 1976; Minson, 1976). Davidson and Cowan (1981) experimented with this method in Australia using three treatments: *control, slashing* (10-14 cm height above ground) and *variable SR* (three and five Friesian cows/ha). The trial was designed to determine the effect of different pasture management strategies on individual cows' milk yield during the summer wet season using *P. maximum*, Gatton and *B. decumpen* (signal grass). The results indicated that milk yields/cow/day was higher ($P < 0.05$) for cows in the slash treatment in week 10, 11, 12 and 13 and on cows in the variable treatment in week 11 (Figure 4.9). However, each time the pasture was slashed or an extra cow was added, the milk yield fell and the extent of this fall depended on the severity of slashing or the number of extra cows added. Additionally, yield steadily increased as pastures re-grew or whenever the extra cows were removed.

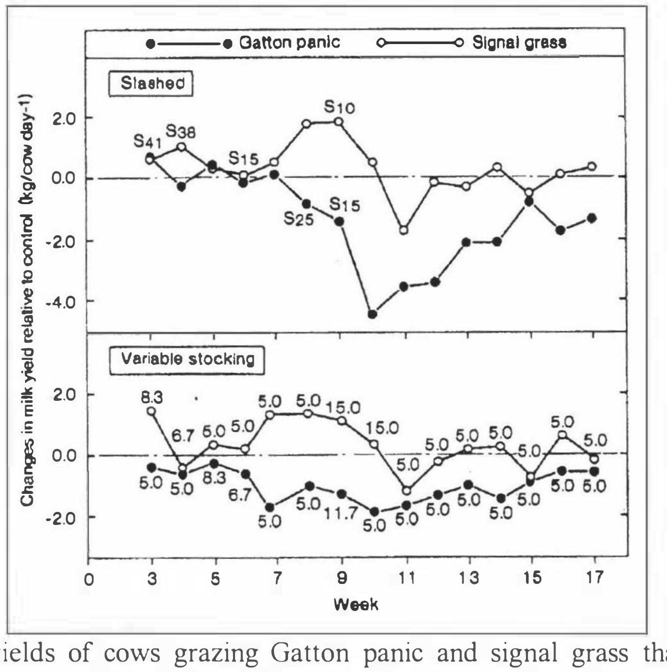

Figure 4.9. Milk yields of cows grazing Gatton panic and signal grass that were slashed or stocked at variable rates relative to the milk yields of cows grazing continuously. S denotes the time and height of slashing (cm above ground) and the numbers on the variable stocking rate (cows ha^{-1}) (Davidson *et al.*, 1981).

4.4. GRAZING AND FEEDING MANAGEMENT

Grazing pastures are different from concentrate feeds, because the pasture must re-grow, time after time, to provide cows' feed for next week, next month and next year. Therefore good grazing management must also be good feeding management, and it must cater for the present and future needs of both the pasture and the cattle. In addition, pasture is a 'live-feed' with a short 'self-life' before it begins to age, deteriorate and decay. The main objectives of good grazing or feed management are to maintain the balance between the rate at which the pastures grow and the rate at which the pastures are consumed (Figure 4.10), so that:

- the herd is fed adequately throughout the year

- the majority of the pasture which grows is also eaten by the herd and thus the wastage of pasture is reduced
- the development, growth and survival of vigorous new shoots or tillers in grasses and legumes is assured
- after each grazing, the pasture is in a condition which will ensure vigorous re-growth
- the nutritional quality of the pasture is maintained at high level (Holmes *et al.*, 2002).

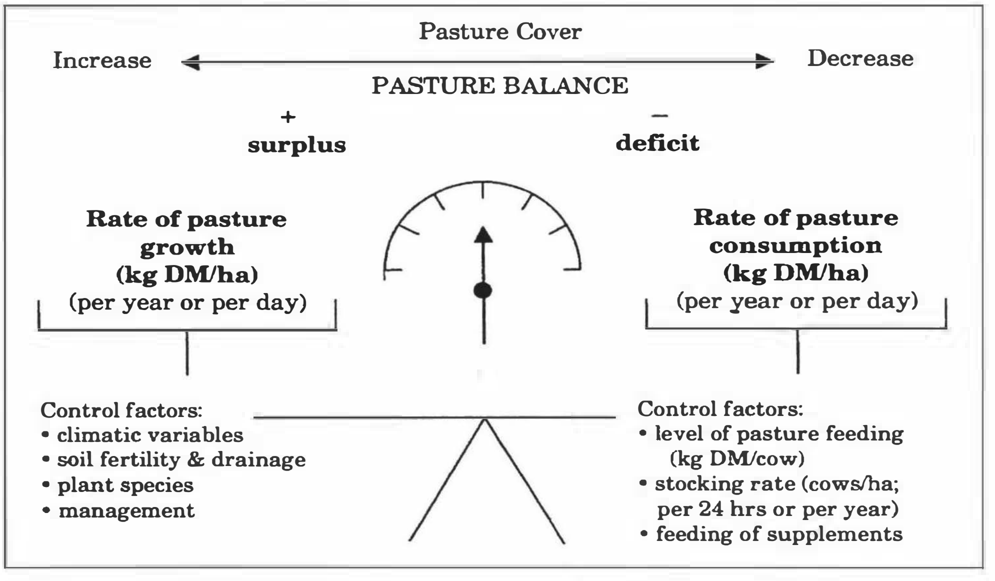

Figure 4.10. The balance between the rates of pasture growth and consumption (per hectare) necessary to minimise the development of surpluses on deficits (Holmes *et al.*, 2002).

Holmes (1980) stated that good grazing management can make certain a supply of nutritious herbage over the growing season at low cost, avoid physical waste of herbage, ensure efficient utilisation by the animals and maintain a long, productive sward life. It should obtain the highest yield DM per ha without significantly reducing production per animal (i.e. producing a maximum net return from pasture, livestock and fertiliser applied). Animal production per unit area (UA) of land depends on two independent factors: 1) animal performance; and 2) pasture carrying capacity. Whiteman, (1980) reported that the output of animal production per unit of land is a function of the production per animal and the number of animal per UA.

Animal production = Production^{-1} x Number of animal^{-1}
(pasture production/ha) (no. of animal/ha)

In the dairy production enterprise, it is the manager's function to regulate the numbers of animals per UA so cows can use the fluctuating supply of herbage most effectively and efficiently. The production per head of animal is a reflection of their:

- genetic potential
- the standard of animal management and husbandry
- the quantity and quality of the herbage eaten.

The number of animals required per hectare (SR) will depend on the pasture available at a certain time or the pasture yield (Whiteman, 1980). In tropical pastures, the average DMI per cow per day ranges from 10-12 kg DM/day for Friesian cows, 7-9 kg/day for Jerseys and 6-10 kg/day for crossbred cattle. The potential of these pastures for MP was suggested to be 4,000 kg milk/lactation for Friesian and 2,700 kg milk for Jersey (Cowan *et al.*, 1975).

4.4.1. GRAZING SYSTEMS

The following are recommended grazing systems which satisfy the requirements of both pastures and livestock with minimum labour and costs. Many grazing systems can be used on dairy farms, but only a few can be practiced in Tonga (including the following systems).

4.4.1.1. Rotational grazing

In these systems, the cows are moved on to a fresh area of pasture at regular intervals, which allows the grazing paddocks to be rested and re-grow after every grazing (Holmes *et al.*, 2002). This type of grazing management is suited to most intensively used pastures (Crowder and Chheda, 1982). This system can obtain a more uniform grazing of the pasture sward than continuous grazing. Its main advantages include minimising pasture wastage, simple control of grazing and conservation of pasture and production of higher forage yield than continuous grazing (Crowder and Chheda, 1982; Holmes *et al.*, 2002). Paddocks are grazed in rotation according to a specific rotational length. When the cows return to previously grazed paddocks, the grasses should have grown to a uniform growth ready for grazing. The interval between grazing periods is dependent on pasture growth, pasture species, moisture availability and types of grazing livestock (Crowder and Chheda, 1982).

The re-growth periods of the grasses are very important in scheduling grazing times. The rotation program must be controlled to avoid harming the re-growth potential of pastures. Special consideration must be given to the phenological and morphological characteristics and physiological responses of the plant species that comprise the pasture sward and the effects of grazing pressure of re-growth potential. Thus this system should be designed to allow flexibility in resting times and the grazing period (Crowder and Chheda, 1982).

4.4.1.2. Strip grazing

Strip grazing (break grazing or block grazing), a form of rotational grazing, is recommended for larger, permanent paddocks. This method is able to achieve additional control over the grazing rotation. In this method, a small section of a pasture or grazing area is separated by a temporary electric fence and the cows are permitted to graze fresh pasture each day. The area given each day will determine the quantity eaten per cow daily and the amount of the feed that is wasted (Holmes *et al.*, 2002).

4.4.1.3. Grazing intensity

Grazing intensity (GI) is used to describe the number of animals grazing per UA at a point in time. It is normally expressed as the number of animals/ha/day. Grazing intensity is a function of the overall farm SR and the proportion of the farm grazed each day (i.e. rotation length). Mathew *et al.* (2002) defined this relationship as:

Grazing intensity	=	Stocking rate	**x**	Rotational Length
(animals/ha/day)		(no. animal/ha)		(days)

For example: calculating the rotational length (days):

Assume this is a farm's grazing details:

a) Farm size	=	40 ha
b) Herd size (total cows)	=	120 cows
c) Pre-grazing herbage mass	=	2,500 kg DM/ha
d) Intake required per cow per day	=	15 kg DM/cow/day
e) Residual herbage mass (for intake)	=	1,400 kg DM/ha

1) **Pre-grazing DM** = 2,500 kg DM/ha
Post-grazing 1,400 kg DM/ha
Harvested DM = **1,100** kg DM/ha

2) **Grazing intensity** (cows/ha/day) = $\frac{\text{Harvested DM}}{\text{Intake/cow/day}}$ **OR** $\frac{\text{1,100 kg DM/ha}}{\text{15 kg DM/cow/day}}$ = **73.3 cows/ha/day**

3) **Area grazed** (ha/day) = $\frac{\text{Herd size}}{\text{Grazing intensity}}$ **OR** $\frac{\text{120 cows}}{\text{73.3 cow/ha/day}}$ = **1.64 ha/day**

4) **Rotational length** = $\frac{\text{Farm size}}{\text{Area grazed}}$ **OR** $\frac{\text{40ha}}{\text{1.64 ha/day}}$ = **24.4 days** (or **25** days)

This calculation can determine a rotational length that can feed a dairy herd at the required intake level (15 kg DM/cow/day). It is important to consider whether this harvested DM (1,100 kg DM/ha) can be maintained again (2,500 kg/ha) when the herd returns in the second rotation.

This will occur in the second rotation (25 days rotation) if the rate of pasture production is 44 kg/DM/ha/day, because 44 x 25 = 110 kg DM/ha:

Post-grazing DM	= 1,400 kg/ha
Pre-grazing DM	= 2,500 kg/ha
DM increase required	= 1,100 kg/ha
Pasture production required	= DM increase required

OR $\frac{\text{1.100 kg/ha}}{\text{44 kg DM/ha/day}}$

Rotational length required = **25 days**

If the rate of pasture production is above 44 kg DM/ha/day, then the herbage mass (the amount of pasture per unit area i.e. kg DM/ha) and average cover will increase. This will lead to a reduction in pasture quality and therefore affect both intake and production (milk). If the rate of pasture production is below 44 kg DM/ha/day then the average cover will fall, the pre-grazing DM will be less than 2,500 kg DM/ha and intake per animal and MP will not be sustained.

The GI per ha can be increased when rotation length is increased, if the same amount of FI per cow/day is maintained when this change is made; the pre-grazing and post-grazing HM also requires an adjustment. The changes in rotational length are usually associated with the level of FI - with intake decreasing if rotation is lengthened because less pasture is offered per cow per day (Holmes *et al.*, 2000). Grazing intensity has a strong effect on livestock intake performance and on long term economic returns to animal enterprises primarily based on grazing. In this way, the generalised livestock response to low grazing intensity versus high grazing intensity (overgrazing) are summarized as follows:

Low grazing intensity:

- higher gains per head
- lower gains per area
- higher milk yield per herd
- higher DMI/cow
- higher DM/ha
- less time and energy spent grazing
- higher pregnancy rate and calving (%)
- reduced forage harvest efficiency
- greater nutritional adequacy of diet
- future pasture quality lower

High grazing intensity:

- lower gains per herd
- higher gains per area
- reduced milk yield per herd
- reduced DM intake/cow
- higher DMI/ha
- more time and energy spent grazing
- lower pregnancy rate and calving (%)
- greater forage harvest efficiency
- greater nutritional deficiency of diet
- future pasture growth higher

4.4.1.4. Subdivision of paddocks

Grazing paddocks should be divided into smaller sizes, especially when there is only one mob (40-60 cows) on the farm. About 28-30 equally-sized paddocks are suitable for managing smaller farms and mobs of dairy cows. Matthew *et al.* (2002) recorded these rotational lengths recommended if there is only one mob on the farm:

- one paddock each milking (two paddocks/24 hrs) - 14 days rotation

- one paddock day/half at night - 21 days rotation
- one paddock per 24 hours - 28 days rotation
- two days per paddock - 56 days rotation
- three days per paddock - 84 days rotation.

The advantages of having smaller sizes of paddocks include:

- ease of controlling rotational length
- avoidance of selective grazing
- pasture receiving uniform grazing
- the re-growth can be faster
- avoiding persistence of older forage
- enabling cows to graze young and fresh pasture.

4.4.1.5. Continuous grazing

This is an extensive system in which cows can remain on the pasture for longer periods of time. This is common in the tropics where low-yielding pastures can be grazed more satisfactorily. The number of animals kept per UA of land is usually constant. Spot-grazing is likely to occur because cows repeatedly graze in 'patches' which will keep the sward height at a lower level than in areas avoided. This system is recommended for drying off cows, where selective grazing of more nutritious species and for specific parts of the plant in mixed sward pastures is preferred (Crowder and Chheda, 1982).

Cowan (1975) stated that cows grazing in tropical pastures required 10-12 hours of grazing per day to satisfy their nutritional needs. They are usually reluctant to graze for longer when the temperature is high (< 30°C); therefore, night grazing and feeding is strongly encouraged during hot weather. Milk production/ha is linearly increased with an increase in SR, but MP/cow is linearly decreased (Cowan, 1984). There is also a wide range of SR used according to different type of pasture for milking cows. The following SR have been suggested after field testing:

- 1.6 cows/ha (Friesian) on Guinea-glycine mixed pasture, produce 5,351 kg DM/ha/yr or 3,345 kg of milk/ha/year

- 3.5 cows/ha (Friesian) on fertilised Guinea pasture, produce 8,880 kg/ha/year milk yield.

Therefore, both of the SR were able to maintain a stable pasture of about 2,500 kgDM/ha on offer, or the amount of forage thought to minimise dairy production (Aminah and Chen, 2006).

4.4.1.6. Cut and carry system

The cut and carry system (or zero grazing) refers to the practice of cutting and harvesting all the herbage or fodder and feeding it to the cows on feeding pads; the pastures are not grazed at all (Holmes *et al.*, 2002). It is an expensive method for larger farms, but suitable for smaller herds consisting of 30-50 milking cows. Residual feedstuffs can be used for this system, such as alfalfa; sweet potato forage; banana leaves; maize; cassava leaves; and mowing grasses.

4.4.2. FEEDING MANAGEMENT DURING HOT WEATHER

The first feeding response of a hot cow is to reduce FI (Davidson *et al.*, 1996). The use of any feeding technique to maximise FI during hot weather in Tonga is unusual. However, a few feeding and management techniques have been used in some tropical countries (mainly Australia) to satisfy FI during hot weather. The following are suitable feeding and management techniques which will possibly be executed in the dairy system in Tonga.

4.4.2.1. Water and shading effects

Water is undoubtedly the most important nutrient for dairy cows during hot weather. It should be always available, fresh and clean during the hot days, or whenever they are needed. Water troughs should be cleaned regularly and should be conveniently located to encourage drinking during the summer season. West (1987) recommended that water troughs be shaded, to encourage drinking during the hot part of the day and to keep the water cool. Figure 4.11 shows that shading lactating cows while sprinkling produced a considerably higher dry matter intake.

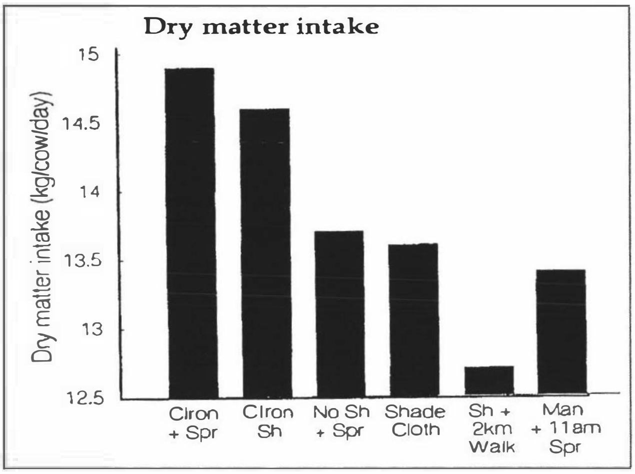

Figure 4.11. Average dry matter intake of a mixed ration from **am** to **pm** milking for six day cooling options. **CIron + spr** = cows under corrugated iron with sprinkler; **CIron sh** = cows under corrugated iron without sprinklers; **No sh spr** = cows without shade but with sprinkler; **Shade cloth** = cows under 65% shade cloth; **Sh + 2 km walk** = cows under shade with 2 km return walk to the dairy; **Man + 11 am spr** = a managed system - cows with no shade, but sprinkled if their 11 am respiration rates were above 80 breaths/minute (Davidson *et al.*, 1996).

From Figure 4.11, daily DMI were highest for cows shaded under corrugated iron (14.8 kg DM) compared to other treatments. The patterns of DMI were exactly opposite to rectal temperature and respiration rates when recorded at 2 pm. Shading cows from direct sunlight could avoid additional heat loads, including heat energy that is reflected from the objects surrounding them. Their coat colour and thickness, and the angle of their body position in relation to the sun, also contributed to the heat stress of the cows (Davidson *et al.*, 1996). Shading management is a judicious plan to keep body temperature lower and prevent it from exceeding its zone of thermoneutrality. Natural shading trees are the cheapest and easiest way of minimising heat stress of dairy cattle for Tonga (Figure 4.12).

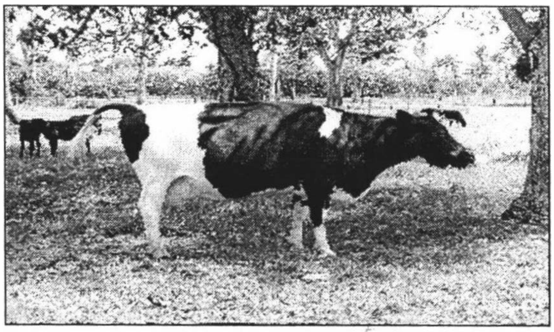

Figure 4.12. Shading trees for cows in the grazing paddocks (photo taken at Tupou College, Dairy farm, Tonga by Fisi'ihoi, 2006).

Trees protect cows from solar radiation and should be included in the overall farm management plan. Artificial shade is also recommended if no natural shade is available (e.g. open sidewall, shade cloth, corrugated iron shelter).

4.4.2.2. Energy feed supply

Energy is a critical nutrient and should be supplied during hot weather because FI declines due to the effects of heat stress. This is the biggest limitation to milk production, therefore cows should eat diets containing more energy per kg DM in order to maintain higher milk yield. This can be done by providing concentrate feeds ($\pm$ 50% grain) and decreased proportions of forage in the diet (West, 1987). Dietary fat content should not exceed more than 5-6% of the total DM so as to avoid depression of milk fat content, acidosis and rancidity in the feed. Adding dietary fat in feed is an excellent way to increase the energy content of the diet, especially in the summer, but too much fat in feed can cause digestive upset (West, 1987).

4.4.2.3. Feeding fibre feeds

Supplying cows with feeds that have higher fibrous content produces more heat than the digestion of concentrate feed stuffs (West, 1987). Heat stressed cows usually reduce their FI, therefore the following feeds and preparation procedures can be practiced to maintain higher FI during hot days:

- provide green sweet potato forages (vines)
- provide young, palatable forages for the cows
- chop pumpkin into smaller pieces
- chop cassava tuber and leaves into smaller pieces (must be dried before eaten)
- add wet ingredients (e.g. brewers grain) to the supplemented feed (Smith, 1992)
- if possible, add water to maintain freshness and improve intake.

Therefore, the total DM (e.g. sweet potato vines, pumpkin, maize, or any crop residues) provided per feed should not be less than 400 kg DM raw materials for 40 milking cows. This mixed ration can be served either indoors on a concrete floor or in an adequate space suitable for cows.

4.4.2.4. Feeding succulent feedstuffs

Cows should be provided with succulent feedstuffs or feeds that are high in moisture such as green, chopped forages and by-products such as wet brewer's grain, during hot conditions. The inclusion of succulent feeds in the dairy ration will encourage FI during hot weather. However, the ration should not be too wet or exceed 50-55% water, because this could restrict cows' intake (West, 1987). Additionally, succulent feeds can spoil more quickly than dry feeds, particularly during hot weather.

4.5. MANAGEMENT OF HEAT STRESS

Heat stress (HS) management is an on-going activity aimed at minimising stresses imposed by high temperatures (HT) during the summer and drought seasons. The ideal AT for dairy cows is between 6-25°C; above 25°C cows need energy to cool themselves by losing heat through increased respiration (Gerald *et al.*, 1999). High producing cows are the most sensitive to HS due to their higher FI (which is responsible for their level of production). Their DMI may decrease by 8-12%, with milk production losses of 20-30%, when temperatures exceed 90°F (Gerald *et al.*, 1999).

Chapters 1 and 2 have discussed the effects of high temperatures on both dairy and pasture production in tropical regions (e.g. Tonga). The two primary factors which cause heat stresses are HET and high RH. In addition, direct radiation energy from the sun also contributes to HS of cows standing under the sun without shade. Australia has developed outstanding management techniques for minimising HS imposed by higher temperatures. Some of these management techniques are appropriate to practice in Tonga, and are described in the following sections.

4.5.1. WATER

Water is undoubtedly the most important nutrient for dairy cattle during times of HS, because it is necessary for the dissipation of evaporative heat through the lungs and by sweating (Beed, 1992; Harris and Beed, 1993). Voluntary intake of water ranges from 4-14 gallons per cow per day (Shirley, 1985). Cows' milk contains 87% water. Water intake (WI) is highly correlated with milk production (MP) and DMI (correlation coefficient of .94 and .96, respectively) (Dado and Allen, 1994). Cows should consume 1-2 kg of water for each kg DMI, but this increases if water contains high levels of *cations* and *salt*, or if they are eating high protein feed. Water consumption is increased consistently when the ET increases.

Cows' bodies constitute 60-70% water, therefore the amount of water a cow can drink will depend on their body size and weight; milk yield at lactating period; quantity of DMI; ET and temperature humidity index (THI); RH; body temperature; water in the faeces; physiological needs (lactating/dry); and the chemical and physical nature of the diets (Brook and Morel, 2003). The physical properties of water are important for the transfer of heat from the body to the environment. For example, during cold stress, the high heat capacity of cows' bodies will act as insulators to conserve body heat (Waldner and Looper, 2005). The important roles of water include the following:

- maintenance of body fluids and proper ions balance
- digestion of the food consumed
- providing a fluid environment for the foetus
- metabolism
- removal of waste
- control of body temperature
- transfer of nutrients to and from the body tissues.

Water intake can be raised by 50-60 L/cow/day during summer to cool themselves when temperatures rise from 30-35°C (Beed, 1992). With inadequate water supply during the hot summer, milk production decreases by 50% and reproductive proficiency of lactating cows also decreases (Bray *et al.*, 1996). An adequate water supply will reduce such HS problems. Lactating cows satisfy their requirements with 80-90% higher WI than dry cows.

European breeds can consume the same DM and drink more water than the *B. indicus* at similar ET. When water is restricted in ruminants, both the DMI and WI to DM ratio declines, particularly in Brahman cattle when compared with European breeds. Cows can be encouraged to consume water by the following methods:

- putting the troughs closer to shading trees, where cows can rest and drink during hot days
- providing excess clean and cool water right after milking (a large intake of water shortly before milking could elevate the freezing point of milk)
- ensuring that there are enough troughs and sufficient water supply in each paddock per group
- always keeping the water troughs clean and fresh (brushing empty troughs with Cl solution to disinfect surfaces and reduce algae growth).

The decline of voluntary water intake in lactating cows is affected by the level of milk yield; DM of feed; higher temperatures (< 32°C); water supply at peak demand periods; cleanliness of troughs; and water quality (too acid: 5.1-5.5, or too alkaline: 8.9-9.0 pH) (Shirley, 1985). Holmes (1979) reported that as the amount (kg) of DM eaten increases, so too does the amount of water cows should drink (kg DM eaten/kg water intake) when they are exposed to high temperatures. For example, *B. indicus* cattle drink 3 kg of water/kg DM at 4°C and 12 kg at 38°C; the corresponding values for *B. taurus* cattle are 3 kg and 18 kg respectively (Winchester and Morris, 1956). Inadequate WI can be observed in cows, by the following signs:

- constipated faeces and low urinary output
- infrequent drinking
- decreased milk production
- drinking their urine and puddles.

In conclusion, availability and quality of water are extremely important for animal productivity and health. Limited supplies of water will depress production, FI, LW and growth. In order to increase WI during the summer weather, cool water must provided in large quantities and always be fresh and clean.

4.5.2. SHADING OF DAIRY COWS

Modification of the environment is necessary when productivity needs to be maintained at high levels for dairy cattle. Shading cows from solar radiation can reduce rectal temperatures by 2-4%, respiratory rate by 29-60%, improve DMI by 6.8-23.2% and improve milk yield by 9.4-22.7%, compared with unshaded cows (Schnieder *et al.*, 1984; Mallonee *et al.*, 1985; Schnieder *et al.*, 1986; Robison, 2005). Cows shaded during the dry period yielded 4.5% and 13.6% more milk at 100-305 days postpartum, and delivered calves weighting 3.1 kg more than cows receiving no shade (Collier *et al.*, 1982). Figure 4.13 indicates the response of milk yield to various shading trials conducted by Davidson *et al.* (1996) at Matdapilly Reseach Station, Australia.

a) **b)**

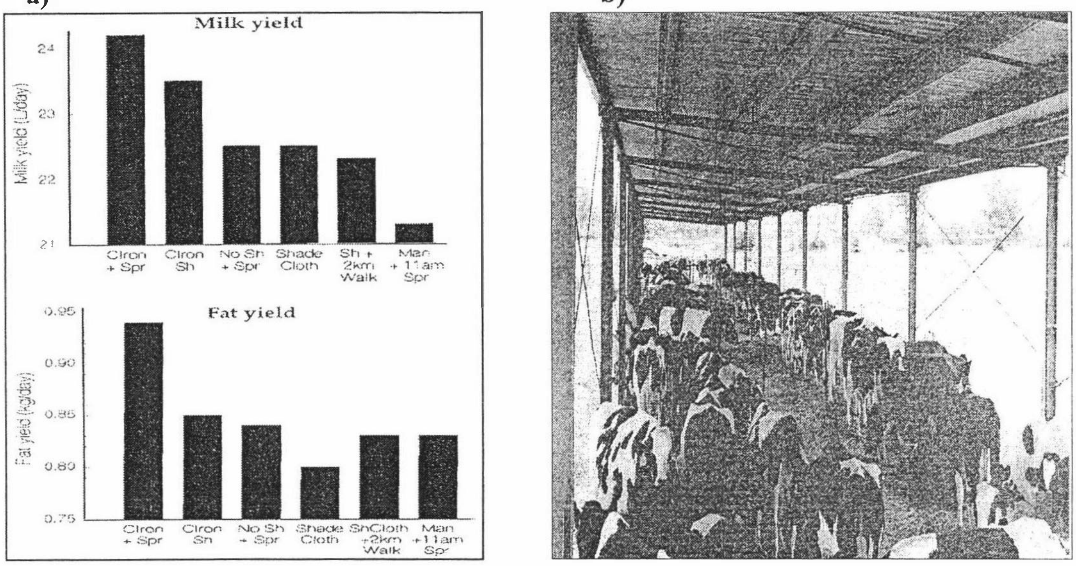

Figure 4.13. a) Average milk yields and fat yields for six cooling options over summer; **b)** cows shaded under corrugated iron roof during the hot days (right) (Davidson *et al.*, 1996).

As shown in Figure 4.13, the highest milk (L) and fat (kg/day) yields were produced when cows were shaded under corrugated iron roofing with sprinklers. Davidson *et al.* (1996) stated that the cows shaded under the corrugated iron with sprinklers quickly achieved an 80% pregnancy rate.

4.5.3. COOLING/SPRINKLING WITH WATER

Sprinkling milking cows with water is a simple and cost low technique designed to minimise HS (Davidson *et al.,* 1999). This method has been practiced and approved in some tropical countries, e.g. Australia, Israel and USA, for managing heat stress in cows. Wealthier countries use electrical cooling systems such as the "*spraying and fan system*" to cool cows. This method can result in big dividends for both dairy farmers and cows in terms of increasing milk yield, FI and weight gain (Morrison *et al.,* 1974;

Davidson *et al.*, 1996; Mullinax, 1999). Cooling systems can reduce the effects of high AT by 7°C; and can be effective if there is adequate air movement around the cows to increase evaporation of water soaked into their coat (Davidson *et al.*, 1996).

Sprinkling cows increases milk yield, but reduces rectal temperature and respiratory rate (Figure 4.14). These strategies will only be effective if there is adequate air movement around the cows (Davidson *et al.,* 1996). The main response to cooling is the increase of the DMI (e.g. in Florida by 7.1%, in Kentucky by 9.2% and Missouri by 7.1%), and increased milk yields (e.g. by 11.6%, 15.8% and 8.6% for the same three states, respectively) (Bucklin *et al.*, 1991).

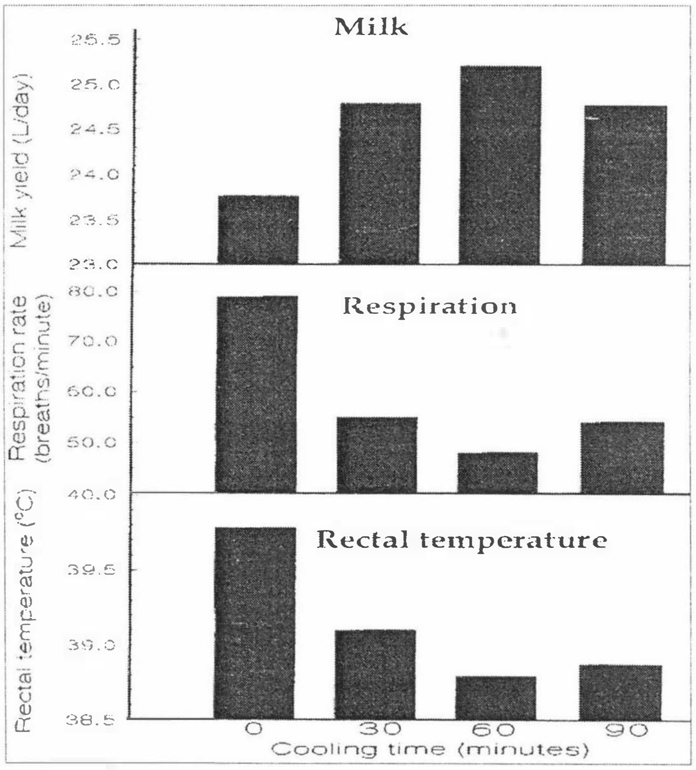

Figure 4.14. The effects of cooling cows in the yard prior to the afternoon milking (Davidson *et al*., 1996).

The data in Figure 4.14 shows that milk yield was higher and the cows were more comfortable when they were cooled for 30-90 minutes prior to the afternoon milking. Cows should be sprayed with a fine mist for a few minutes (i.e. a pattern of two minutes on and five minutes off) to provide effective cooling. Morrison *et al.* (1974) reported that spraying cattle at different time intervals could stimulate FI (Table 4.3). Sprinkling at 30 minute intervals (C) effectively increased FI by more than the other options.

Table 4.3. Performance of cattle in a test, over 112 days, with 21 animals per treatment (Morrison *et al*., 1974).

Treatment	Daily food intake/kg DM/head
No cooling	16.1^{a}
60 minute sprinkling interval	16.87^{b}
30 minute sprinkling interval	18.60^{c}
Refrigeration	17.79^{d}

a, b, c and d values with appropriate comparisons having different superscripts are significantly different at $P < 0.05$.

Animals inhaling cooled air can exchange heat with the air, increasing the rate of heat removal from their body (MacFarlane *et al*., 1966). Cows should be cooled in the holding pen one hour prior to afternoon milking when temperatures are cooler. Sprinkling can also increase water consumption, presumably to replace water lost due to the high temperatures (Thompson *et al*., 1978; Webster and Wilson, 1980). The following are recommendations for cooling cows in the dairy yard before they are milked in the afternoon:

- cows should be sprayed prior to the afternoon milking when the THI is above 78% and the respiration rate is above 60 breaths/minute
- turn on yard sprinklers prior to the cows arriving in the yard to cool the cement or spray with a hose if there is no sprinkler (e.g. in Tonga)
- when the cows arrive at the yard, cooling may start. Cool them either continuously, or at a 'two minutes on, five minutes off' sprinkling system for 30-60 minutes prior to milking. The hotter the cows are, the longer the cooling time needs to be
- cows needed to be cooled down when relative humidity reaches 72% with water to increase evaporative cooling prior to milking
- evaporative cooling can be used in any covered area and on concrete floors (Davidson *et al.,* 1996).

In conclusion, cooling of lactating cows prior to milking can provide profitable returns on a farm's investment, as it makes the cows more comfortable and more productive.

4.5.4. CHANGE OF MILKING TIMES

Alteration of milking times, together with suitable systems to cool the cows, should increase milk yields. Altered milking times have been practiced and approved in many tropical countries during the summer and in longer day lengths (e.g. at Kairi Research Station, Australia). Milking times were delayed from 6 am to 8 am in the morning and from 3 pm to 5 pm in afternoon. Half of each experimental group was sprinkled at the milking shed, and temperatures ranged from 24-33°C during the period of the experiment (Davidson *et al.,* 1996). The results (Figure 4.15) indicate that delaying milking to the later times (8 am and 5 pm) resulted in higher milk yields than those produced by cows milked at usual time (6 am and 3 pm), regardless of sprinkling. The cows milked later, with sprinklers, had lower rectal temperatures; while the other groups with sprinklers had lower respiration rates after milking.

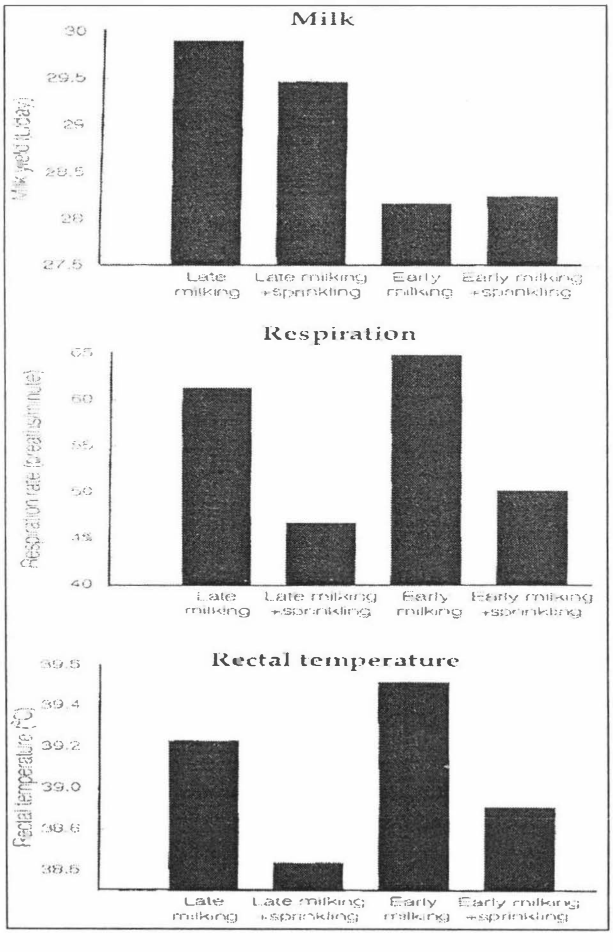

Figure 4.15. The effect of milking late (8 am and 5 pm) compared with milking early (6 am and 3 pm) in summer, with or without pre-milking sprinklers (Davidson *et al.*, 1996).

Milking times can be varied depending on seasonal variation, especially in the summertime. Cows should be milked when TA are low, especially in the afternoons.

4.6. HERD HEALTH MANAGEMENT

4.6.1. MANAGEMENT TO IMPROVE REPRODUCTIVE EFFICIENCY

Reproductive problems of dairy cattle in tropical conditions can be managed with physical practices according to Davidson *et al.* (1996). The effects of hot temperatures on cattle reproduction have been documented in Chapter 3; however, in order to amend these reproductive problems, the following sections describe management techniques that can be used.

4.6.1.1. Shading cows

It is strongly advisable to give all pregnant heifers and cows access to effective shade during hot periods of the year. This method has been well-practiced (e.g. in Australia); cows kept under an insulated iron roof had increased CR (44%) compared to cows that were not shaded (25%) (Davidson *et al.*, 1996).

4.6.1.2. Evaporative cooling

In addition to shade, cows should also be cooled with water spray, to facilitate transfer of heat from their body to the air. This method can be used when temperatures rise above 28°C. Cooling cows tends to encourage oestrous behaviour two-fold when compared to non-cooled cows, regardless of the stage of the reproductive cycle.

4.6.1.3. Recording of mating dates and heat detection

Synchronisation of mating and calving is strongly advised; alternatively, heat detection techniques should be improved (see Chapter 3). Using K-mars or tail paint is recommended for heat detection. Mating should be avoided during periods of severe heat loads; and cows should be kept cool by shading and sprinkling when they are close to their oestrous period, in order to increase CR. The interval between calving and first heat depends mainly on management, particularly feeding and heat detection (Chamberlain, 1989). Mating date should be recorded for two main reasons:

1) so that the cows' calving date can be predicted
2) to follow the progress of mating and to detect any problems at an early stage (Holmes *et al.*, 1984).

Careful heat detection is needed, because the oestrous can be short (10-11 hours or less) with few signs shown. Therefore, the cows should be watched at least three times a day (for approximately 30 minutes), including early morning and before dark (Chamberlain, 1989). Holmes *et al.* (1984) designed a simple table (Table 4.4) where mating records of all the cows in a herd are listed. This reveals the cows which have apparently become pregnant after one mating (e.g. numbers 1, 2, 7 and 9); cows which have been remated after a normal oestrous cycle between the two matings (e.g. numbers 3 and 6); and those cows which exhibited a short return (e.g. number 10).

Table 4.4. An example of a table which records the dates of mating for individual cows (Holmes *et al.*, 1984).

Cow number	Mating dates			
	1	2	3	4
1	29/10			
2	4/11			
3	21/11	13/12		
4	2/11			
5				
6	27/10	16/11		
7	25/11			
8				
9	31/10			
10	5/11	13/11		

Excessive returns to oestrous indicate a problem with oestrous detection, or a problem with the bulls. Cows which are not mated or are mated several times should be examined by a veterinary surgeon.

4.6.2. MANAGEMENT OF COW HEALTH

Two major health problems threatening dairy production throughout the year are mastitis and brucellosis. Mastitis usually leads to an immediate and obvious drop in milk yield; while brucellosis causes abortion during the last third of pregnancy (Chamberlain, 1989.; Holmes *et al.*, 2002)).

4.6.2.1. Mastitis

Mastitis is an inflammation of the mammary gland caused by bacterial infection, commonly *Staphylococcus agalactiae* and *Streptococcus aureus*. They infect the secretory tissue in the udders; they then grow, multiply and produce toxins that are harmful to the mammary gland; and spread from cow to cow during milking time. Mastitis represents an economic loss and causes health problems in dairy cows throughout the year. *Streptococcus uberis* is the bacteria that mainly causes mastitis in New Zealand (clinical mastitis). About 90-95% of mastitis problems are caused by organisms that enter the mammary gland via the teat end and 5-10% of mastitis infections are caused by teats injuries (Holmes *et al*., 2002).

Mastitis occurred in two broad categories: **clinical** and **subclinical mastitis**. **Clinical** mastitis is detectable from its symptoms, including blood clots or blood in the milk; swelling, hardness or high temperature of udder; and less frequently, general fever in the cow (Holmes *et al.,* 1984; 2002). **Subclinical** mastitis shows none of these detectable signs and can be recognised only by a special test on milk, i.e. the somatic cell count (SCC) used in New Zealand. (Somatic cells are not bacterial cells; they are part of the body's self-defence mechanism.) Somatic cell count test results that are higher than 250,000-300,000 cells/ml in milk from a cow (or a quarter) indicate the cow (or quarter) is probably affected by subclinical mastitis (Holmes *et al.,* 1984). The SCC results provide an indication of the general incidence of mastitis in the herd.

Mastitis is also spread by improper or poor milking procedures, faulty milking equipments, teat injuries and sores. Mastitis infections can be cured by a rigorous treatment of affected quarters with an appropriate antibiotic, which is infused through the streak canal of the teat after it has been milked and thoroughly stripped of all remaining milk (Holmes *et al*., 1984). The following are methods to prevent and cure mastitis:

- infected teats must be tested prior to milking and sprayed with germicide after each milking, to prevent any further spread of bacteria and new incidence of the disease (Figure 4.16)
- the infected quarters must be treated with dry cow **antibiotics** at the end of lactation
- infected cows should be milked last or a separate milking claw should be used for them
- milking claws must be flushed with hot water or germicide after milking infected cows ('back flushing')
- milkers should have clean hands and wear latex gloves during miking
- new miking cows joining the herd must have their milk tested, and persistently infected cows which have high SCC must be assessed for milking (Kingwill *et al*., 1977)
- lesions on teats should be minimized (from chapping, frostbite, stepped-on teats, lacerations, or milking machine damage)
- heifers can be given dry cow antibiotic treatment during gestation if *S. aureus* is a problem in the heifers
- the milking machine and teats must be washed properly with disinfectants containing iodophors or chlorhexidine, usually with emollients, to promote good teat skin condition.

Teat disinfection is likely to kill bacteria transferred onto the teat surface during milking; this helps to prevent colonisation or infection of teat orifices or lesions and to aid in the prevention or healing of lesions (Holmes *et al.*, 2002). Due to the awareness of economic losses associated with mastitis, more attention is focused on detecting mastitis (Figure 4.16), identifying the causative agent(s) and preventing the transmission of organisms by removing the source of the agent, such as milk contaminated fomites, bedding and persistently infected cows, etc. The incidence of mastitis can cause major economic losses for milk production systems.

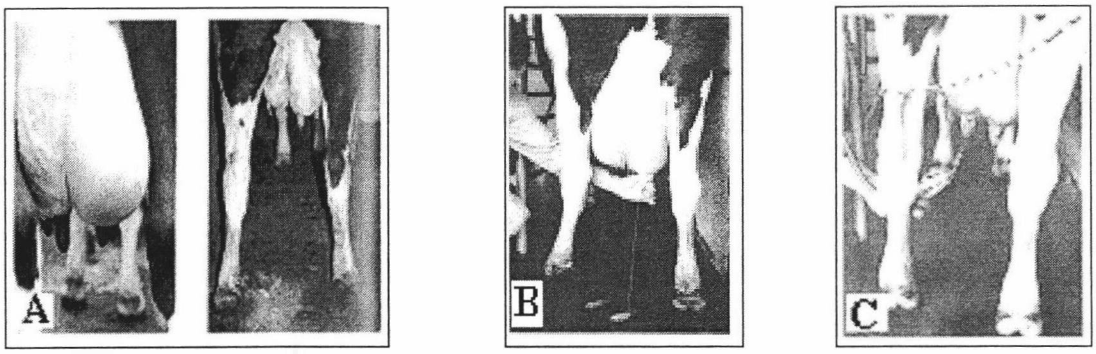

Figure 4.16. A: Severe swelling typical of acute mastitis, showing enlarged rear quarter and clots of milk; **B:** the foremilk before milking to examine abnormalities in milk in order to detect clinical mastitis; **C:** the disinfection of the teats after milking, in order to reduce the incidence of new mastitis infections (Holmes *et al.*, 1984; Akam and Spencer, 1992).

Finally, using long acting antibiotics after final milking (dry cow therapy) prevents the establishment of infection during the dry period. Good hygiene in the milking parlour before, during and after milking is essential. Disinfection of teats after milking is by far the most effective individual method and is widely recommended for prevention of mastitis (Holmes *et al.*, 2002).

4.6.2.2. Brucellosis

Brucellosis (Bang's disease) is a contagious disease caused by the bacteria known as *Brucella abortus* (in bovine cattle). This disease mainly causes abortions in dairy cows, either at the early or late (last three months) stages of pregnancy. This has economic implications due to its adverse effects on cattle fertility and its potential to transfer to humans (Chamberlain, 1989). The bacterium grows within various cells types, including the endometrium. The bacteria are transmitted mainly by ingestion of uterine discharges; milk and placenta tissue of infected cows; occasionally during mating; and through contaminated pastures and faeces (Holmes *et al.*, 1984; Chamberlain, 1989). Signs of infection include pretension of foetal membranes, premature birth, metritis and low herd fertility (Chamberlain, 1989).

Holmes *et al.* (2002) stated that abortion also occurs during late pregnancy in cows that eat the foliage of Macrocarpa and other types of cypress trees (*Cypresses* spp.). The cows usually abort several days after the foliage is eaten. This problem is caused by the isocupressic acid contained in foliage from these trees.

Prevention of brucellosis

Prevention of this reproductive disease should be focused on the introduction of replacement animals, including cows, heifers and breeding bulls. Farmers must confirm that their annual replacements are from healthy herds and are disease-free. In addition to the animal health management, they should also commit to the following preventative procedures:

- all replacement animals should be vaccinated and checked for all diseases
- always test new animals for other reproductive diseases with the recommendation of the local veterinarian
- all heifers must be vaccinated between 4-12 months of age
- use AI in reproduction schedules if possible
- general sanitation of farm areas is important for preventing the infection
- breeding bulls must free of brucellosis and all other reproductive diseases
- cull infected cows (cows that have aborted) from the herd immediately after the incident
- clean or disinfect areas where incidents have happened; and vacate the paddock(s) for a month (Chamberlain, 1989; Holmes *et al.*, 2002).

The most effective way to control brucellosis has been conducted in New Zealand since 1972. It is the combination of vaccinations, animal testing and slaughter of affected animals (Chamberlain 1989). Prevention is better than cure; animals should be watched for any reproductive problems and immediate action should be taken. This reproductive disease usually develops gradually and is not recognised until it is well established in the herd. Some animals never show symptoms of the disease, yet they remain major threats to the rest of the herd because they are a vector for the disease organisms. This disease must be guarded against by practicing good management techniques, such as vaccinations when necessary. Finally, dairy farmers should always work closely with veterinarians to keep cattle healthy. This disease has no cure; the best management practices are to ensure all animals are vaccinated, testing of the entire herd and slaughtering of infected animals.

4.6.3. MANAGING HEALTH PROBLEMS IN CALVES

4.6.3.1. Curing facial eczema in calves

This disease is initiated by the fungus toxin Hepatotoxin that causes liver damage (McDonald, 1981) and Sporidesmin known as Pithomyces chartarum (which acts as a liver toxin), growing on dead litter in pasture, which generally occurs in late summer (Holmes *et al.*, 2002). McDonald (1981) stated that a dry summer followed by a mild autumn, with warm nights and bright humid days, accompanied by sufficient rain, favours the growth of both rye grass and the fungus. The spore numbers may build up on pasture and soil when temperatures are above 12°C for three or more consecutive days.

McDonald (1981) stated that Sporidesmins (pathogen) can cause pathological changes in all the main components of the liver (i.e. hepatocytes, bile duct and stroma). This impairs the biliary excretion of phylloerythrin (porphyrin derived from chlorophyll by bacteria) in the rumen, which will later accumulate in high concentrations in the peripheral blood. The phylloerythrin sensitises animals' skin to sunlight. Photosensitising agents then absorb light energy and become activated with the production of free radicals in the presence of oxygen, leading to the formation of lipid peroxides with disintegration of structure membranes in the cell. Lysosomes are damaged, releasing acid hydrolases and leading to cellular necrosis. Exposed areas of skin, especially ears, face, eyelids and lips, develop an acute dermatitis with intense irritation. This condition is given the term 'facial eczema'.

The toxins normally damage cows' livers and enter into the general blood circulation with heavy spore intakes on areas including skin, face and udders. This leads to jaundice, photosensitivity of the skin and general weakness of the animals (Holmes *et al.*, 2002). Cows with liver damage may not show clinical signs, but can be detected by the high concentration of a liver enzyme (gamma glutamy/transferase) in their blood (Holmes *et al.*, 2002).

Clinical signs of facial eczema include:

- a reduced appetite, with affected animals becoming weak and thin

- eyes becoming red; and areas of the skin, particularly on the head, back, udder, legs and where the skin is white, becoming sunburned and may peel off
- milk production can decrease suddenly and dramatically
- young calves shows scaly, dried skin on their face or head.

Practical management techniques recommended to control this disease include:

- affected areas of skin should be treated with sun block and antibacterial material
- infected cows and calves must be culled from the rest of the herd
- cows should be shaded from direct sunlight to avoid sunburn
- the prevalent preventative treatment since the 1980s has been to use zinc oxide, given by drenching at 3 g zinc oxide daily per 100 kg LW, or on every second day at 6 g zinc oxide per 100 kg LW (the zinc oxide must be of stock-food grade to ensure no contamination). The zinc can be given to younger cattle as a long-acting (40 days) bolus of zinc oxide, which dissolves slowly in the rumen
- pasture should be sprayed with fungicides to prevent the growth of the fungus, although this practice is not common
- new born calves should not be kept in overcrowded conditions
- calf rearing sheds should be kept clear and dry, with good ventilation
- calves should be grazed on clean pasture that is not heavily contaminated with worm larvae (Holmes *et al.*, 2002).

4.6.3.2. Calf scours

Calf scouring (diarrhoea) is one of the major problems during calf rearing (the first three months after calving) every year. This results in major economic loss and threatens reproduction planning for future development, because almost 30-40% of calves die per year as a result of scouring problems. This is probably due to poor feeding management, poor hygiene and poor rearing management.

Young cattle are commonly affected by a variety of parasites that can infect the digestive tract (various types of worms), the respiratory tract (lungworms), or the skin (lice). Younger cattle that are fed inadequately are particularly susceptible to the effects of parasites and their growth rate is likely to be reduced by infestations. Affected cattle may have scours, cough persistently or chew at their coats. Young calves fed on milk or milk substitutes are susceptible to several diseases of the digestive system, which may cause scouring. Young calves are particularly susceptible because of their non-ruminant, simple-stomached digestive tract.

This problem is likely to occur when calves drink an inadequate quantity of colostrum (the first milk of the cow after calving) in their first days of life (Holmes *et al*., 2002). Other problems, including infections of protozoa (Cryptosporidia and coccidia) and bacteria such as Salmonella and Escherichia coli (E. coli) also cause diarrhoea. As a result, calves become dehydrated and lose certain body salts (electrolytes, including K, Na and Cl). The calf may show depression, electrolytes become unbalanced, energy reserves are depleted and the calf can develop shock and die.

Older weaned calves may also have scours with **liquid faeces** and **dirty hind quarters**. These signs can be seen in calves that are not thriving and are probably caused by parasitic worms in the digestive tract. Infestations of these worms can be controlled by an effective program of dosing or drenching with an appropriate drug; and by suitable grazing management for the calves, including access to clean, fresh, leafy pasture either by grazing rotationally, or at a low density of calves per hectare of pasture (Holmes *et al*., 2002).

Calves can show signs of **respiratory distress**, e.g. persistent coughing. If this seen in a calf that is not thriving, it may be caused by an infestation of lung worms, which can be controlled by suitable dosing and drenching. Calves that persistently **lick** or **chew** their coats and skin may be infested with external parasites such as lice, which can be controlled by treatments similar to those mentioned above for respiratory distress.

Digestive disorders and scouring are the main causes of mortality in calves in pastoral conditions. Affected calves can be found with the following symptoms:

- increased dehydration or loss of body fluids
- severe depression, with no appetite and an increased death rate
- sunken eyes and a gap appears between the eyeballs and the inner eyelid
- their urine output drops or stops completely

- body electrolytes loss and imbalance
- their limbs and ears look cold and the skin is tense.

Holmes *et al*. (2002) stated the following preventative measures for calf scouring:

- ensure a routine treatment of younger cattle with the appropriate drugs to kill parasites
- provide adequate hygiene in the calves' feeding utensils and environment
- avoid sudden changes in feeding, or any other forms of stress
- affected calves that excrete pale, watery faces should be kept in dry, warm, well-ventilated, sheltered places and given no milk for one or two days
- dehydration should be prevented by giving the calves a solution of water and electrolytes; glucose may be added to provide additional energy
- ensure newborn calves receive at least 2 L of colostrum within 12 hours of birth
- adequate feed must be provided during cold weather to increase FI.

These measures are sufficient to prevent and cure many cases of scours, but in other cases appropriate drugs may be required which should be given after veterinary advice has been sought. Scouring calves should be allowed to drink plenty of water. Electrolyte solutions should contain 10 g NaCl (common salt), 5 g $HaHCO_3$ (bicarbonate of soda) and 250 g glucose (or dextrose) in 5 L of solution.

Rather than having to treat the disease, it is better to prevent it from the beginning. With good management of feeding, hygiene and shelter, and good luck, mortality rates can be maintained at less than five calves per 100 births.

4.6.3.3. Shelter of calves

Young calves should be well sheltered from wind and rain and well fed, because they are more susceptible to the effects of cold weather (e.g. temperatures lower than 12°C for Friesian calves and 15°C for Jerseys).

When young calves are exposed to cold, wet and windy weather conditions, the risk of death is high, particularly in their first or second week of life when they have a weaker body. Therefore, young calves should be provided with hedges, partially enclosed sheds, or other suitable barriers against wind and driving rain. In a shed, providing clean bedding materials is very important to prevent a build up of infectious organisms. It should have fresh air, good ventilation and sunlight to minimise the risk of respiratory infections (Holmes *et al.*, 2002). Wet and old bedding material should be removed and the floor cleaned with proper disinfectants.

4.7. CONCLUSION

This study reveals that the whole pastoral system and current dairy management practices in Tonga should be modified by adopting techniques currently used in other countries. The problems with lower milk production imposed by higher temperatures (< 27°C) with high relative humidity (80%) could be improved by using tropical crossbred breed cattle rather than purebred *B. taurus* breeds. *Bos indicus* breeds are likely to be superior due to their inherited capacity for grazing, heat tolerance and disease resistance.

The low productivity and NV of tropical pasture can be improved. It has been found that the FV of grasses can be improved when grown together with various improved legumes species. In addition to this, it increases animal FI, pasture mass (kg DM/ha) and the nutritional and feeding value of pastures as a whole. It is also a relatively cheap method, as it avoids buying expensive fertiliser. Selection of pasture species (grasses and legumes) is an individual decision, because not every species has the criterion required for optimal milk production and animal health.

There are effective grazing systems designed for efficient grazing of pasture in addition to the single system (rotational grazing) used in Tonga. The grazing techniques recommended in this paper should lead to improved grazing management, better control of pasture herbage mass and sufficient feed intake, all of which lead to increased milk yields. These methods are easier, save labour and cost less. Pastures can have enough time to rest, re-grow and serve cows with fresh and nutritious forage for their next rotation. Pastures, in particular tropical pastures, must be grazed or "mechanically topped" as required to maintain fresh, leafy, re-growth of young herbage.

Management of dairy cattle during hot weather can be expensive and time consuming. However, the VFI of dairy cattle can be increased when cooling systems are practiced. The only effective ways to increase FI during hot weather is to keep cows' bodies cool by sprinkling them with water, providing shade and high energy feedstuffs. Additionally, there should be a reduction in the amount of fibrous feeds provided, but an increase in the amount of succulent and concentrate feedstuffs during times when environmental temperatures are higher (e.g. above 27°C).

Cooling strategies can minimise problems caused by heat stress. Additionally, sprinkling cows, providing shade and increasing the amount of cold drinking water available will lead to a reduction of respiration rate and rectal temperature, but an increased milk yield and FI (Davidson *et al.*, 1996). These heat stress management techniques can be applied to all types and ages of cattle. Changing the milking time to a cooler part of the day can also increase milk yield. This is simple technique, suitable for the conditions in Tonga.

Herd health management is crucial for tropical livestock because they are vulnerable to the effects of high temperatures > 27°C), pests and disease invasions. Reproductive problems can be managed by practicing proper health management plans and programs. Understanding the physiology of reproduction and its cycle, together with proper heat detection, can lead to successful mating and a high CR. It is advisable to keep heifers and cows due to be mated cool, by shading and sprinkling if required, especially when temperatures are above their critical thermoregulatory zone.

Disease is detrimental to farms' incomes and can threaten their future, particularly in small-scale dairy farms, such as those in Tonga. The two major important diseases affecting dairy cattle, mastitis and brucellosis, can be minimised by keeping the herd healthy and clean. Using clean pastures, proper cleaning of milking machines and maintaining a regular treatment program, will contribute towards a longer-lived, healthy herd. Persistently infected animals must be culled or slaughtered immediately to avoid spread of disease.

Better feeding and sanitation programs for young and new born calves produces healthier and faster-growing calves. In addition, young calves must be protected from intense sunlight, as well as wind, rain and cold. Understanding the early stages of growth, their digestive system and feed types leads to easier management. Mortality rates can be reduced by careful feeding and treatment programs whenever diseases are noticed. Total sanitation of living areas must be maintained throughout calf rearing periods.

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CHAPTER 5:

GENERAL DISCUSSION AND CONCLUSIONS

This study reveals that many production factors require tremendous modification in order to maximise milk yields in the tropics. The influence of environmental factors (high temperatures and high relative humidity) can be overwhelming; they are capable of significantly reducing both pasture and animal productivity. These environmental factors also threaten the management methods recommended for practice in Tonga. This literature review has not identified a specific management technique that can combat nature and its sometimes negative influence on animal production. However, it is the responsibility of dairy farm managers to devote time and effort in order to be prepared for specific seasons when high temperatures adversely affect both pastures and animals.

Chapter 2, "**factors affecting pasture production in the tropics**", reveals that feeding management is a top priority for increasing milk yield. Feeding aimed at producing higher milk yields should be focused on supplying enough high quality nutrients to animals all year round. So that feeding may be economically feasible, it should be based on the existing tropical feeding sources. Tropical pasture species must have high FV and digestibility. The pasture based feeding system should be combined with supplements in order to improve the diet, digestibility, FI quantity and milk yields. The degree of lower performance of pastoral productivity is inescapable because of the high temperatures in tropical regions.

Pasture productivity can be improved by maintaining soil fertility through the inclusion of legumes species together with grasses and individual species which can adapt to tropical conditions. The individual morphology, anatomy and chemistry of grasses and legumes must be considered; and management of pastures to maintain maximum leaf content is important.

Chapter 3 discussed the "**effects of feeding and environment on performance of dairy cattle**". Good pasture management is crucial to maintaining high nutritional value, pasture productivity and high milk yields. The hot conditions in the tropics can cause heat stress in cows, with reductions in feed intake and performance, including decreased fertility. Methods of reducing heat stress were discussed in Chapter 4. The effects of environmental temperatures must be recognised and reflected in management practices. However, the productivity of pasture and animal fertility (conception rate, submission rate, lower mortality and better health and target condition scores) can be corrected with expert management of feeds, environment and cows, skilled farmers and an understanding of the seasonal changes during the year.

There is a need to improve the general understanding of the constraints of the environmental factors imposed by climate, infertile soils and lower FV of pasture species. Further research is needed on feed factors, the influence of environmental factors and appropriate management aimed at maximising pasture and animal productivity.

The final review chapter (“**pastoral dairy production for Tonga**”) explained several successful management techniques adopted from larger dairy industries in both tropical and temperate countries (e.g. Australia and New Zealand), all aimed at the future improvement of dairying systems in Tonga. This study suggested that modifying existing systems by adopting more technical methods can increase milk yields. Modification of the surrounding environment and the species of cows would lead to improved production. The following management strategies are recommended for dairy farming in Tonga:

- sprinkling cows with water prior milking in the afternoon, when temperatures rise above 27-30°C
- increasing the use of shading trees around farm boundaries and paddocks
- changing milking times to cooler parts of the day
- maintaining cool drinking water and providing enough water on hot days
- avoiding walking cows long distances on hot days
- providing succulent supplementary feeds during hotter months to improve FI and digestibility
- locating water troughs closer to shade trees to prevent cows walking long distances across paddocks for water.

All of these management techniques are successful in improving MP and are recommended because they are simple, cheap and applicable. They all contribute to minimising heat stress in cows, increasing their comfort so as to increase FI and milk yields.

Improved MP through genetic selection is important in the tropics. The best breeds will be produced through heavy selection based on environmental factors and production performance (e.g. MP). Using European breeds in the tropics requires high standards of care and management because of their susceptibility to heat stress and parasites, even though they have higher milk yields. The dairy breeds recommended in this paper (e.g. Australian Friesian Sahiwal, Australian Milking Zebu and Jersey) have potential advantages for use in the tropics, due to their ability to thrive on predominantly poor quality feeds under heat stress, despite exposure to pests and diseases.

However, the important characteristics considered for tropical breed selection include milk yield, cow fertility, calf viability, MP, tolerance of hot conditions, resistance to tropical diseases and ability to meet their feed requirements from relatively low quality diets (mainly tropical pasture). Lastly, dairy production in the tropics depends on the interaction between environmental factors, feed factors and management factors.