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Tree foliage
in ruminant nutrition

139

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Contents

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Foreword

The required intensification of production to satisfy the increasing demand for milk and meat needs to be achieved by environmentally friendly technology that does not prevent future generations in meeting their requirements. In this context, maximising agricultural outputs by increasing the efficiencies of capturing solar energy per unit of the transformation into the food chain appear as logical strategies.

Multipurpose trees can make a significant contribution to agricultural systems by providing a variety of useful products, including valuable forage and wood. The feeding value of low quality agricultural residues and tropical grasses can be greatly improved by foliage from leguminous trees, which can be grown integrated directly to pastures, in fences and in the so called "protein banks". In mixed farming areas, the tree-strata concept significantly raises the overall photosynthetic capacity of the agricultural system by enlarging the leaf-area index and favouring nutrient enrichment and recycling. In some cases, pure

stands of forage shrubs and trees can be the best option to intensify animal production replacing traditional low performing grass—based systems.

In general, it is now clear that agricultural production in the tropics, and animal production in particular, should be based, whenever possible, on systems with trees, that try to simulate the original multi—strata plant communities.

The purpose of this valuable documents is to provide the scientific basis for the contribution of legume tree foliages to ruminant production, particularly from the points of view of their overall high nutritive value, and positive effects on rumen function, microbial yields and body metabolism, and to encourage livestock experts and producers to consider the inclusion of forage legume trees in ruminant production systems.

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Contents

List of Figures

List of Tables

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Chapter 1

Trees—components of farming systems

1.1 Introduction

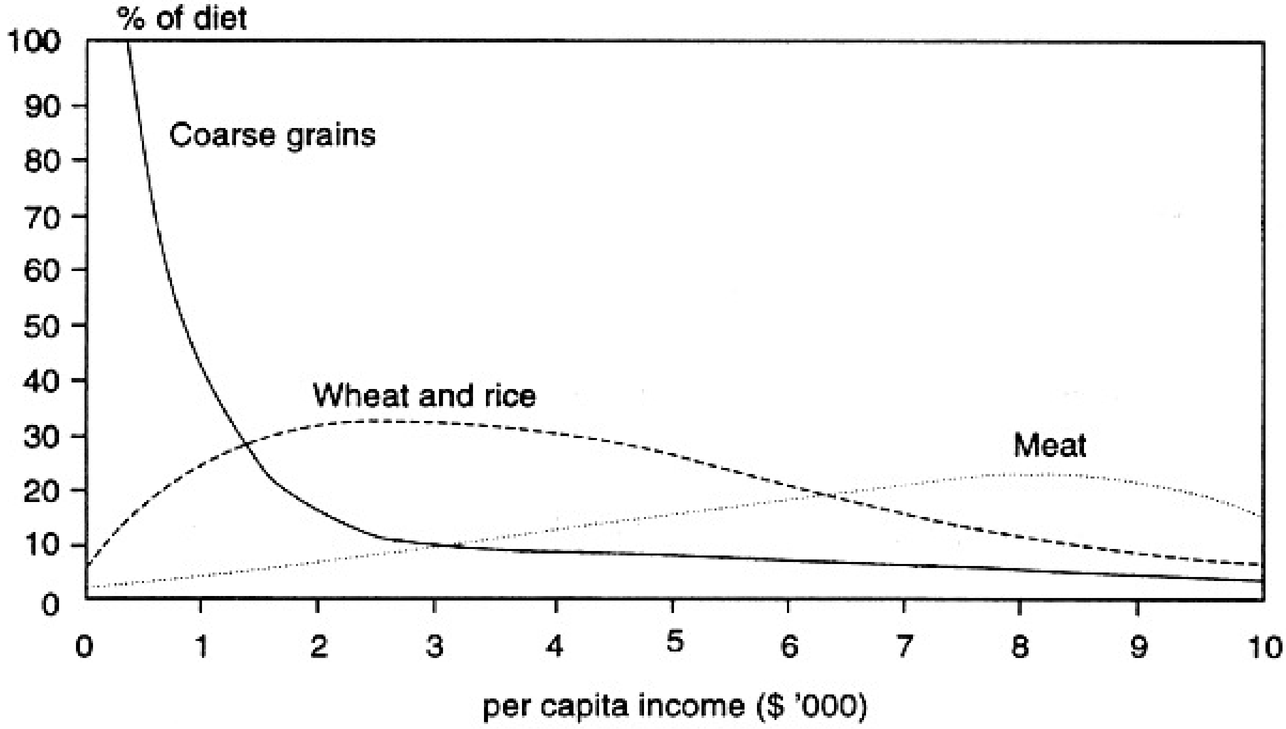
Animals have crucial rôles to play in human food production, either directly or indirectly. In developing countries, ruminants

are primarily kept as a source of draft power, as an accessible source of funds when sold, for milk production (mostly as a byproduct, but in some cases large dairy herds have been established) and often they are important as an indication of wealth and standing. Generally they are only slaughtered for food when crops and other resources become scarce.

Whilst cattle have remained largely as draft animals in developing countries, more emphasis is now on them as a source of high quality food (protein) particularly for the middle class. People demand more animal protein in their diet as their standard of living increases (see Figure 1.1 on the next page). Over many years, milk and meat availability increased only through expanding numbers of animals and there was little increase in production per animal (Jackson, 1981); this was largely owing to the secondary importance of meat or milk production to draft power. The main feed resources for large ruminants have remained crop residues, agro-industrial byproducts or pastures

from infertile lands, which, in general, support only low levels of production.

Figure 1.1: ***The changing demand for meat/milk in developing countries according to*** **per capita** ***income (Marks & Yetley, 1987).***



The push for increased food from animal sources is probably only 30–40 years old, but it is now suggested that the demand for animal products will increase by 3.6% per annum in developing

countries as compared with only 2.4% for plant products.

Increasing the efficiency and extent of ruminant production in developing countries will depend on:—

- **improving the balance and availability of nutrients from a diet based mainly on agro-industrial byproducts and crop residues**
- **improving feeding, breeding and disease control**
- **developing ruminant production as a primary production rather than a byproduct of crop production**
- **developing animals with the genetic capacity to utilize feed efficiently within the environmental and management practices of a locality**
- **developing equitable markets for the products.**

It is a basic premise in this publication that these changes must be brought about using local rather than imported resources.

1.2 Feed resources available for ruminant production in developing countries

Because large ruminants are mainly found in cropping areas where land for pasture is scarce or non-existent, crop residues (straws and stovers) remain a single major resource used for feeding ruminants in developing countries. Another major resource is grassland that is either too difficult to cultivate or is of low inherent fertility. Pastures hand cut from roadsides, railway embankments, boundaries between crops and any other wastelands are also a major feed resource particularly in Asia. Another source of significant amounts of feeds is agro-industrial byproducts such as bagasse, molasses, sugar cane tops, sisal waste and oilseed cakes or meals.

Cellulose is the greatest single feed resource for ruminants world wide, with some 100 billion tons available worldwide annually. Cellulosic (fibrous) biomass is only usable as a major component of a diet by herbivores and ruminants in particular as it requires microbial fermentative activity for its digestion.

1.3 Overview: the potential uses of tree foliages

Recognition of the potential of tree foliage to produce considerable amounts of high protein biomass has led to the development of animal farming systems that integrate the use of tree foliages with local bulky feed resources. In order to determine the suitability of trees/shrubs as components of ruminant fibrous diets, knowledge is required in many areas, including:—

- **the capacity and ability of the tree to regenerate foliage when grazed or harvested**

- **the feeding behaviour of animals when confronted with tree forages**
- **the voluntary intake of tree foliage under different environmental conditions**
- **the adaptation of trees to the local conditions and their potential to become weeds**
- **the ease of seedling establishment, rate of growth and regeneration**
- **the growth pattern of trees/shrubs in relation to crops or pasture**
- **the required soil pH characteristics and nutrient status**
- **the nutritive value of the foliage and its change with harvesting, grazing or cultivation.**

1.4 Tree foliage as ruminant feeds— perspectives and properties

Ligneous plants, which may be large/small trees or shrubs, are an important component of the cellulosic and high protein fodder resources available for use by livestock and wildlife alike.

Foliage has been used as animal feed since Roman times and it appears to be the preferred forage of goats and some breeds of sheep as well as numerous species of deer, particularly on the arid savannahs. In more recent times, trees and shrubs have been introduced into cropping and grazing systems to provide green fodder high in protein to supplement the available low protein forage. These are grown in banks or hedges, between crops (alley farming) or as components of pastures and also as shade trees.

Tree foliage is being increasingly recognized as a potentially high quality feed resource for ruminants, particularly to supply crude

protein. This is especially true in harsh and arid conditions where trees often provide more edible biomass than pasture and this biomass remains green and high in protein, even when pastures dry off and senesce. Because of their deep rooted nature, trees are able to tap water and nutrient resources deep in the soil profile. Many trees have micro-organisms associated with their root systems that allow them to mobilize soil bound mineral resources such as phosphorus and to fix N_2 from the atmosphere into organic compounds.

In some mountainous or arid areas, it has been found that grazing ruminants contribute 90% to rangeland production and use 40–50% of the total feed available (see Lellourou, 1980). In the wet tropics of Latin and Central America, the Caribbean Islands. S. E. Asia. and Africa, fodder from trees and shrubs, especially from leguminous species, are being used widely as sources of dietary supplement for ruminants.

Table 1.1: *World trade in oilseed cakes (Bergstrom, 1980)*

Table 1.1: *World trade in oilseed cakes* (*Borgstrom, 1980*). *Industrialized countries imported the major proportion of oilseed cakes produced in developing countries. Figures are in* 10^6 *tonnes.*

	Imports	Exports	Net imports	Net exports
Industrialized countries	18.7	9.4	9.3	-
Developing countries	1.7	10.8	-	9.1

In the context of increasing human population numbers in the developing countries, decreasing land availability for forage crop production, increasing dependence of ruminants on “low quality” basal feed resources and competition for the available protein meals (most developing countries export their protein meals to developed or industrialized countries, see trade of protein meals, Table 1.1), tree foliages are increasingly seen as potential protein and energy supplements to increase productivity by ruminants.

Whilst foliage of trees has been a traditional supplement to straw based diets fed to ruminants in many countries, little has been

done to develop the use of tree foliages to balance critical nutrient deficiencies. The greatest potential use is by small farmers who gather foliage from hedges, woodlands and waste ground to supplement goats, sheep and cattle fed straw based diets, or by ranchers in extensive grazing systems.

1.5 Trees in the agricultural ecosystem

It must be also recognized that apart from their role as animal feeds, trees and shrubs are valuable sources of:—

- **fuel wood**
- **timber and fencing materials**
- **chemicals with pharmacological and other properties (about 50% of all pharmaceuticals arise from plants)**
- **food for humans (mainly fruits)**

- **green manure or mulch**
- **landscape improvement**
- **shelter and shade**
- **wild life habitat**

and they play important roles as they:—

- **provide employment**
- **generate income**
- **protect soil from water and wind erosion**
- **cycle nutrients through leaf fall**
- **store carbon, which is important in decreasing atmospheric**

carbon dioxide accumulation and thus reducing the Greenhouse Effect.

Of these, the most important issues for small farmers in developing countries are food, feed, fuel wood and timber. The order of importance of these depends on the particular country or region. Many of the other uses of trees and their products will influence the adoption of ‘strategies’ for utilizing tree foliages as a component of the diets of ruminants and must be considered in the overview of trees on farms.

1.6 Tree foliage as basal feed or as supplements to other foliages

The purpose of the discussion here is to review the potential of fodder trees as important nutrient sources for ruminants. Whilst it is well recognized that some tree foliages are palatable, digestible and are often high in protein, the detailed roles of these forages as sources of critical nutrients in forage based

diets are largely unknown.

The four potential roles of tree foliages in ruminant nutrition are as a:—

1. **high quality, high digestibility biomass resource**
2. **supplement to provide nutrients deficient in the diet, an enhancement of microbial growth and digestion of cellulosic biomass in the rumen of cattle, sheep and goats**
3. **source of protein that escapes rumen degradation to be digested in the intestines and enhance the protein status of the animal**
4. **source of vitamins and minerals to complement deficiencies in the basal feed resource.**

In the following discussion the basic concepts of ruminant

nutrition and the mechanisms by which these animals use low quality forages are discussed to enable the reader to appreciate the potential of tree foliages to fit into the above four rôles. The use of tree foliages as the only feed resources is not discussed at length because it is apparent that in most developing countries such a system is probably uneconomic, although it is occasionally encountered. For example, mulberry (*Moracea sp.*) foliage in Costa Rica forms a large proportion (i.e., 3.4%DM liveweight) of the feed intake in goats, supporting high levels of milk production (Rojas & Benavides, 1994).

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Chapter 2

Background nutrition, digestive physiology, metabolism of ruminants

2.1 Introduction

Rates of growth and milk production by ruminants grazing tropical pastures or consuming crop residues alone are generally low and are only about 10% of the animal's genetic potential. The reasons for this low productivity are complex, but in order of priority they appear to be:-

1. **the imbalanced nature of the nutrients that arise from digestion of such forages when these are fed without supplements**

2. **the high incidence of disease and parasitism, which is exacerbated by poor nutrition**

3. **the hot, often humid environment which lowers feed intake of ruminants, particularly by cattle.**

Feed concentrates such as grain are often recommended as supplements under the above conditions as the animals are usually thin and believed to be energy deficient. However, the poor condition of cattle in the tropics is more likely to be the result of inefficient digestion in the rumen and inefficient utilization of the nutrients absorbed. In hot environments the heat generated by such inefficiencies is hypothesized to lower overall feed intake, which is then expressed as a frank energy deficiency (Leng, 1990).

Research has shown that large improvements in ruminant productivity and efficiency of feed utilization from low quality forages can be achieved by small amounts of supplements that provide essential nutrients in the basal feed (Preston & Leng, 1986; Leng, 1990). These increases are not restricted to

laboratory studies and have been observed on a large scale in terms of milk production in cattle and buffalo on small farms in India (NDDB, 1989). These principles of supplementation are also being used to develop beef production in cropping areas of China, where over six million cattle are being fattened by small farmers using straw treated with ammonia to improve both its digestibility and non-protein nitrogen (NPN) content; the straw is then supplemented with bypass protein (Guo Tingshuang & Yang Zhenhai, 1994; Dolberg & Finlayson, 1995; Sansoucy, 1995). These projects emphasize the large potential impact of the feeding strategies that are discussed in the coming sections

Increased production of meat and milk are the obvious benefits from strategic supplementation of large ruminants fed poor quality forages. The improved body condition of animals, which is a major response to balancing nutrition in dairy, beef or draft animals, also affects work performance and reproductive efficiency; the age at puberty of heifers is lowered, the

intercalving interval in mature cows is decreased and the work capacity of animals is improved.

It is possible, through strategic supplementation, to increase efficiency of production by up to five fold over similar animals fed only poor quality forages. This has been done without changing the basal feed resources and has been achieved by identifying and providing critical nutrients that are otherwise deficient in the diet. In this way nutrient availability is balanced with animal requirements and forage intake is stimulated at the same time (see Leng, 1990; Preston & Leng, 1986).

In general, the supplements to such diets for ruminants include a source of fermentable N, minerals for the rumen organisms and a source of protein that is protected from degradation in the rumen but moves rapidly to the lower tract to improve the essential amino acid supply to the animal.

In many tropical countries the appropriate supplements are readily available, e.g.,

- **urea and molasses as N and trace mineral sources respectively**
- **local minerals**
- **oilseed meals and protein byproducts of other industries.**

There is, however, a need to identify the most appropriate sources of non-protein nitrogen (NPN), minerals and protein available locally and provide them in a form to complement the nutrients absorbed from fermentative digestion of a poor quality forage diet.

Within the developing countries the basic resources for ruminant production are pasture, crop residues and other cellulosic biomass; these are generally low in total protein and fermentable

N and are quite often deficient in a range of minerals. Soils in the tropical and subtropical climate zones are almost always associated with low content of such minerals as P, S, K, Ca, Mg, Cu, Mo, Co, Se and B (Kerridge *et al.* 1986) and high aluminium saturation or acidity which are restrictive to root growth (Chen *et al.* 1992). In tropical soils, phosphorus is often a major mineral deficiency.

Often a source of bypass protein is not available locally, particularly in the grasslands or savannahs. In the rangelands, leguminous forages, tree foliages, their seeds and pods are by far the greatest potential source of protein meals, soluble N and source of minerals. When fed with pasture or straw, they provide many of the nutrients deficient in the basal forage and create a rumen environment more efficient in microbial growth, which is also often accompanied by a higher rate of digestion of the basal forages.

2.2 Forage/feed resources in developing countries

Although the quantitative production of crop and livestock products in third world countries has increased in the last 25 years, this has been achieved largely by way of increased animal numbers (Jackson, 1981).

In some developing countries, high levels of grain are being fed to ruminants, emulating the feedlot strategies of North America. Increasing pressure on cropping lands and massive demand for grain for monogastric animal production, particularly in China, suggest that this is a transient feature, which is likely to cease as population increases and surplus (subsidized) world grain is reduced.

In the future, ruminants in tropical countries and cattle in particular, are likely to depend almost entirely on crop residues, particularly straws and stovers, pasture biomass and agro-

industrial byproducts such as sugar cane tops and molasses.

The fibrous feeds contain large amounts of complex carbohydrates which are not digested by intestinal enzymes and therefore require fermentative digestion by microbes. The common characteristics of such feeds are low digestibility, low protein content and a low mineral content.

2.3 Animal productivity from forage resources in the tropics

It is the contention of the writer that there has been a major misconception throughout the scientific literature: the low productivity of ruminants fed poor quality forages in tropical developing countries is mainly a result of the low energy density of the feed. There is now a large volume of evidence that the primary constraint to productivity is rather an inefficient utilization of the feed because of deficiencies of critical nutrients in the diet. The deficient nutrients may be those critical to the

growth of rumen microbes which ferment the feed; they may be those required to balance the protein to energy ratio absorbed. Supplementation of animals to supply these nutrients often results in levels of production that would be highly acceptable under temperate country practices. The evidence for these statements has been considered in detail recently by Leng (1990) who suggested that a marked interaction of heat generation in consumption, digestion, metabolism of ruminants and environmental heat load has major implications for ruminant production in the tropics.

2.3.1 Effects of high heat load on animal production

The laws of thermodynamics suggest that inefficient utilization of feed by ruminants for tissue deposition must result in increased heat generation. Such heat generation could have large implications for ruminant production in the humid tropics. The often low intakes of poor quality forages by cattle in hot climates

may be imposed by accumulation of heat in the body from both an inefficient rumen microbial ecosystem (Table 2.1) and an inefficient utilization of acetate in metabolism of the animal. This would be exacerbated by a high environmental heat load (Leng, 1990). Correction of a nutrient imbalance by supplying nutrients deficient for microbial growth and feeding a bypass protein often increases a depressed intake of poor quality forages (i.e., 50–60 g/kg$^{0.75}$/d) to normal, i.e., between 80–100 g/kg$^{0.75}$/d (see Figure 2.1 on the following page).

Table 2.1: *Effect of different efficiencies of microbial growth on the production of end products in the rumen of a steer consuming 4 kg of organic matter which is totally fermentable (Preston & Leng, 1986).*

	Y_{ATP}			
	8	**14**	**19**	**25**
Microbial protein synthesized (g/d)*	500	800	1010	1212
VFA produced (MJ/d)	41	34	30	26

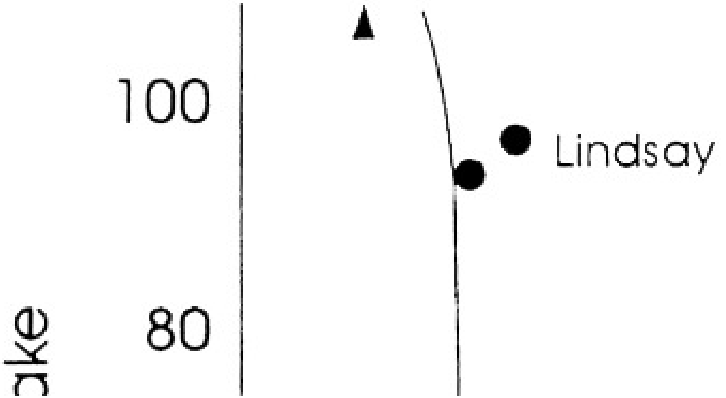
Methane produced (MJ/d)	9.4	8.5	8.0	7.6
Heat (MJ/d)	6.4	5.1	4.3	3.1
P/E ratio (g protein/MJ)	12	25	34	47

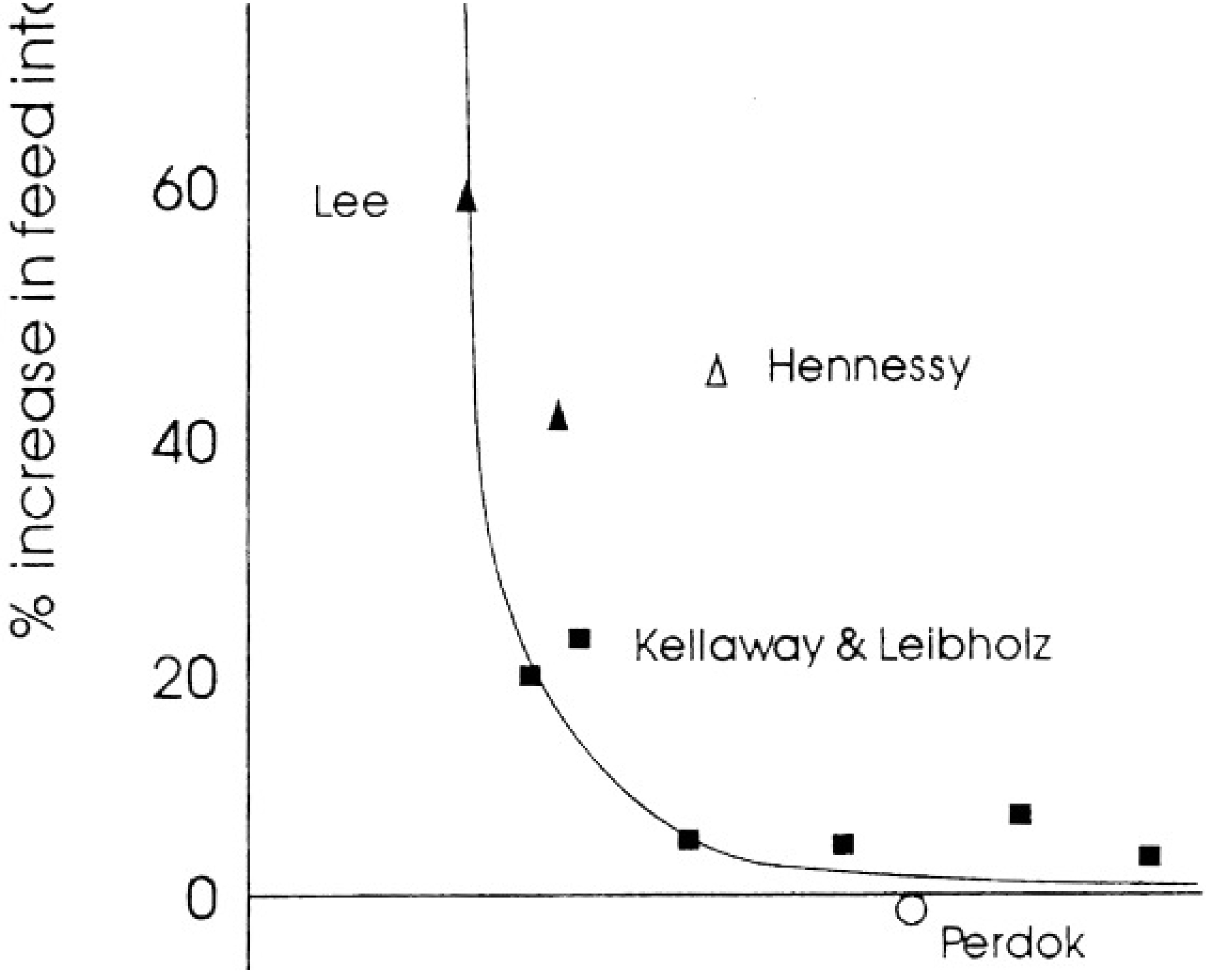
*** Microbial protein may be only 75–85% digestible.**

Cattle in the tropics, as compared to those in cool countries, may require less nutrients for maintenance as they do not have to combat cold stress. If the nutrients spared oxidation are used for tissue synthesis, animals in warm climates can be more efficient users of forages than animals in cold climates. Ruminants use acetate or fat as energy sources when cold and such animals have a lower requirement for amino acids relative to energy (P/E ratio) than animals under hot conditions. Thus the requirements for amino acids are higher relative to energy substrate in cattle in the tropics than in animals on the same feed in cool environments: the total amount of nutrients required is lower in animals in the tropics relative to temperate areas.

Similar scenarios are seen in the poultry industry where the protein requirements as a percentage of the diet are increased from 16 to as high as 21% and the feed intake is decreased as temperature/humidity increases (Mastika & Cumming, 1994).

Figure 2.1: ***Intake by cattle of low digestibility forages either unsupplemented or supplemented with bypass protein, or bypass protein and urea (Lindsay & Loxton, 1981; Lindsay*** **et al.** ***1982; Hennessy, 1984; Perdok & Leng, 1990; Kellaway & Leibholz, 1981).***

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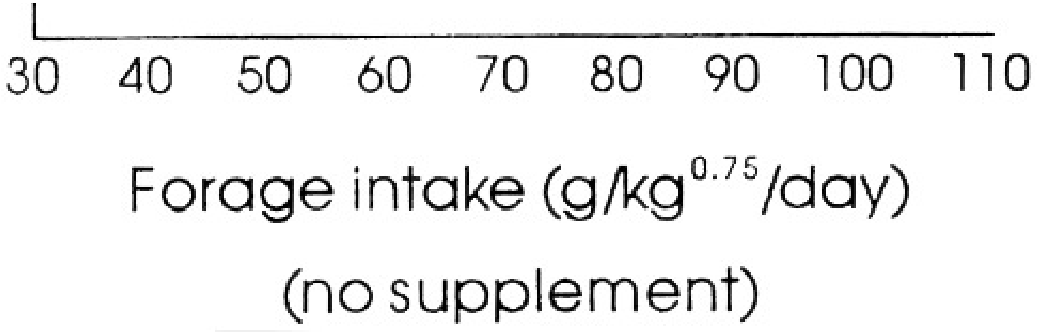


2.4 Improving ruminant production on low digestibility forages

The rationale on which the following discussions centred has been reviewed by Leng *et al.* (1977), Preston & Leng, (1986) and Leng (1989, 1990). The basic concepts are as follows. Ruminants fed low quality forages require supplementation with critically deficient nutrients to optimize productivity. The required supplements in order of priority must:—

- **correct nutrient deficiencies for the rumen microbes, particularly ammonia and sulphur and phosphorus**

- **increase the ratio of protein (absorbed amino acid) to energy (VFA) available from digestion so that it more closely corresponds to the animal's requirements.**

2.5 Rumen digestive physiology

Ruminant animals obtain their nutrient requirements mainly from the products of rumen fermentation (i.e., microbial cells and VFA) and, in some situations, dietary bypass nutrients. They receive the majority of their essential amino acids from microbial protein on forage based diets, particularly when they are low in true protein. It is, therefore, important to consider how microbial growth efficiency, and therefore amino acid availability from this source, can be maximized so as to minimize the need for expensive bypass protein supplements.

The composition of rumen microbial cells is relatively constant (Hespell & Bryant, 1979; Czerkawski, 1985). A typical analysis is:

—

- **true protein 32–42%**
- **small nitrogenous molecules 10%,**
- **nucleic acids 8%,**
- **lipid 11–15%**
- **polysaccharide 17% and**
- **ash 13%.**

Higher lipid contents have been noted in bacterial dry matter isolated from the particle-associated phase of rumen contents (Merry & McAllan, 1983) and from rumens where the microbial modifier rumensin has been fed to animals.

2.6 Microbial growth in the rumen

Growth of microbial cells in the rumen requires:—

- **a source of fermentable carbohydrate to supply:—**
  - **monomers (building blocks) for synthesis of cellular material**
  - **ATP to provide the energy for polymer synthesis. ATP is generated during carbohydrate fermentation by substrate level phosphorylation and also by other processes associated with electron transfer and transmembrane vectorial metabolism**
- **N compounds for synthesis of proteins and nucleic acids, including:—**
  - **ammonia**

  - **perhaps some extremely small amounts of some amino acids**

- **an array of minerals and vitamins.**

2.6.1 Requirements for amino acids by rumen microbes

Ammonia can be the sole source of N for the synthesis of protein and other nitrogenous compounds in the majority of rumen bacteria (Bryant, 1973). Forage fed to ruminants may contain high levels of soluble protein, however and 30–80% of the microbial N of mixed bacteria is apparently derived from dietary peptides and amino acids under these circumstances (Nolan *et al.* 1986; Nolan, 1975). For starch-or sugar-based diets, peptides or amino acids in small quantities appear to be essential N sources for efficient growth of rumen microbes (Broderick *et al.* 1988; Maeng *et al.* 1986). The organisms fermenting fibrous carbohydrate in the rumen, however, appear to require little, if

any, peptides or amino acids and can grow efficiently on ammonia alone (Maeng *et al.* 1989; Kanjanapruthipong & Leng, 1996). The cellulolytic species which utilize ammonia for amino acid synthesis may, however, require some branched chain VFA.

It seems reasonable to suggest that, since a large number of soil microbes can establish in the rumen, an efficient microbial ecosystem will develop independent of an amino acid supply if the microbes are fed diets without amino acids but with ample non-protein nitrogen.

2.6.2 Inefficiencies of microbial growth

The yield to the intestines of microbial cells per mole of dietary OM digested in the rumen and therefore the P/E ratio, is always considerably below that theoretically achievable. A major reason is that a variable part of the ATP generated in the production of volatile fatty acid (VFA) is not available for synthesis and is used

to maintain cellular homoeostasis (i.e., maintenance of intracellular ion concentrations, enzyme and other protein molecule turnover), mobility and feeding activity in the case of protozoa. This proportion is termed 'maintenance ATP' (Leng, 1981; Czerkawski, 1985). Microbes are able, at times, to partially or totally dissociate catabolism from anabolism. Energy-spilling reactions within the cell (uncoupling) may also be responsible for dissipating ATP energy as heat without cell division and growth. This will occur when there is a deficiency of minerals, ammonia or other nutrients essential for microbial growth and also when microbial cells lyse in the rumen.

2.6.3 Inefficiency, microbial growth and heat generation in the rumen

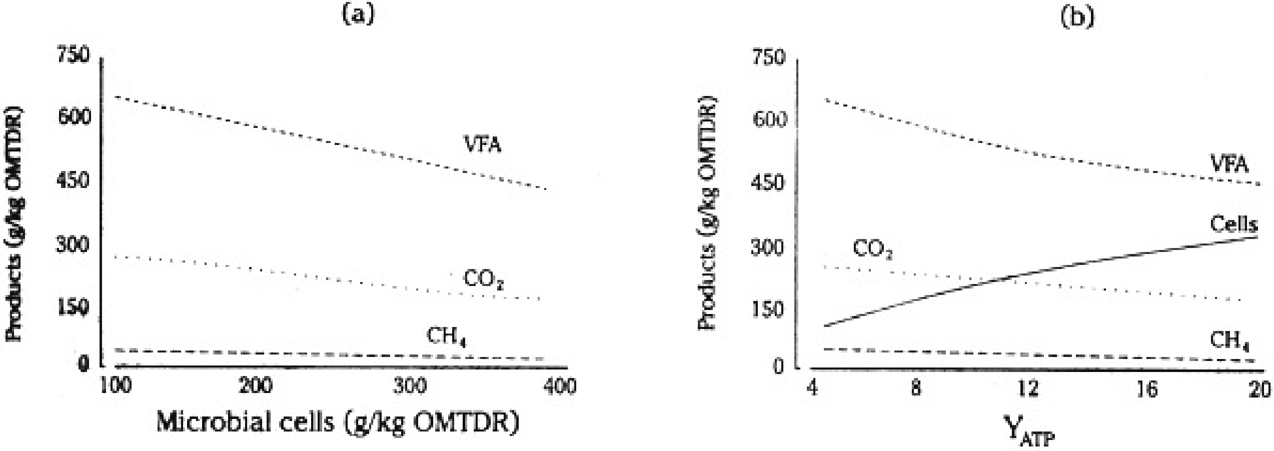
In the mixed microbial system in the rumen, bacteria are engulfed and digested by protozoa and lysed by bacteriophages. Materials excreted by living cells and the debris from lysed bacterial,

protozoal and fungal cells may be fermented by other microbes, inevitably yielding less ATP than that used in their initial synthesis. These extracellular processes and those associated with maintenance and uncoupling dissipate the potential energy in ATP to heat without achieving synthesis. This is termed the heat of fermentation. In theory this can vary from 4–10% of the gross energy of the carbohydrate fermented depending on the microbial growth efficiency (Table 2.1 on page 12) and therefore the availability of microbial growth requirements.

It needs stressing here that the higher levels of heat production in fermentation may be capable of creating a heat stress in animals existing in climates with high humidity and temperature.

Figure 2.2: ***A model of the effect of increasing efficiency of cell synthesis on microbial cell dry matter, volatile fatty acid production, carbon dioxide and methane production from true digestion (OMTDR) of 1 kg of polysaccharide in the rumen***

(acetate: propionate: butyrate molar production ratio was assumed to be 70: 20: 10) (Leng, 1981, as modified by Nolan & Leng, 1989)



In practice, on some poor quality forages, deficiencies of essential nutrients can reduce microbial growth to very low levels. Under these circumstances, the efficiency of ATP use for microbial cell synthesis (Y_{ATP}) must be below 2–4 and

considerable heat and methane are generated. Supplementation to correct these deficiencies often increases Y_{ATP} to 14 or higher. This alters considerably the balance of nutrients available. As microbial cell yields per unit of digested substrate (organic matter truly digested in the rumen, OMTDR) is increased (Figure 2.2), or Y_{ATP} is increased (Figure 2.3 on page 19), a greater fraction of the digested OM is used to provide building block material for the synthesis of cell polymers and proportionally less is channelled into VFA, CH_4 and heat production (see Table 2.1 on page 12). The P/E ratio in the products available to the host animal is increased as the efficiency of microbial synthesis or Y_{ATP} increases (Table 2.2 on the next page) by providing deficient essential nutrients to increase microbial growth and provide increased amounts of bypass protein from diets of low quality forages (Figure 2.2).

Changes in the proportions of VFA produced have a relatively

minor effect on ATP generation by rumen micro-organisms and therefore on the quantity of cells synthesized per mole OM digested. Microbial mixes in the rumen producing higher proportions of butyrate in the VFA, however, appear to be associated with lower net yields of cells. Higher rates of production and absorption of propionate benefit the animal tissues by potentially generating more ATP per mole VFA oxidized in the body, and by supplying a higher level of glucose availability. Glucose availability could, at times, limit growth (Preston & Leng, 1986) or milk production (Linzell, 1967) in ruminants.

Table 2.2: *Effects on P/E ratio in the nutrients absorbed of supplementation with a bypass protein to cattle with a poor or optimized (i.e., supplemented) microbial milieu in the rumen. The values are calculated for a steer digesting 4 kg DM in the rumen (Leng, 1981).*

		Microbial	**Protein**		**Total**	

Rumen environment	**Protein bypass (g/d)**	**cells produced (gDM/d)**	**from microbial cells (g/d)**	**VFA produced (MJ/d)**	**protein available (g/d)**	**P/E* (g/MJ)**
Deficient	0	830	500	41	500	12
Supplements	0	1680	1010	30	1010	33
Deficient**	400	830	500	41	900	22
Supplements	400	1680	1010	30	1410	47

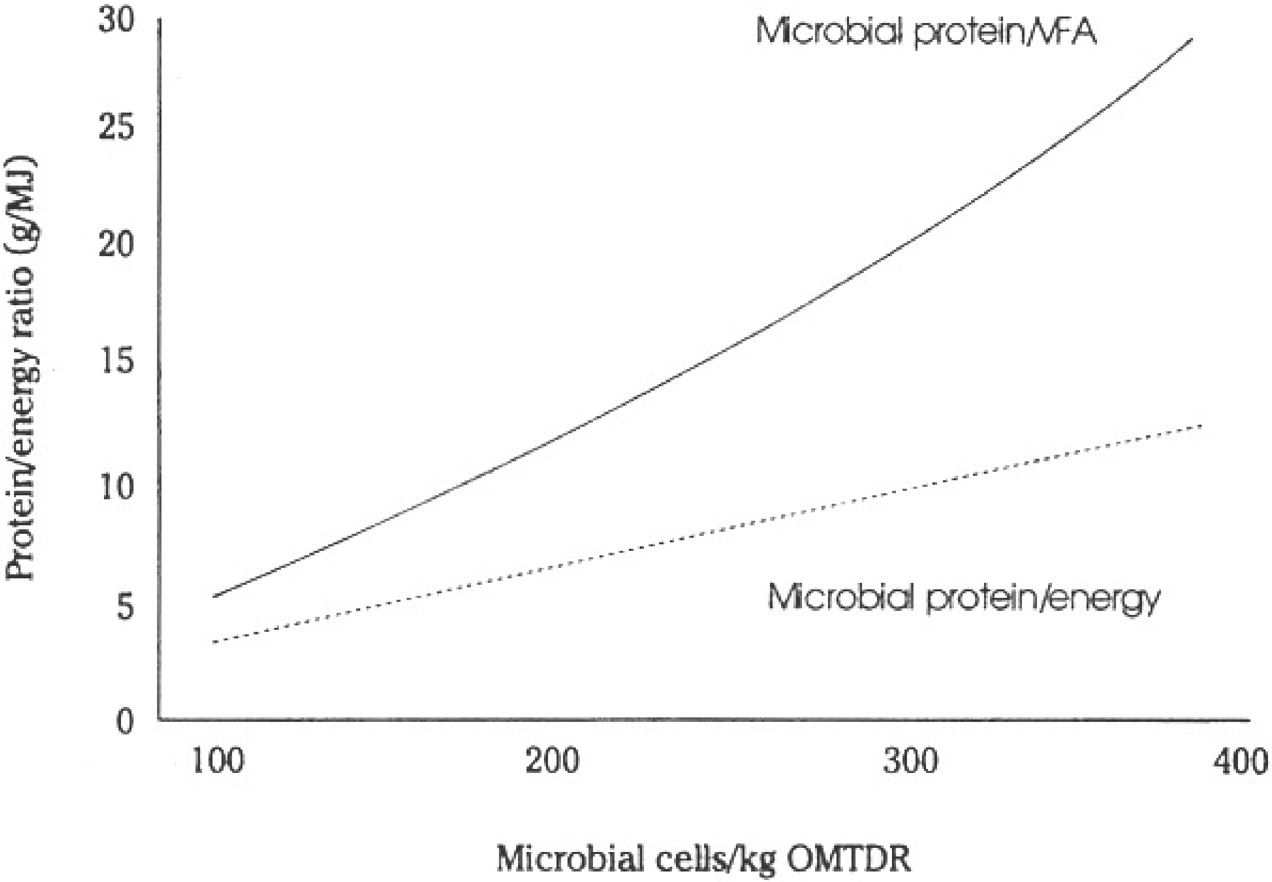
*** Ratio of microbial protein plus dietary protein to VFA energy**

**** Although the rumen environment is deemed not to change through the additionof protein meal, in fact it will have been improved, but may not be optimized tothe extent it would by feeding a molasses/urea block. P/E ratio here is thereforeunderestimated.**

The diets given to ruminants in developing countries seldom

approach the high nutrient densities of those used in the temperate countries and the benefits of supplementation are more obvious the poorer the quality of the diet. Responses in cattle grazing dry pastures to molasses urea multinutrient blocks in the tropics are greater than those in animals on similar diets in the temperate areas. These observed different effects of supplementation are explained when climate/nutrition interactions are considered (see page 11).

Figure 2.3: ***A model of the relationship between the efficiency of nett microbial cell synthesis and the ratio of protein to volatile fatty acids (g/MJ) and protein to absorbed oxidizable substrates (energy) in the products of digestion of 1 kg polysaccharide truly digested in the rumen (OMTDR) (Nolan & Leng, 1989)*****.**



2.7 The effects of specific nutrient deficiencies on rumen

microbes

Forages contain mineral components which reflect soil conditions and may therefore be low in essential nutrients such as Na, Mg, P, Ca and S as well as trace minerals such as Co, Cu, Se and Zn. The nett effect of such deficiencies in the rumen is similar to a deficiency of N or ammonia, that is, a lowered microbial cell yield per unit of carbohydrate digested (Figure 2.2 on page 17 and see Leng, 1981) and at times a lowered digestibility. The first effect of any mineral deficiency will be on microbial growth; thus the symptom that first arises is one of malnutrition or protein deficiency.

It is pertinent to stress here that microbial growth efficiency in the rumen may decrease without a concomitant effect on digestibility or feed intake until the washout of the rumen of microbes causes a decrease in microbial pool size (see Kanjanapruthipong & Leng, 1996).

The levels of sulphur and ammonia in rumen fluid which maximize digestibility of fibrous carbohydrates appear to be 1–2 mg S/l and 50–80 mg ammonia N/l respectively (Bray & Till, 1975; Satter & Slyter, 1974), whereas maximum microbial growth efficiency seems to require 4–10 mg S/l and 150–200 mg ammonia N/l respectively (Kandylis, 1984; Moir, 1975; Perdok & Leng, 1990; Boniface *et al.* 1986; Leng *et al.* 1993). Growth of fungi is highly dependent on sulphur availability (Akin *et al.* 1983) and fungi are absent from the rumen on low sulphur diets; this could be a major constraint to digestion of poor quality forages by ruminants in the nonindustrialized tropics. Sulphur deficiency appears to be widespread in the tropics as this mineral is leached from soils readily and quickly. A partial or total loss of fungi from the rumen could reduce digestibility of a mature forage by up to 5 digestibility units, which in turn would lower feed intake by 20–40%.

It is probable that similar relationships to those applying to

sulphur and ammonia also apply to the relative availability of other critical minerals, particularly phosphorus, which also affect digestibility and microbial growth efficiency.

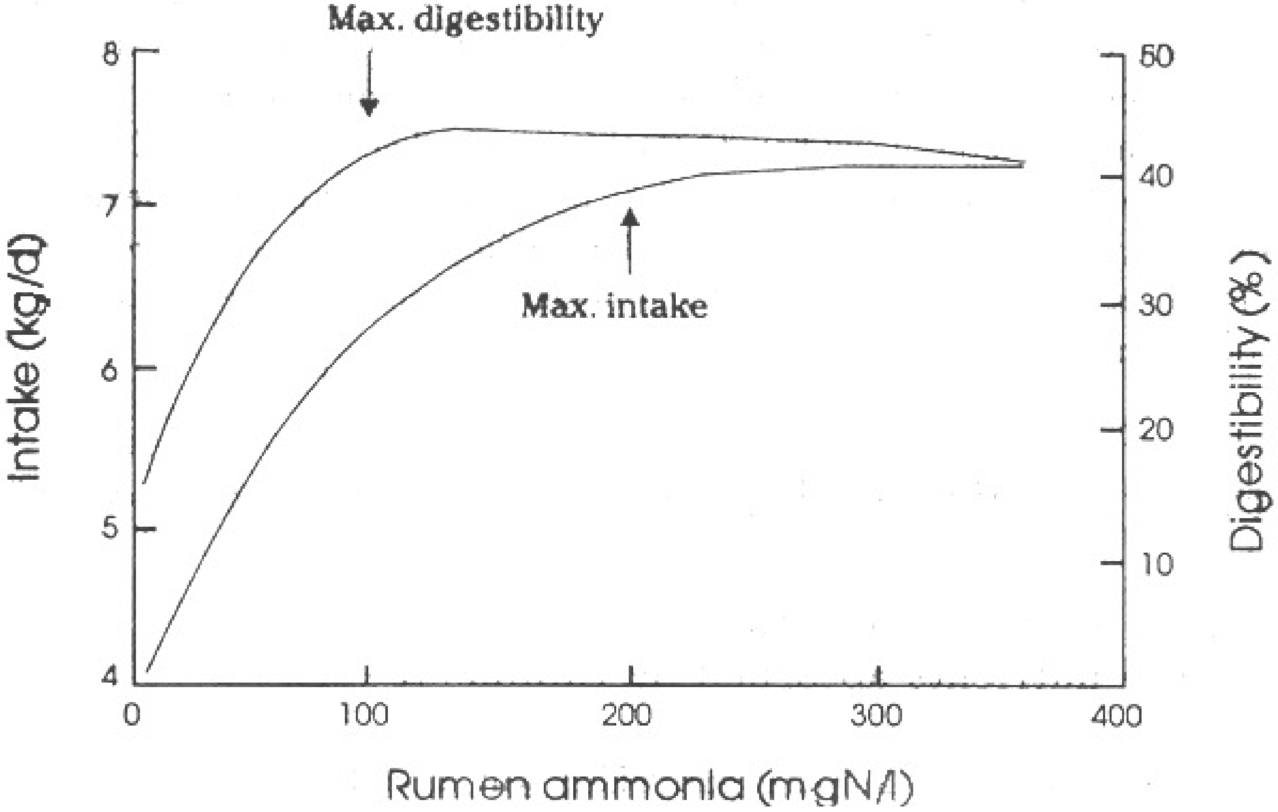
A marginal deficiency in the diet of a number of essential microbial nutrients may be undetectable and have no effect on forage digestibility but may significantly lower the protein/energy ratio without effecting metabolizable energy availability (see Leng, 1981). These marginal deficiencies, through their effects on the balance of nutrients from the rumen also affect the efficiency with which the absorbed nutrients are used by the animal.

2.7.1 Recent studies on the effects of ammonia levels on digestibility of forage and microbial growth efficiency in the rumen

The effects of ammonia availability on digestibility and straw

intake of cattle (Figure 2.4 on the following page) suggest that there are two critical ammonia levels. These are 80– 100 mg N/l for optimum fibrolytic activity and 150–250 mg N/l for optimal microbial growth and therefore optimum P/E ratio in the nutrients absorbed.

Figure 2.4: ***The effects of the level of rumen ammonia on the intake and*** **in sacco** ***digestibility of straw by cattle (Perdok*** **et al.** ***1988)*****.**



Studies at the University of New England, Australia (Kanjanapruthipong & Leng, 1996) have recorded that on a low

protein forage (oaten chaff) the rumen environment of sheep is markedly changed with increasing levels of ammonia. The availability of microbial protein was assessed by using purine excretion as an index of microbial biomass reaching the intestines to be digested and absorbed (Chen & Gomes, 1992). Initially, increases in rumen fluid ammonia of between 10 and 50mg N/l optimized fibre digestibility and apparently stimulated the rumen microbial populations of protozoa and fungi. Thereafter increasing the rumen ammonia level further led to linear decreases in protozoal density in rumen fluid (Figure 2.5 on page 23)

Excretion of purine derivatives in the urine of the sheep decreased initially as ammonia levels increased (which is an indication of the extent of movement of microbes to the lower gut for digestion and absorption of the amino acids (Smith & McAllan, 1971; Chen & Gomes, 1992) and then increased thereafter. Thus, net microbial protein reaching the small

intestine with increasing ammonia in the rumen was initially depressed and then increased almost linearly with ammonia concentration. These results indicate a complex series of changes within the rumen ecosystem as ammonia is increased in rumen fluid. It seems that much more ammonia is needed to maximize P/E in the nutrients absorbed than has been previously recommended. This indicates the importance of feeding strategies that maintain ammonia levels in the rumen at high levels at all times, such as occurs when ammoniated straws are fed to cattle or tree foliages are included in low N-forages fed to ruminants. The results also point to a reason why urea supplementation does not always promote increased levels of production from low quality forages. It seems that at the low ammonia levels, protozoa are highly efficient and competitive, reducing bacterial cell flow to the lower gut. Therefore a small amount of extra N in such diets can be detrimental unless it provides an ammonia level that exceeds 40 mgN/l. Even though feed intake and digestibility are increased under such conditions,

P/E ratios may be decreased and the benefits of more intake are balanced by a decreased efficiency of feed utilization.

2.8 Overview of microbial growth efficiency

2.8.1 Strategies to alter P/E ratio in the nutrients absorbed by ruminants

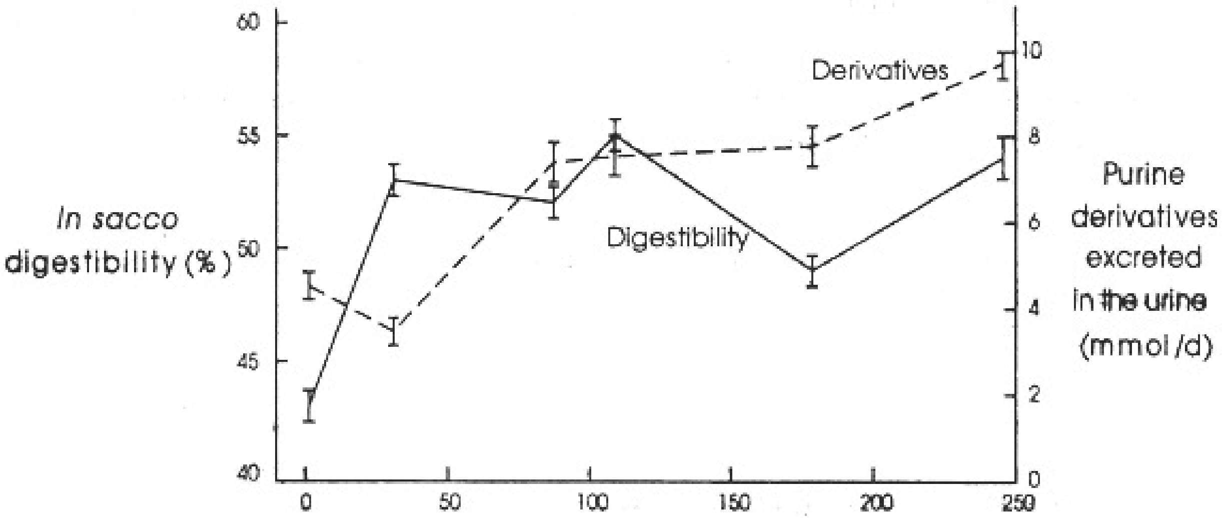
There are a number of dietary manipulations which will alter the P/E ratio in the nutrients absorbed. These include manipulation of:—

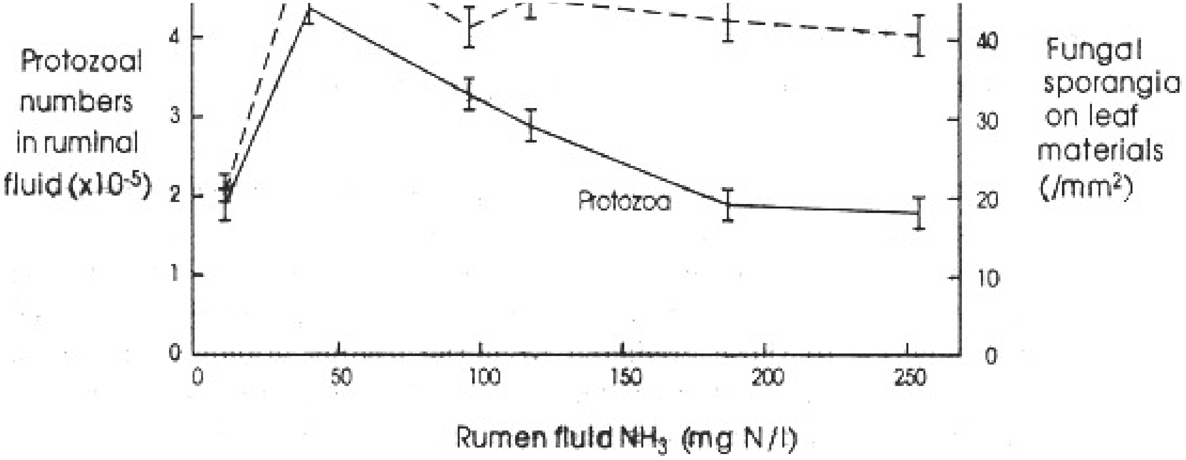
- **the rumen. As has been discussed above, a suboptimal level of any nutrient critical for microbial growth will result in low protein to energy (P/E) ratio in the nutrients absorbed. The first nutritional strategy for ruminants is, therefore, to ensure a nutrient non-limited microbial digestion in the rumen by complete supplementation. This automatically** improves the P/E ratio in the nutrients available for digestion in the animal from poor quality feeds.

- the protozoa in the rumen (Bird & Leng, 1978). This is not discussed at great length here because, as yet, there are no practical methods that are economic to accomplish the defaunated state in ruminants. However, a number of plants have been identified that contain antiprotozoal compounds which may have application in the use of these trees foliages in the future (see Leng *et al.* 1992). Immunisation against rumen protozoa has recently shown promise. In general, defaunation increases microbial growth yield by 20–25% as shown in trials with sheep cannulated at the level of the intestines (Viera *et al.* 1983) or with wool growth of sheep (Bird *et al.* 1979).

Figure 2.5: ***The effects of increasing levels of rumen ammonia caused by infusing urea continuously into the rumen on rumen***

microbial growth (as indicated by purine excretion)**, in sacco** ***digestibility of oaten chaff (the basal diet) and fungal and protozoal biomass (Kanjanapruthipong & Leng, 1996)*****.**





- the diet. Feeding a supplement in which the protein has been made insoluble or otherwise non-degradable by rumen microbes is a major strategy to adjust the P/E ratio upwards, provided there is adequate ammonia production in the rumen to meet microbial requirements. Where the diet contains a soluble readily fermentable protein (e.g., leaf protein), it has been shown that including small amounts of bentonite results in more dietary amino acids reaching the small

intestines of ruminants (Fenn & Leng, 1989). This is a new area for research, particularly where tree foliage is fed.

The reason for discussing the theoretical calculations of P/E ratio in the nutrients absorbed is to emphasize the large differences that can occur depending on the adequacy of the diet.

2.8.2 Manipulating P/E ratios using bypass protein supplements

Ruminants on a diet containing a high level of bypass protein already have an appropriate level of essential amino acids absorbed relative to VFA energy (see Table 2.2 on page 18) and therefore it is not always necessary for the rumen microbes to grow efficiently as long as digestibility is optimized. The inefficient rumen will, however, have a higher heat of fermentation and produce more methane per unit of carbohydrate fermented; these are disadvantagous and again the

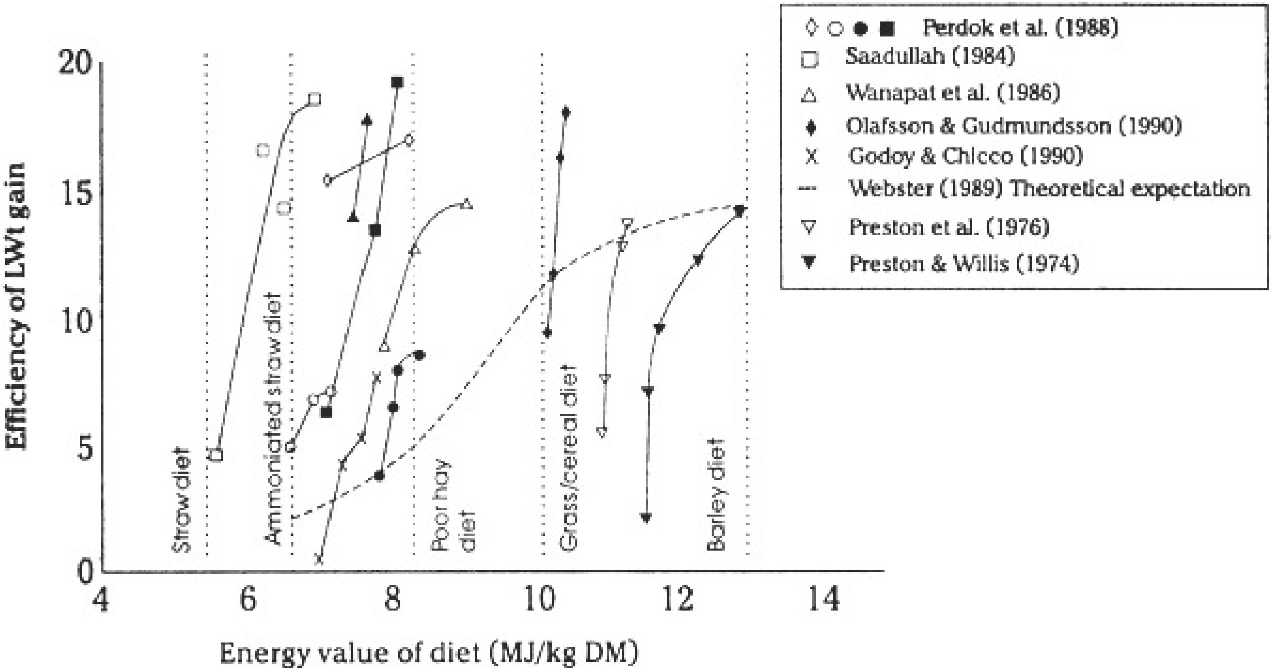
increased heat from rumen fermentation may result in different effects in cool as compared with hot environments.

2.9 Feeding standardsare they applicable to forage diets?

The ratio of P/E in the nutrients absorbed, through its effects on the efficiency of feed utilization has a large effect on growth, milk yield and, in particular, reproductive performance of ruminants (Perdok *et al.* 1988). The levels of production achieved when the P/E ratio is increased by supplementation in ruminants fed roughage based diets have been greatly superior to those predicted from the feeding standards based on metabolizable energy of a feed (see Figure 2.6 on the next page). The results for the efficiency of cattle growth where molasses and sugar cane are fed with supplements illustrate that low efficiency of utilization of even high energy diets may occur at times. The latter are the diets low in protein and which promote large population densities of protozoa in the rumen (Leng & Preston,

1976) and therefore the ratio of protein to energy in the nutrients absorbed is lower than in ruminants on high grain based diets where protozoal density is low or even zero (see Preston & Leng, 1986).

Figure 2.6: ***Schematic relationship between diet quality (metabolizable energy/kg dry matter) and food conversion efficiency (g liveweight gain/MJ ME) (from Webster, 1989). The relationships found in practice with cattle fed on straw, or ammoniated straw, or poor quality pasture with increasing levels of supplementation are shown for individual studies (see Leng, 1990 for references). A recent response curve in cattle fed silages supplemented with fish protein sources (Olafsson & Gudmundsson, 1990) is shown. For comparisons, similar responses to bypass protein supplements for cattle fed molasses (Preston*** **et al.** ***1976) and sugar cane (Preston*** **et al.*****1974) are included.***



Forage for cattle in the tropics is usually 40–55% digestible. The metabolizable energy in the dry matter (M/D) thus ranges from 8.5 to 4.8 MJ/kg DM. According to feeding standards, a metabolizable energy content in a feed of 8.5 will support a

liveweight gain of approximately 3g/MJ of ME intake in cattle. At 4.8MJ/kg DM intake, cattle should be in negative energy balance (see ARC, 1980 and also Webster, 1989). Contrast this with results of supplementary feeding trials based on balancing the nutrition of animals with urea/minerals and bypass protein, where growth rates equivalent to 18g/MJ of ME intake have been achieved in cattle fed straw (see Figure 2.6 on the preceding page). Obviously the presently accepted feeding standards are misleading for roughage based diets. The application of the basic concept of balanced nutrition, as discussed here, can improve animal growth by 2–3 fold and the efficiency of animal growth by as much as 6 fold over previous estimates (a range of 2–10 fold). Also, although growth rates of cattle are below those on grain based diets, cattle in the tropics on forage based diets can be as efficient in converting feed to liveweight gain as those in the temperate countries grazing quality pastures. Overall the ability of cattle to consume supplemented roughage has been underestimated by the feeding standards once the rumen is

efficient and the balance of protein to energy is improved (McLennan *et al*. 1995).

The low productivity of tropical ruminant livestock has been accepted as an inevitable result of a poor feed base and a low feed conversion efficiency. This is no longer tenable. Application of the new feeding strategies detailed here will have a flow-on effect of improved reproduction, increased percentage of a herd in production, and an increased offtake from a herd. The benefit of improved reproduction outstrips the direct effects on liveweight gain or milk yield *per se* from the application of such strategies.

The challenge is to develop the necessary supplements and to get these to the animals in the various production systems. This is an important deviation from past practice. Vastly superior levels of production can be achieved with this approach as it is much more appropriate than replacing forage with concentrates

to achieve increased levels of production.

2.10 Rôle of fodder trees in the nutrition of ruminants

With the above discussion in mind, the rôle of fodder trees in ruminant diets can be seen as three fold:—

- **as a N and mineral supplement to enhance fermentative digestion and microbial growth efficiency in the rumen of cattle on poor quality forage**
- **as a source of post-ruminal protein for digestion. In this rôle the influence of secondary plant compounds in binding protein and making it insoluble is of particular importance**
- **as a total feed, supplying almost all the biomass and other nutrients needed to support high levels of animal production.**

A further rôle is presently emerging, that is the potential of

constituent secondary plant compounds to manipulate the balance of micro-organisms in the rumen. The ability of secondary plant compounds to reduce protozoal populations has important implications for protein availability to ruminants (see Leng *et al.* 1992).

In the following chapters, the practical implications of tree foliages in providing deficient nutrients in the rumen are discussed. The comparisons made are between the data from feeding studies with foliages, as compared with data from feeding multinutrients aimed at correcting deficiencies for rumen microbes. The potential results of using bypass protein in addition to feeding deficient microbial nutrients are discussed in order to understand the potential benefits of using different foliages in the two roles or being able to process the same foliage to provide either rumen nutrients, bypass protein or both. This discussion, then, identifies the present inefficient use that is made of tree foliages in ruminant nutrition.

In their rôle as a complete food, fodder tree plantations offer alternatives to pastures. Such tree pastures are costly to establish and maintain, but the payoff in the yields of high protein foliages may, in some countries, warrant the management and fertilizer input necessary.

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Chapter 3
Balancing nutrition to maximize forage utilization

3.1 Concepts of balanced nutrition

The basic concepts of ruminant nutrition reviewed in the last

chapter are briefly revisited below.

To optimize the utilization of poor quality forages, the appropriate supplements are:—

- **an array of macro- and microminerals and a source of ammonia to meet requirements of the rumen microbes for efficient growth**

- **a supply of protein containing a substantial proportion of bypass protein to augment the protein supply to the animal.**

Further increases in ruminant production, once these two requirements are met are obtained by increasing the energy density of the basal feed resource consumed by:—

- **treatments that improve digestibility of a forage**

- **supplementation with higher digestibility forages that** increase overall digestibility

- addition of small quantities of readily digestible feeds with a low rumen load, e.g., molasses

- using feeding strategies that allow selection from a forage. In this case ruminants will select the most nutritionally available components and reject the least valued materials (Boodoo *et al.* 1988; Aboud *et al.* 1990). The strategy is to feed 150% the quantity of a forage that would have been consumed when no selection was possible.

3.2 Meeting nutritional requirements of ruminants with appropriate supplements

In most regions or localities it is not practical to identify the deficient micro- and macrominerals in pasture or other forages, as these will vary from site to site and year to year and also with

the pattern of fertilizer application and weather conditions. The practical approach is one that uses ‘rules of thumb’ to supplement effectively, i.e., to provide a best bet or ‘shot-gun mixture’ of minerals and a source of ammonia nitrogen in the rumen as economically as possible. A concentrated plant extract such as molasses, or the concentrated residues after fermentation of sugar to alcohol provides such mixtures and can be fortified for specific areas where local knowledge points to specific deficiencies. In this respect, molasses distillers slops (the residues of molasses fermentation) offer a useful sources of these minerals. Molasses or slops are also palatable to livestock and are useful for disguising less palatable nutrient sources. An oilseed byproduct meal or wheat and rice bran or a tree forage or other green forages can also be used to provide the animal with minerals.

Mineral salt mixtures are commercially available. They usually have a high content of sodium chloride and added quantities of

trace elements. In practice, fortified molasses or molasses blocks will be superior to these mixtures as they present a greater coverage of all the minerals required and they are also a valuable source of other nutrients (e.g., B vitamins) and a small amount of fermentable energy.

3.3 Supplying the rumen microbes with ammonia

The requirement for ammonia by rumen microbes may be met from urea, other nitrogenous components or soluble proteins. Urea is commonly administered to livestock on dry forages together with minerals, and its concentration in such mixtures is controlled by safety concerns and difficulty of incorporation. It therefore rarely exceeds 10–15% of such mixtures. However, this is usually sufficient to allow an intake of between 50 and 100 g of urea by cattle from a molasses-urea multinutrient block (MUMB) which is usually sufficient to provide the rumen microbiota with their requirements of ammonia on a low N pasture. The amount

needed may be reduced where an animal is able to consume urea at regular intervals, which then maintains rumen ammonia high at all times throughout a day. It has been found to be quite safe to feed mixtures with up to 30% urea in Australia where livestock are accustomed to taking such a mixture and it is always continuously available.

Many leaf proteins and some seed proteins appear to be readily degraded in the rumen and are therefore an available source of ammonia for microbial growth. As both soluble protein and urea can supply the microbes with ammonia, the results of feeding urea to ruminants gives insights into the potential value of highly soluble leaf proteins. In this instance, if leaf foliage is supplying only minerals and ammonia to the rumen microbes, the response will be similar to that from multinutrient blocks containing urea, but if they impart additional benefits then the response per unit of N will be considerably higher for leaf meals than urea combined with minerals. There are numerous other sources of

rumen ammonia, including chicken and pig fheces, which are regularly included in ruminant diets.

3.4 Some examples of the value of multinutrients in cattle given forage based diets

The effects of correcting deficiencies of nutrients for rumen microbes in cattle given poor quality forage by supplementation with leaf foliage may be anticipated by examining the effects of multinutrient mixtures on production of ruminants on such diets. Thus an examination of the literature detailing responses of forage-fed ruminants fed molasses urea multinutrient blocks (MUMB) gives a good model to compare cattle responses to tree foliages. For this reason, data on the value of molasses/urea blocks as supplements to cattle and forage based diets are given below. From this point in the discussion, molasses-urea multinutrient blocks, which differ in composition depending on the country/place of manufacture, will be referred to as MUMB.

3.4.1 Effects of supplementation with urea/molasses/multinutrient blocks (MUMB) on cattle production

Only a few examples are given here as a more comprehensive review of this area is in preparation.

Table 3.1: *Effects of MUMB supplements on growth rate of Friesian Holstein steers, Ongole steers, sheep and goats fed cut/carry pasture in Indonesia (Hendratno* et al *1991). This study indicates the value of multiminerals included in the MUMB, as the cut-andcarry forage was green.*

	Growth rate (g)			
Animals	**N (g/d)**	**Nil**	**+ MUMB**	**% Increase in production**
FH Steers	156	210	560	166
	171	400	810	102
Ongole Steers	161	333	526	57
	204	478	465	-2.7

	291	388	822	111
	110	183	403	120
Sheep (Local)	30	36	67	86
	32	140	316	126
Goats (Does)	32	40	88	120
Goats (Kids)	52	91	105	15

3.4.2 Effects of multinutrient mixes on growth rates and milk yield of cattle

Growth Rates In research at the small farmer level in Indonesia with both growing and milking animals fed green grass/forage mixtures in a cut and carry system, responses to MUMB have been spectacular (Tables 3.1 on the page before, and 3.2 on page 34), but in this case the effects were due to both minerals and urea in the blocks. A probable explanation for the results in Table 3.1 on the page before is that microbial growth efficiency in the

rumen was depressed by mineral deficiencies, particularly, for example, sulphur, phosphorus and trace minerals (these deficiencies are widespread in the tropics) the responses in this case being due to their correction. In other countries the responses to multinutrient blocks observed may also be due to correction of other macrominerals as well as trace mineral deficiencies.

In the results from Indonesia, *in vitro* studies using rumen fluid from unsupplemented and supplemented animals showed that without the multinutrient source, rumen microbial growth was undetectable using the incorporation of ^{35}S, but was improved to normal by the provision of multinutrients in the form of MUMB (Hendratno, C., personal communication[1]).

Trials, feeding molasses-urea mixtures to cattle on dry native pasture in Northern Australia over five years of experimentation are shown in Figure 3.1 on the following page. The effects

illustrate the variable responses and the differing minimal requirements for urea under grazing systems. It also indicates that under some circumstances other mineral deficiencies quickly become a primary limiting nutrient for the growth of rumen microbes.

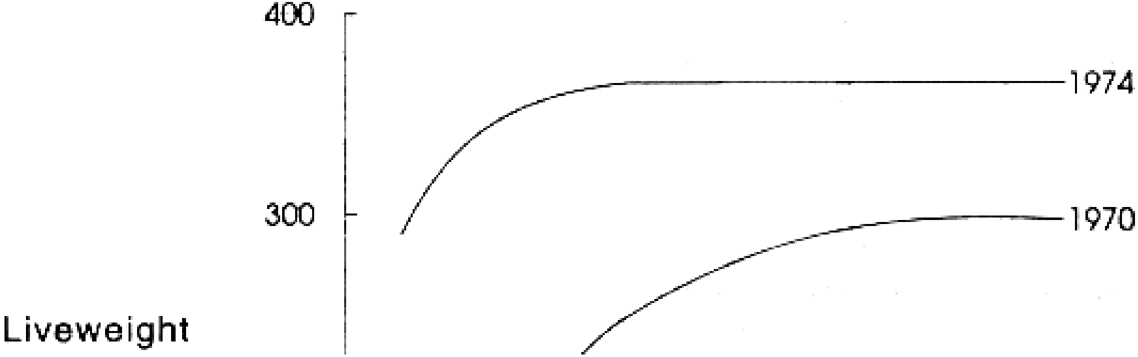
Milk Yield In recent studies in India, even where buffalo and cattle have been fed considerable amounts of a concentrate, green forage and millet straw that made up 60% of the diet, a molasses-urea-multinutrient block, improved milk yield by an average of 30% (Figure 3.2 on page 35).

Milk production from dairy cows on tropical pastures supplemented with or without MUMB in Cuba and The Dominican Republic is shown in Table 3.4 on page 35. These results are highly typical of results from various countries and show that these supplements have a marked effect on milk yield where cattle are fed tropical forages and crop residues under a wide

variety of conditions.

[1] Dr C. Hendratno, Centre for the Application of Isotopes and Radiation, National Atomic Energy Agency, Jakarta, Indonesia.

Figure 3.1: ***Summary of liveweight responses of young Bos indicus cross cattle (initially 18–24 months of age) to various levels of urea fed through molasses/urea roller drums during the dry season in Northern Australia (Winks*** **et al.** ***1972; Winks*** **et al.** ***1979; summary by Dixon, 1995).***



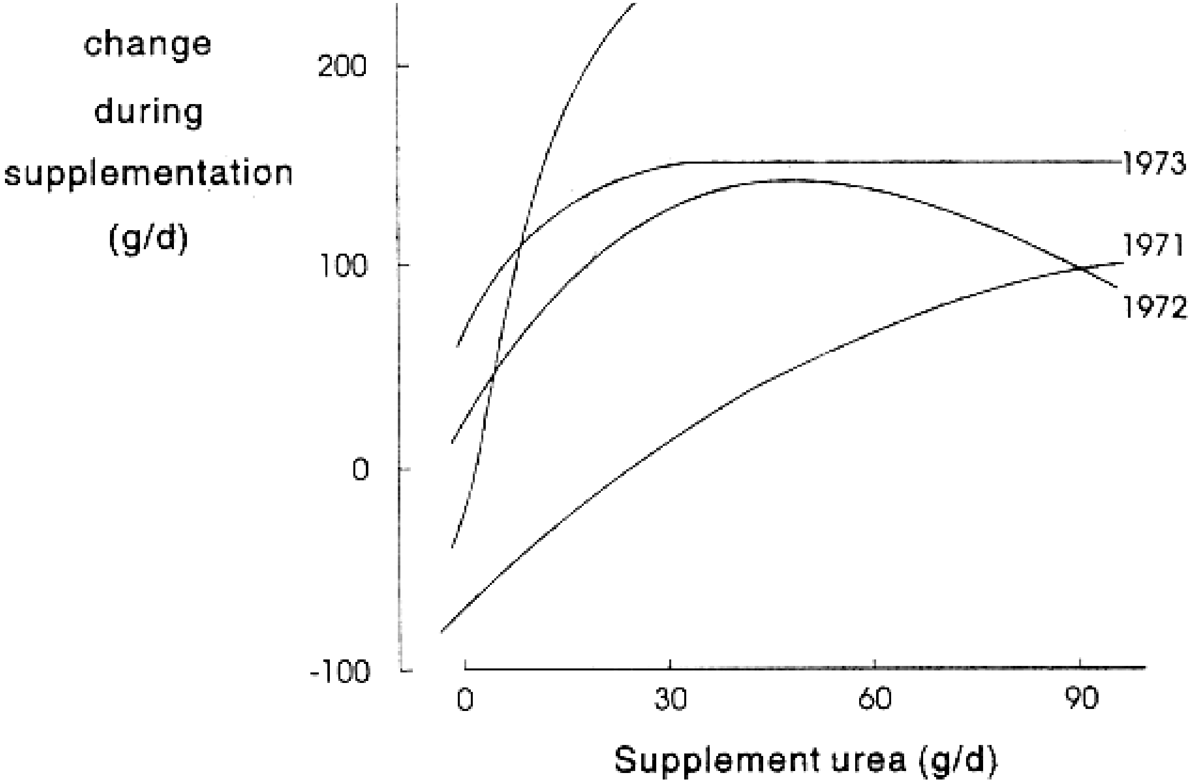


Table 3.2: *Effect of MUMB supplement on milk yields of Friesian-Holstein dairy cattle given cut and carry green forage in Indonesia*

(*Hendratno* et al. *1991)*

	Milk yield (18 weeks, in litres)			
	N intake (g/d)	**Nil**	**+MUMB**	**% increase**
Lembang, West Java	297	1008	1019	1
Garut, West Java	197	900	1107	23
Mageland, Central Java	270	871	1119	28

3.4.3 Effects of MUMB on reproduction of cattle, sheep and goats

Reproductive rates of cattle/sheep have been strongly affected by supplementation to balance nutrition of ruminants fed low quality forage based diets. Australian researchers showed that where cattle and sheep have only poor quality forage during the last trimester of pregnancy, the birth weight of the calf or lamb is adversely affected unless the rumen is made efficient by the use of urea and mineral supplements (Table 3.3). The chances of

survival of the lightweight offspring from unsupplemented cows or sheep are extremely low because of their low body weight.

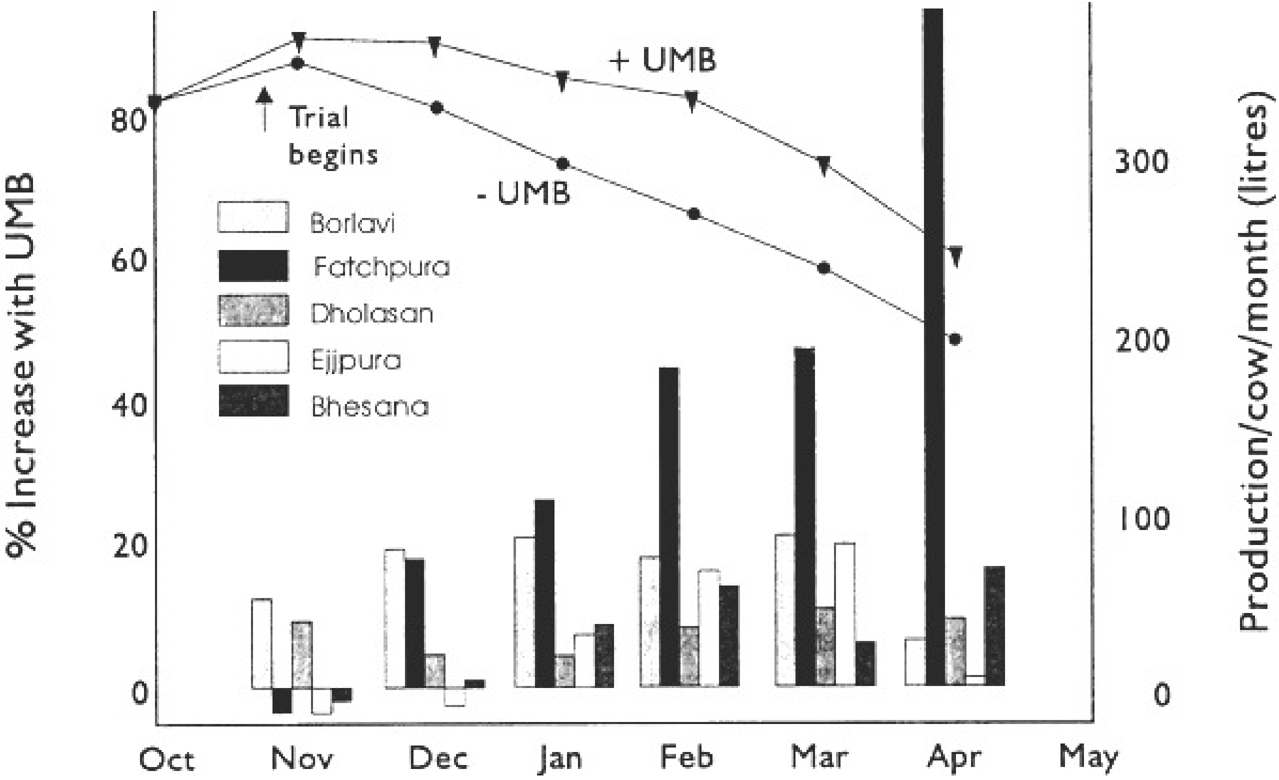
Table 3.3: *Effects of urea/sulphur supplementation on birth weight of lambs and calves fed poor quality forages. Sources: Lindsay* et al. *(1982) and Stephenson* et al. *(1987)*.

Animal	Supplement	Birth wt. (kg)
Sheep	+ urea/sulphur	3.2
	Nil	2.9
Cattle	+ urea/sulphur	22
	Nil	32

The effects of feeding MUMB on reproductive performance of African hair sheep are shown in Table 3.5 on page 36. The sheep were fed chopped cane tops supplemented with *Gliricidia* foliage (Vargas & Riviera, 1994).

Figure 3.2: ***The pattern of milk production in several villages in***

India where similar cattle and buffalo were fed with or without MUMB. See Table 3.4 for diets. The overall averages from 77 animals in each group are shown (Manget-Ram* et al., *personal communication.*[3]*)



[3] A.K. Manget-Ram, A.K. Tripathi, A.S. Dave, A.K. Metha and M.P.G. Kurup, The National Dairy Development Board, Anand,

India.

Table 3.4: *Effect of MUMB on milk yield of grazing cows in Cuba (Diaz* et al. *1994) and Dominican Republic (Prodeleste, 1991).*

	Nil	**+ MUMB**	**Increase (%)**
Cuba (litres/day)	3.1	4.3	39
Dominican Republic (bottles/day)	5.5	6.9	28

3.4.4 Conclusions on reproductive efficiency

It appears that, provided the rumen microbial ecosystem is efficient (i.e., microbial growth is optimized) even on low digestibility forages ruminants will reproduce at normal rates and produce offspring of an adequate size with nutrient reserves to ensure their viability following birth. However, this is not true in cattle with high genetic capacity for milk yield which require much higher protein levels; these levels can only be achieved with bypass protein in addition to a MUMB.

Table 3.5: *Effect of MUMB on performance of African hair sheep (Vargus & Riviera, 1995).*

	Nil	**+ MUMB**
Liveweight at weaning (kg)		
ewes	32	34
lambs	12	14
% ewes pregnant		
at 150 d *post partum*	56	85
Mortality rate (%)		
maiden ewes	20	6
lambs to weaning	32	8

3.5 Conclusions on the use of supplements that provide critically deficient nutrients

The overall conclusion from a wide variety of studies throughout the world is that the value of supplements that are aimed at

correcting deficiencies of microbial nutrients in the rumen in cattle given poor quality forage based diets are:—

- **increased weight gain**
- **increased milk yield**
- **increased conception rate**
- **increased survival of mature animals**
- **increased survival of offspring**

The operative question here is whether these nutrients, required for efficient microbial growth, can be adequately supplied to ruminants by tree foliages.

3.6 Crude protein requirements of ruminants

Up until some 20 years ago the protein requirements of ruminants were defined in terms of crude protein (N × 6.25) in the diet. It is now recognized that crude protein in the diet may contribute a significant amount of the ammonia utilized for microbial growth in the rumen. However, some protein meals, because of various physical and chemical properties or as a result of processing, have properties that slow their rate of degradation in the rumen: protein escapes to the intestines and augments the total amino acid supply to the animal. Microbial protein and dietary escape or bypass protein provide the essential amino acid requirements of the animal and also supply glycogenic substrate.

Table 3.6: ***Results of strategic supplementation to balance nutrition of cattle consuming poor quality roughage supplemented with bypass protein. In most cases the basal diets received MUMB or some other form of urea and minerals in addition to 0.5–1.0 kg/day of a bypass protein meal such as***

cottonseed meal.

- **Improved feed intake (in tropics/subtropics)**
- **Improved efficiency of feed utilization**
- **Improved productivity**

growth rates of grazing cattle	from -330 g to + 300 g/d
body condition of pregnant cattle over last third of pregnancy improved	from 850g/d to + 750g/d
milk yield, beef & dairy animals	2–3 litres milk/kg supplement
age at first calving decreased	from 4–5 years to 2 years
calving rates of cattle improve	50% to 85–95%

• birthweight of calves increased	from 22 kg to 32 kg
• survival of young animals increased	from < 30% to > 80%
• intercalving interval of cattle reduced	from 2 years to 12–15 months

Some protein meals when added to poor quality feeds increase productivity of ruminants to a greater extent than can be attributable to an enhanced rumen function. It became a major issue when the unexpectedly large responses to bypass protein of ruminants on poor quality forages were recognized. A general description of response to a bypass protein are shown in Table 3.6 on the page before and this area has been reviewed by Leng *et al.* 1977, Preston & Leng, 1986 and Leng, 1990).

Undoubtedly the level of bypass protein in a diet of poor quality forage is critical. The responses of ruminants on low protein forages to bypass protein meals are, therefore, a model to test

whether such protein sources as tree foliages provide bypass protein.

3.7 Application of the new feeding strategies based on balancing nutrients

Even though the principles of balancing the rumen and feeding bypass protein to improve productivity of ruminants on poor quality forages have been known for many years, uptake and application has been slow and unspectacular in many developing countries. In the developed countries the compounding feed industries have quickly recognized the value of bypass protein. Industrial processing has been developed to produce bypass protein from vegetable proteins, particularly for the dairy industry.

The uptake and application of such strategies by scientists and farmers alike in most tropical countries has been slowed by:—

- **the dependency of many scientists trained in the traditional temperate country institutions on the feeding standards that apply to those countries**

- **the inability of research scientists to communicate with and have their suggestions accepted by applied technologists and those who apply agricultural policies**

- **the often unavailability of protein, minerals, and non protein nitrogen in the areas with large populations of ruminants and therefore the heavy cost of delivering these to the animal**

- **the controversies surrounding the principal mechanisms of action of protein supplementation which cloud the major issue. The major issue is that poor quality feeds can be turned into feeds of good quality by strategic supplementation**

- **the availability on international markets of inexpensive grains which have usually been heavily subsidized and are relatively easy to feed. However, movements in fuel prices, competition from pig and poultry production and general removal of protective trade barriers has seen the prices of these surplus grains increase recently. Any dependency on feed resources that are also used by humans could be calamitous for developing countries if supply decreases and/or the price rises.**

The operative question now is whether tree foliages can be sources of bypass proteins or nutrients specifically needed in the rumen or both. A second major question is how to develop these as combination sources of each nutrient.

3.7.1 Major applications of balanced nutrition in developing animal production systems

Extensive application of the use of supplements of multinutrient blocks and bypass protein has occurred in India through the initiatives of The National Dairy Development Board of India (NDDB). For the reasons given above, progress was initially slow (the development started in 1980) but it is now accelerating at a pace which should see most of their feed mills dedicated to the production of bypass protein supplements within the next five years. At the present time between 200,000–300,000 MT of bypass protein are being fed annually to around 500,000 dairy animals sustained on poor quality feeds and owned by village farmers in the central parts of India. In many situations, this is coupled with the use of molasses urea blocks compounded to provide a spectrum of nutrients for the rumen microbes (NDDB, 1989).

Monthly milk collections are shown in Figure 3.3 on page 42, for a major dairy co-operative in the Kedah district of India that changed from feeding a traditional concentrate to a new

supplement containing 30% of a protein meal with a high level of bypass protein. In this figure, the quantities of milk collected from villages in the area are shown for the previous five years and for the twenty-six months since conversion to the new feeding system. Whilst a number of changes have occurred in the area which could contribute to the increased quantity of milk collected, local research confirms that the responses in milk production to the new supplements (Leng & Kunju, 1988) are in agreement with observed increases in milk collected. A large proportion of the increased milk collected appears to be a result of more animals in the milking herd due to increased reproductive efficiency (i.e., a reduced intercalving interval).

The effects of the change to balanced feeding strategies based on supplementing with nutrients for the microbial ecosystem and bypass protein appear to be a 30–50% increase in milk collection from 1st December, 1988 to 1st December, 1989. A further similar increase in production is apparent in 1989–1990 (unpublished

observation). This increase probably represents a flow-on effect that would come from increased reproductive efficiency and the increased proportion and number of cows in milk resulting from the improved feeding strategies.

In China, a major cattle production development based on the same principles and sponsored by FAO has had a very high level of success. It is estimated that around 3.3 million small farmers are presently fattening cattle on straw treated with ammonia to improve digestibility and supplemented with a bypass protein meal (cottonseed meal). The growth response of young cattle given straw or straw treated to improve its digestibility and supplemented with cottonseed meal is shown in Figure 3.4, page 43. A number of similar studies carried out in other countries are also shown in the same figure. China has a policy to increase beef production using this strategy to 10 million tons by the year 2000.

3.8 Availability of bypass protein meals

In many regions or countries, there is often little information on locally available protein sources, particularly the level of protection of these protein meals from degradation in the rumen. As a 'rule-of-thumb', solvent extracted oilseed cakes, fish meals that have been flame dried (but not sundried fish meal or fish silage) and protein sources that have been heat treated, have some protection from rumen degradation. The degree of protection is enhanced by pelleting the protein meal in the presence of free glucose or fructose (as occurs in molasses), when a mild Browning reaction tends to occur (unpublished observations). Recently xylose-a pentose sugar readily produced from bagasse has been added to soluble protein meals to provide a protected protein (Lewis *et al.* 1988). Although tannins in tree foliages may insolubilize constitutive proteins, it is unclear whether these proteins bypass the rumen and whether they are digestible in the intestine.

3.9 Identification of bypass protein sources

Some countries are fortunate in having large amounts of crop residues high in protein, most of which have a high degree of protection brought about by processing methods (e.g., solvent extracted sesame, linseed and cottonseed meal). These materials are convenient for use directly by the farmer or may be processed through existing feed mills for the production of a supplement which can be fortified with minerals and non-protein nitrogen. The most valuable and important source of bypass protein is probably solvent extracted cottonseed meal and where development programmes have been successful in promoting animal production, it is often been where cottonseed meal is readily available. It has been found that a number of oilseed byproducts contain soluble proteins and therefore it is has been necessary to protect, for instance, soyabean meal with xylose; in N. America and Europe and in Australia, canola, sunflower and safflower seed meal are also being protected in commercial

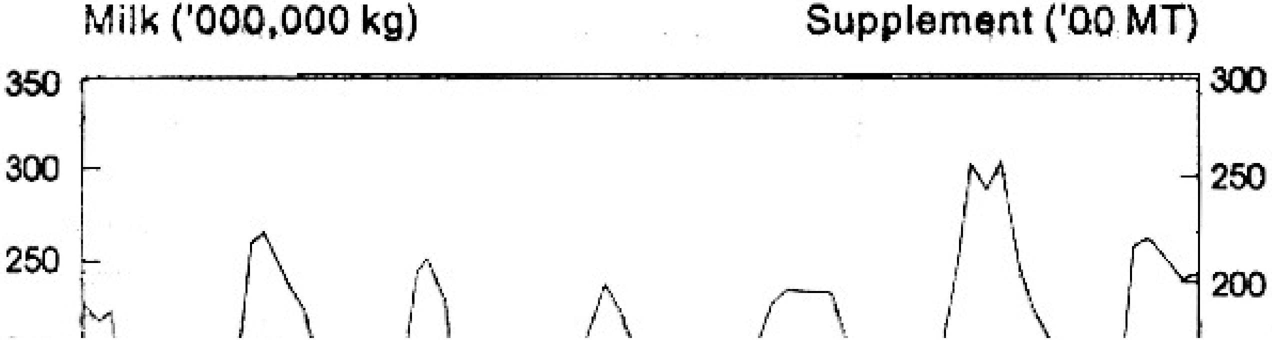
factories with formaldehyde prior to feeding to ruminants as a bypass protein source.

In many countries, particularly with monocultures of cereals, sugar cane or extensive grasslands or savannahs, protein sources may not be readily available, or the sources not so obvious or easily obtainable. Most fresh legume forages, legume seeds, edible tree leaves, seed pods and seeds that are available in these areas, probably contain highly soluble protein which is easily fermented in the rumen. These, when used as supplements, provide a valuable source of rumen ammonia and minerals and appear to have a synergistic effect in lifting the digestibility of the basal diet (Ndlovu & Buchanan, 1985); they then increase feed intake and so increase production of cattle on a basal diet of low protein roughage. When fed as a small proportion of the diet, however, they provide little bypass protein, as the protein degrades rapidly in the rumen. It is important to know whether such supplements are as efficiently

used for these purposes as MUMB supplements.

In the following chapters the potential use of fodder trees to provide ruminants with the nutrients critically deficient in poor quality forages are discussed.

Figure 3.3: ***Milk collection records and the sale of supplements in a milk co-operative in the Kedah district of India when supplements were compounded on traditional concepts (1985–1987) then replaced (1st December, 1988) with a 30% C.P. bypass protein pellet (records provided by the NDDB of India).***



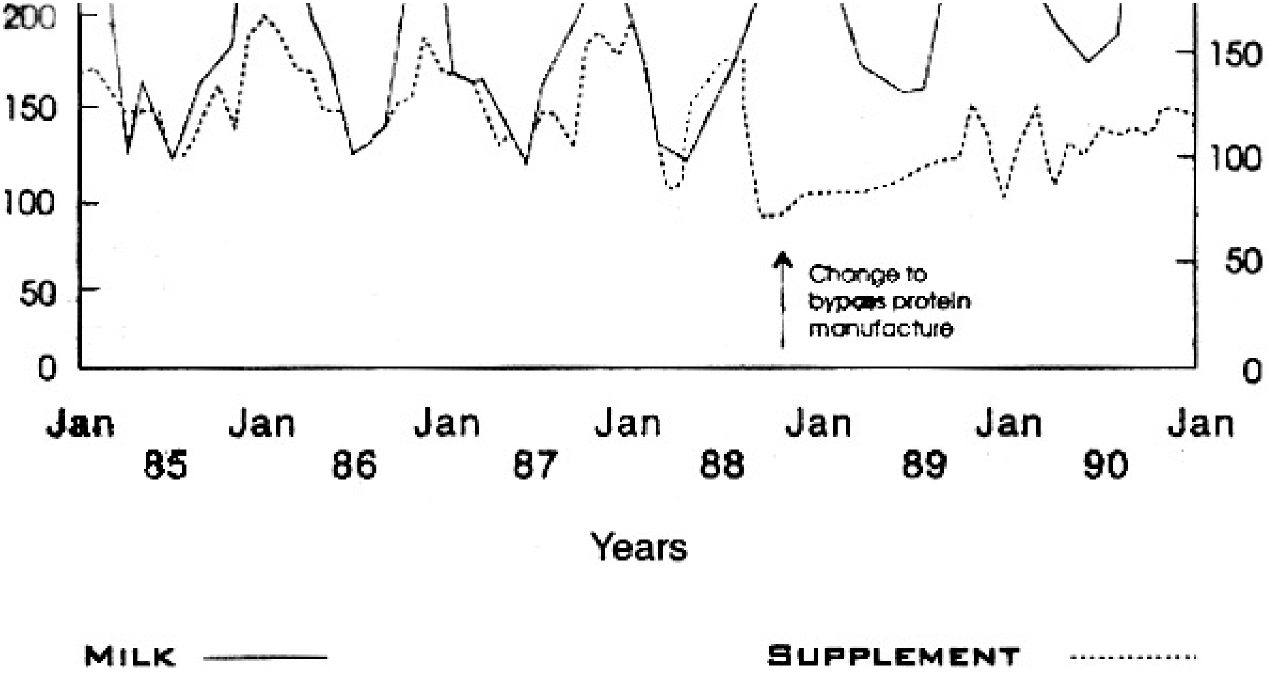
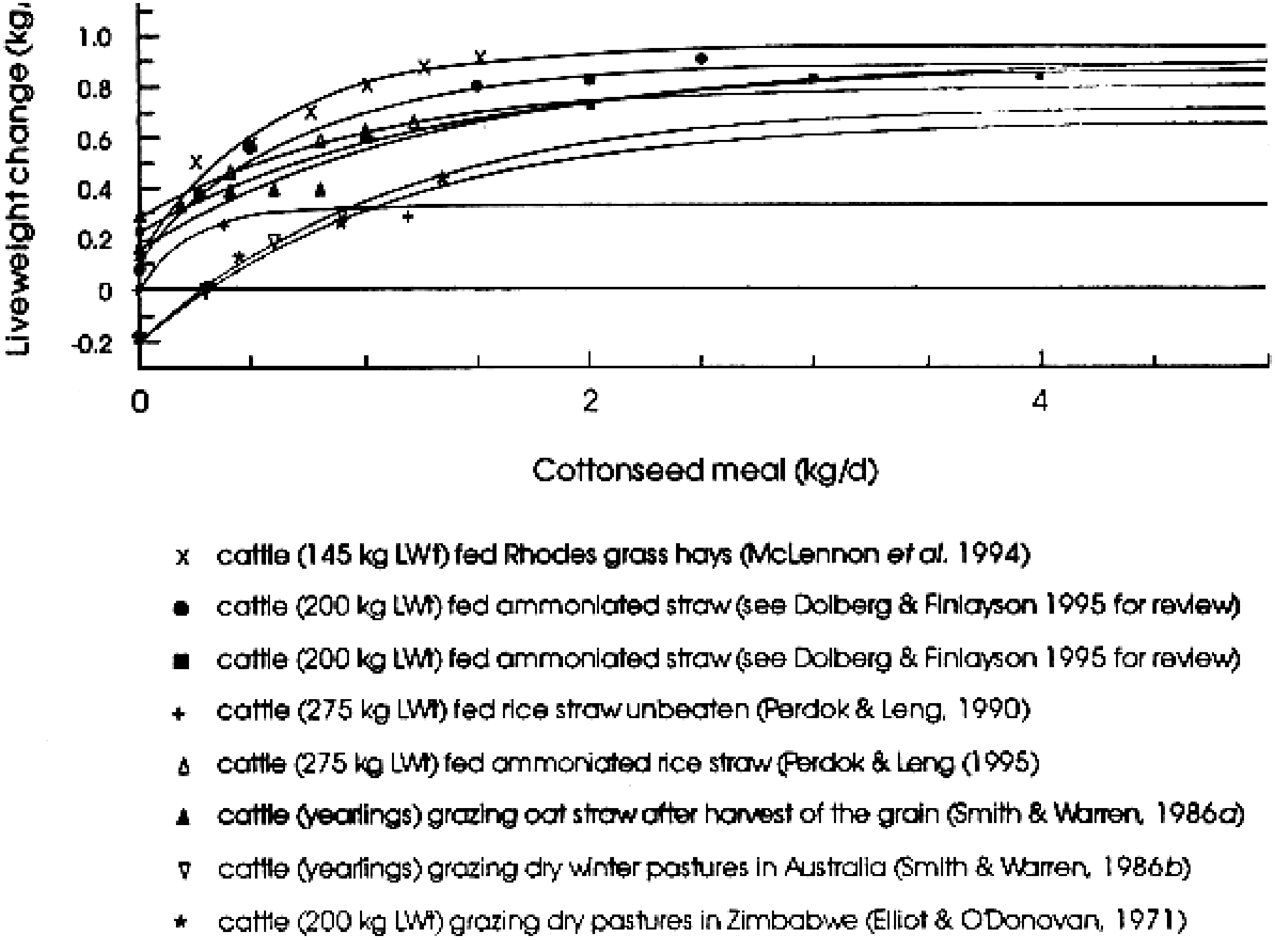


Figure 3.4: *The response in liveweight gain of cattle fed basal poor quality forage supplemented with cottonseed meal (after Leng, 1995).*


Liveweight change (kg)
1.0
0.8
0.6
0.4
0.2
0
-0.2
0
2
4
Cottonseed meal (kg/d)
x cattle (145 kg LWt) fed Rhodes grass hays (McLennon *et al.* 1994)
● cattle (200 kg LWt) fed ammoniated straw (see Dolberg & Finlayson 1995 for review)
■ cattle (200 kg LWt) fed ammoniated straw (see Dolberg & Finlayson 1995 for review)
+ cattle (275 kg LWt) fed rice straw unbeaten (Perdok & Leng, 1990)
Δ cattle (275 kg LWt) fed ammoniated rice straw (Perdok & Leng (1995)
▲ cattle (yearlings) grazing oat straw after harvest of the grain (Smith & Warren, 1986*a*)
▽ cattle (yearlings) grazing dry winter pastures in Australia (Smith & Warren, 1986*b*)
* cattle (200 kg LWt) grazing dry pastures in Zimbabwe (Elliot & O'Donovan, 1971)

Chapter 4
Potential rôles of tree fodders in ruminant nutrition

4.1 Introduction

Tree foliages represent an important source of cellulosic biomass for feeding ruminants throughout the world. Tree and shrub foliages are often selected by grazing ruminants where possible and traditional people recognize those tree foliages which are sought and consumed by ruminants. However, other than traditional knowledge of tree/shrub foliages, there is a dearth of information on their benefits, even though some

progress has been made recently to collate information, for example, Gutteridge & Shelton, 1994 and Shelton *et al.* 1995. It seems that their rôle in ruminant nutrition has not been truly defined and is likely to be different depending on whether they are used as strategic supplements or total feeds. In the next part of this publication, an attempt will be made to clarify these rôles.

4.2 Anti-nutritional and nutritionally beneficial aspects of tannins in forages

Fodder from trees and shrubs (top feed) have been an important source of protein for grazing animals. However, in some cases, not only has their crude protein digestibility been observed to be low, but also several cases of livestock death have been associated with high tannin content of some foliages. The most important property of tannins is their strong affinity for enzyme and feed protein, but even this varies depending on species; for instance, *Prosopis cineraria* has been observed to have tannins

that have a very high protein precipitating capacity-higher than tannins from other tree foliages.

Tannin content, therefore, potentially alter the use and value of tree foliages and may at times be responsible for the poor utilization of such forages by ruminant livestock. On the other hand, lack of tannins in *Gliricidia* is believed to leave the protein so unprotected as to be completely degraded in the rumen. Tannins from *Leucaena leucocephala* afford a good level of protection of the protein (Wheeler *et al.* 1995), but tannins from *Lotus pedunculatus* appear to overprotect protein from ryegrass fed to sheep (Waghorn & Shelton, 1995) with subsequent increased faecal loss of protein.

A selective review of the effects of tannins on ruminant nutrition is given below to provide the rationale for some of the recommendations discussed in the final chapter.

There are two chemically distinct types of tannins:—

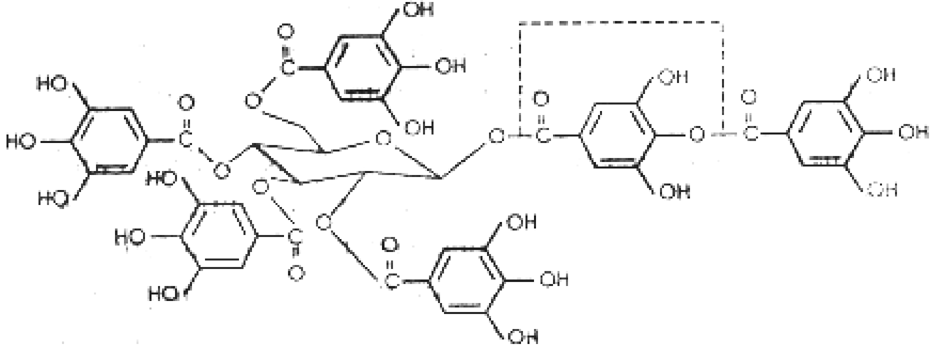
- **hydrolyzable tannins (gallotannins and ellagitannins). These are polyesters of gallic acid and other phenolic acids derived from it, with a sugar (normally glucose). They are readily hydrolyzed by acid.**

- **condensed tannins (flavolans). These are polymers (M.W.≈ 1,000 to > 20,000) of catechins, which are flavonoid phenols. The linkage between the monomers, typically a carbon condensation, is relatively stable under the conditions which cleave ester linkages in hydrolyzable tannins.**

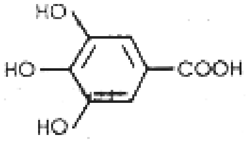
The generalized structures of tannins are shown in Figure 4.1 on the next page.

Figure 4.1: ***Examples of hydrolyzable (gallotannin) and condensed (proanthocyanin) tannins and their constituent units.***

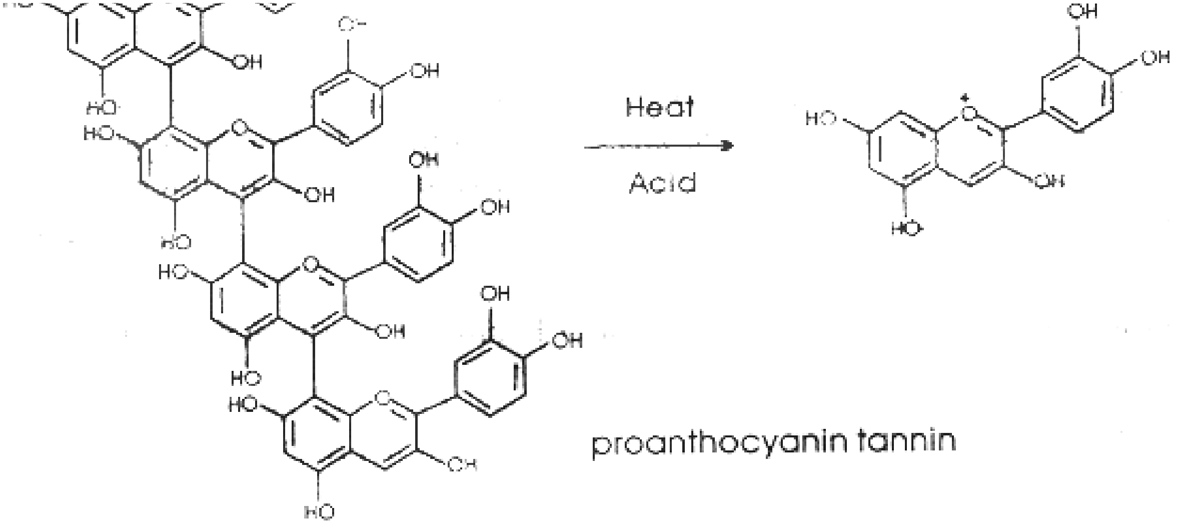
In the case of gallotannin the dotted line indicates the repeating gallic acid unit (from van Soest (1982).



gallotannin



gallic acid



proanthocyanin tannin

4.3 Effects of tannins on rumen function

It has been believed for some considerable period that tannin above 5% can become a serious anti-nutritional factor in plant materials fed to ruminants (McLeod, 1974). Barry (1983) and his colleagues have demonstrated with *Lotus pedunculatus* that the ideal concentration of condensed tannins in this forage legume is

between 2–4% of the diet dry matter, at which level they bind with the dietary proteins during mastication and appear to protect the protein from microbial attack in the rumen. On the other hand, other forages with tannins have anti-nutritional effects in the rumen and reduce N retention (Waghorn & Shelton 1995). If the protein-tannin complex dissociates under acid conditions then the protein can be digested in the lower gut. At higher levels (5–9%) tannins become highly detrimental (Barry, 1983) as they reduce digestibility of fibre in the rumen (Reed *et al.* 1985) by inhibiting the activity of bacteria (Chesson *et al.* 1982) and anaerobic fungi (Akin & Rigsby, 1985) high levels also lead to reduced intake (Merton & Ehle, 1984); above 9% tannins may become lethal to an animal that has no other feed (Kumar, 1983).

Sheep have been shown to adapt slowly to tannins in a diet of *Acacia* leaves, suggesting that there are rumen organisms that in some way detoxify their effects (Reed *et al.* 1985). Recent studies have demonstrated a bacterium in the rumen of goats and sheep

capable of growth at high tannin levels in the rumen (Brooker, J., personal communication[1]).

Thus a little tannin has been usually accepted as being able to protect protein of forages and allow a higher efficiency of feed utilization by the animal. However, recent results throw some doubt on this. Tannins may indirectly effect rumen function by reducing rumen ammonia levels through decreased protein degradation in the rumen. If rumen ammonia levels decrease below 80 mg N/l (see Figure 2.4 on page 21) then fibre digestibility may be depressed and digestibility is reduced well below 10 mg N/l (Leng *et al.* 1993). Whenever tannins are present in forages there may be a need to supplement ruminants with a non-protein nitrogen source such as urea or chicken manure. Conversely, tannins in feed may increase detrimental effects on rumen function when the basal diet is low in protein.

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[1] Dr J.D.Brooker, Department of Animal Science, Waite Campus,

University of Adelaide, South Australia.

4.4 Tannin in plant foliage

Condensed tannins are present in only some plant species. In general, shrub and tree foliages are likely to be higher in tannins than pasture plants, and leguminous forages from the tropics are generally higher in tannin than those from the temperate countries.

The level of tannins within a species has been found to vary considerably depending on a number of factors. For example in New Zealand, *Lotus pedunculatus* grown on fertile, high moisture soils has about one third the condensed tannin content of *Lotus* grown on hill country under water stress (Barry, T., personal communication[2]).

The literature in this area is often confusing as reported levels of

tannins often seem to be higher than can be explained and these values often are rejected by reviewers as possibly due to errors of analysis. For example, *Prosopis* leaves have been reported to have tannin levels of 2.2% of the dry matter (Sehgal, 1984) but in 15 individual trees Joshi *et al.* (1985) reported levels ranging from 10.6 to 25.3% which suggested to some authors that there may have been major analytical difficulties. Certainly the level of tannins in the foliage of trees is highly variable and depends on environmental stress (fertility, soil-water relationships, insect attack etc.). Newer information also points to analytical flaws in preparation of leaf material for analysis and drying reduces the measured tannin levels over fresh material. New leaves often have higher tannin content than older leaves (Vaithiyonathan & Singh, 1989) and in South Africa the tannin content of *Acacia* grazed by Kudu increased with grazing pressure (van Hoven, 1991).

Tannins at 14–16% are present in the bark of many trees (Dalziel,

1948) indicating a very large pool in the tree that can possibly be mobilized. In general it could be expected that the green bark of new growth would contain less tannin than the brown bark, and the leaves and petals less than bark.

4.5 Tannin mobilization

There is a small amount of literature indicating that the tannin content of some tree foliages may be controlled in some way and can be elevated at times of high risk of defoliation (i.e., by insect attack, cutting and harvesting, or grazing).

An investigation in South Africa of the death of a number of Kudu on a wild life farm has led to knowledge that may have major implication for management of some fodder trees (van Hoven, 1985).

[2] Professor T. Barry, Faculty of Agriculture, Massey University,

Palmerston North, New Zealand.

A number of Kudu (member of the deer family) died after grazing on a small area of *Acacia* trees (van Hoven, 1991). Subsequent studies have shown that in the wild these Kudu would approach such woodlands and after grazing on the trees on the periphery move quickly to trees well separated from those recently grazed. However, because of the enclosure these animals were forced to consume more of the foliage from one woodland. Subsequent studies implicated tannin in the death of the animals and this led to a study of tannin in the tree foliage. Tannin levels rose sharply over a 15 minute to 1 hour period, not only in the trees grazed by deer, but in the trees adjacent to those that were being damaged.

Nomads in India, grazing camels on *Prosopis juliflora* on the roadside carefully explained the need to move their camels to fresh trees after a short time of grazing in the one area (Leng, R.A. personal observation). Although not yet tested, this fits the

idea of some trees responding to grazing by increasing the content of anti-palatability secondary plant compounds.

The implication is that there is a pool of tannin which can be readily mobilized by activation of specific enzymes sensitive to air borne materials released from damaged foliage. This obviously has been an important survival mechanism for trees on the savannahs. Also it has major implications for the use of browse trees in pasture/tree associations for cattle production. However, responses of some tree foliages to such treatment is far from clear and a number of trees do not respond to damage in any way. This area requires experimental work in a number of situations.

The effect of simulated grazing on tannin content of a number of tree leaves is shown in Table 4.1 on page 51. The information on such responses in a number of trees needs to be compiled.

4.6 The implications of tannin build-up in foliage

Tannin buildup in foliage has enormous implications for the use of fodder trees. It may partially explain some of the contradictory nature of much of the data on the efficiency of use of fodder trees, and the common rejection of trees for fodder purposes in some areas and not in others.

The quality of harvested foliage will always depend on where it is produced, how it is harvested, the stage of plant growth, the climate, the effects of insect damage and the stocking rate. Where trees respond to damage, it is possible that occasional grazing by animals in a plantation may effect tannin levels in the leaves for up to 4 days.

As tannins appear to be both anti-nutritional and perhaps nutritionally beneficial it is important to determine what factors influence tannin levels in foliage; whether these factors can be

controlled (e.g., strategic fertilizer or water application) and whether harvesting techniques and stocking rates can be developed to optimize or minimize the tannin levels.

If it is too complex to develop such techniques then it is obvious that high tannin levels may be acceptable so long as they are diluted by other feed resources that have sufficient protein to bind free tannins beneficially but this necessitates a cut and carry system for tree fodders.

4.7 Tannins in the rumen

The fate of tannins following ingestion by ruminants depends on the type of tannin. Most tannins form complexes with protein in the plant material, in saliva or the rumen contents. Hydrolyzable tannins hydrolyze in gastric acidity beyond the rumen, releasing protein, amino acids and small units of phenolics that probably pass to the urine. At high levels of tannin intake, both mucoproteins and the epithelial cell lining of the digestive tract are affected. This alters the integrity of the gut wall causing problems of gastritis, slowed propulsion of feeds and constipation (Kumar & Singh, 1984). Only under exceptional circumstances will herbivores consume large quantities of forages containing tannins, although recent studies from Zimbabwe suggests that the intake of browse can be increased by feeding very small quantities of polyethylene glycol (Duncan, 1994). However, from the point of view of this publication, fodder trees are considered only as potential supplements to poor quality forage and not a basal feed reserve.

Drying promotes the combination of tannin and plant protein before ingestion which may result in different responses by ruminants on forage diets to supplements of dry or fresh tree foliage. Proanthocyanidin tannins are held in special organs in the leaves to prevent their interference with the plant's own metabolic apparatus, and this factor favours tannin-tolerant

animal browsers that have tannin-binding proteins in their saliva (Austin *et al.* 1989). In these instances the salivary factor binds the tannins and spares valuable forage protein with a higher concentration of essential amino acids.

Attempts to use tannins to promote rumen escape (“bypass”) of feed protein have had limited success. Fresh forage may be ingested before tannin-protein complexes can oxidatively cross-link, as in the case of dry feeds, although drying has been shown to have favourable effects on productivity (see later). Recently, Waghorn & Shelton, (1995) showed that, in sheep fed freshly cut rye grass, the addition of a third of the diet as *Lotus pedunculatus* (which supplied 1.8% condensed tannin in the total diet) resulted in the digestibility of the protein being significantly decreased from 78% to 65%. The inclusion of *Lotus* forage also lowered dry matter digestibility by 3–7%, which was almost all accounted for by the lowered protein digestibility. Apparently the level of protein availability in the animal from plant and other

sources was unaffected, as wool growth and liveweight gain were not different in groups given *Lotus* forage compared with those on pure rye grass. These experiments suggest that condensed tannins overprotect protein and that the precipitation of protein-tannin complexes protect the micro-organisms in the rumen from the detrimental effects of condensed tannins.

The presence of tannins in forages stimulate salivary flow in animals. A number of studies have shown an apparent increase in microbial protein leaving the rumen after feeding moderate levels of tannin (Beever & Siddons, 1986), but the level of increase is not convincing, considering the technology used to make the measurements. Nitrogen balance is apparently improved in animals that are fed low levels of tannins, although digestibility of forage fibre may be lowered (see Norton 1994a). The effect of condensed tannins overall appears to be to make more amino acids available in the intestine. Whether this is the result of increased microbial growth efficiency or increased

dietary protein availability is unclear.

Table 4.1: ***Tannin increases in three tree species in response to the effects of simulated grazing damage. The tannin levels were elevated for 100 hours before they began to decline.***

Species	**% Rise in 15 mins**	**% Rise after 60 mins**
Peltophorum africanum		
(Weeping wattle)	44	256
Rhus leptodictya		
(Mountain karee)	76	275
Acacia caffra		
(Hook thorn)	94	282

Source: van Hoven, W., personal communication[3]

3. Professor W. van Hoven, Centre for Wildlife Management, University of Pretoria, Pretoria, South Africa.

Polyethylene glycol forms complexes with tannins and has been fed to animals to reduce the inhibitory effects of tannins (see Pritchard *et al.* 1988).

Long-term ingestion of tannins by ruminants may induce enlargement of the salivary glands. Deer and goats and some monogastrics posses salivary proline-rich proteins that specifically bind tannins (Mehansho *et al.* 1987), but these are absent or low in the saliva of sheep and cattle (Austin *et al.* 1989).

4.8 Other secondary plant compounds in fodder trees

Many foliages have chemicals that appear to be produced for the purpose of deterring invasion or consumption of their leaves by

microbes, insects and herbivorous animals. Whilst tannins are the best known of these, there is a long list of secondary plant compounds. Cyanide, nitrate, fluoroacetate, cyanogenic glycosides, saponins, oxalates, mimosine and various sterols are but a few (see Norton, 1994c for a more extensive list). Quite recently, saponin concentrations have been implicated in low productivity in young cattle on young growth of signal grass (*Brachiaria*) (Lowe, S., personal communication[5]). These may or may not be modified in the rumen by microbial action. The primary compound or its breakdown products in the rumen may be toxic or of no nutritional consequence. Some secondary plant compounds are actively detoxified in the liver.

One of the best known secondary plant compound in tree leaves is mimosine in *Leucaena*, which is degraded to the toxic compound 3-hydroxy-4-pyridone by normal rumen organisms and which is usually further degraded by another microbe where animals have evolved in grazing situations containing *Leucaena*.

This microbe is not present in ruminants that have been isolated from *Leucaena* and inoculation is necessary to prevent toxicity when *Leucaena* becomes a high proportion of the total diet (Jones & Megarrity, 1986).

The main reason for the foregoing discussion is to emphasize that these secondary plant compounds should be taken into consideration. However, the toxic compounds often only become of significance nutritionally when the plant assumes a high proportion of the diet. Although some effects of the toxic compounds may persist when these are used to supplement the diets, the beneficial effects of a high protein forage often override their effects. There are, however, important exceptions particularly in the case of fluoroacetate which is an lethal compound that claims the lives of large numbers of cattle on pasture lands with *Acacia georginae* (see Cunningham *et al.* 1981), even though it is of relatively low digestibility. Recently a rumen microbe has been genetically modified to carry and

express a gene that encodes for an enzyme that hydrolyzes fluoroacetate (Gregg *et al.* 1994).

[5] Ms S.Lowe, Department of Agriculture, The Papua New Guinea University of Technology, Lae, Papua New Guinea

Whilst cautionary notes are necessary it is important to stress the advantage of fodder trees. The toxic principles must be kept in mind they should not be given prominence, especially where small quantities of foliage are supplementing forage based diets for ruminants. Even trees not considered as sources of forage may become useful in the future, for instance, *Acacia mangium* which grows vigorously on acid soils is being used to supplement cattle in Vietnam (An *et al.* 1994), even though it is of relatively low digestibility.

4.9 Comparisons of tree foliages and multinutrient blocks as supplements to ruminants fed poor quality feeds

Tree foliages have been given high prominence as protein supplements for ruminants fed low protein forages. However, seldom is it known whether escape protein *per se* is the valuable component of the foliage or whether the protein of the tree foliage is largely providing ammonia (from protein degradation), minerals, or all three. The rôle that tree foliages play in ruminant nutrition determines the required rate of supplementation, so it is extremely important to know what this rôle is.

Tree foliages low in tannins or other secondary plant compounds that might bind protein, are probably degraded rapidly and, at times, completely. In this way they provide ammonia and volatile fatty acids in the rumen. The rate of microbial growth on protein, however, is approximately half that on carbohydrate, so P/E ratios are lower when protein is degraded in the rumen in comparison with carbohydrates. On the other hand, if foliage protein is bound by condensed tannins, microbial degradation of leaf protein in the rumen will be prevented or slowed. This will

allow particles high in protein to move to the lower digestive tract where some of the condensed tannin complexed with protein may be hydrolyzed, which then allows the protein to be digested. Condensed tannin under acid or alkaline conditions of the intestines may be split to sugars and organic acids, mostly gallic acids, releasing protein and amino acids that are digestible in the lower gut. However, lowered N retention in animals fed some tanniniferous forages suggest that much bound protein, is unavailable for digestion in the gut (Mangan, 1988; Kumar & Singh, 1990; Waghorn & Shelton, 1995). Provided some protein remains soluble and can provide ammonia in the rumen and perhaps escape protein, some of the detrimental effects would be reduced. In this case the protein level relative to tannins would be the most critical factor.

Few research studies have defined the rôle required of tree foliages where their feeding objective is as supplements to low digestibility forage. The extent to which tree foliage protein is

degraded in or escapes the rumen is extremely important. If the tree foliage protein is totally degraded then it provides only ammonia and minerals for microbial growth (but both these may be more easily and economically provided from other sources such as MUMB, chicken manure or litter from broiler production).

Tree foliages, on the other hand, often have higher digestibilities than the pasture forage available and thus provide a more energy dense feed, allowing a higher total feed intake. In a situation where the fermentable N and minerals can be provided more economically, say, as MUMB then the use of such tree foliages is counter-indicated. The potential value of the foliage may only be realized by harvesting and processing so that it contains a higher percentage of bypass protein.

The relationships between the generation of microbial protein from various sources are shown in Figure 4.2 on the following page, where the protein available from 1 kg carbohydrate

fermented in a rumen sufficient in ammonia is compared to the protein and energy available from 1 kg of a soluble and bypass protein source.

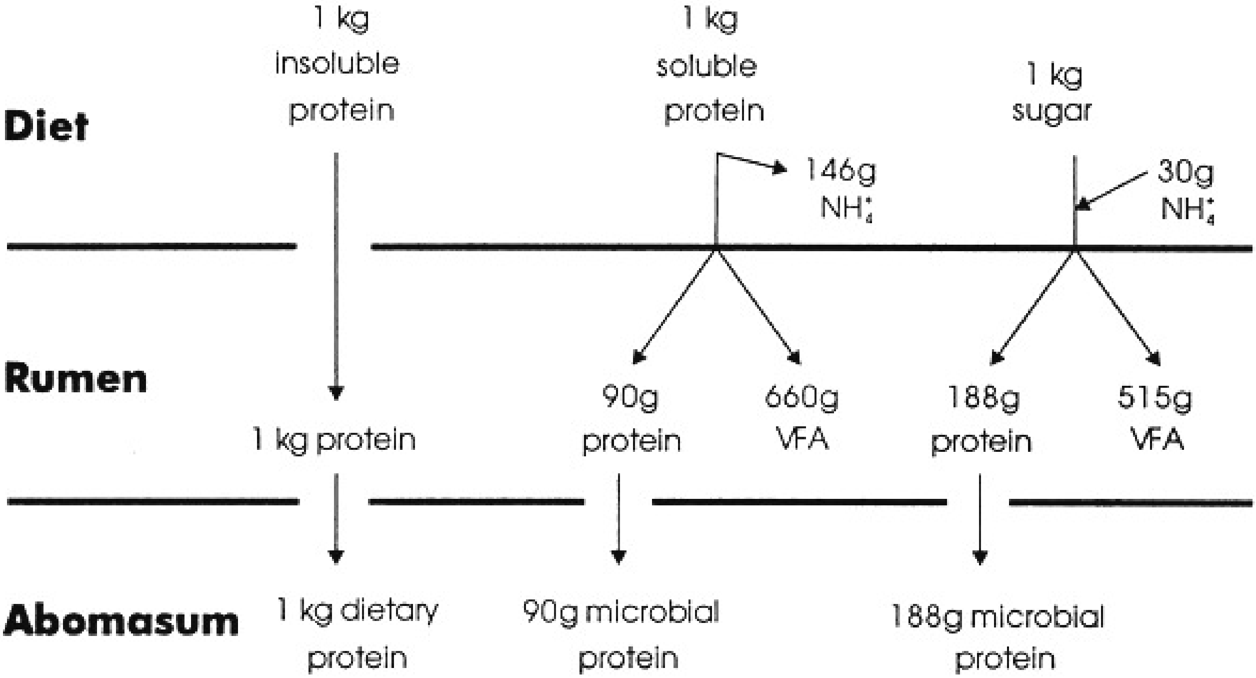
4.10 Tree foliage as supplements to pasture or other low quality forages

The reasons for using tree foliage as supplements to low protein forages such as tropical pasture or straw are similar to those for forage legumes under the same conditions and therefore some comments on forage legumes are pertinent to the discussion here.

The presence of legume forages and tree forages in pastures have been generally accepted to improve ruminant productivity in both temperate (Ulyatt, 1980) and tropical pastures (Milford, 1967). The problems of maintaining legume forages in pastures centre around the competent management of such pastures. The

inability of highly palatable legumes to survive in pastures resides in the inability in most farming systems to manage grazing, but where legumes are established, animal productivity is always greater for legume based pastures than from pure grass pastures (Mannetje, 1984; Thompson, 1977; Walker, 1987) (Figure 4.3 on page 56). A most important attribute of legumes is that their digestibility declines more slowly with maturity and environmental temperature than does that of grasses (Minson, 1980).

Figure 4.2: ***A theoretical balance of nutrients arising from feeding soluble protein, insoluble protein and carbohydrate to ruminants (after Leng, 1981).***



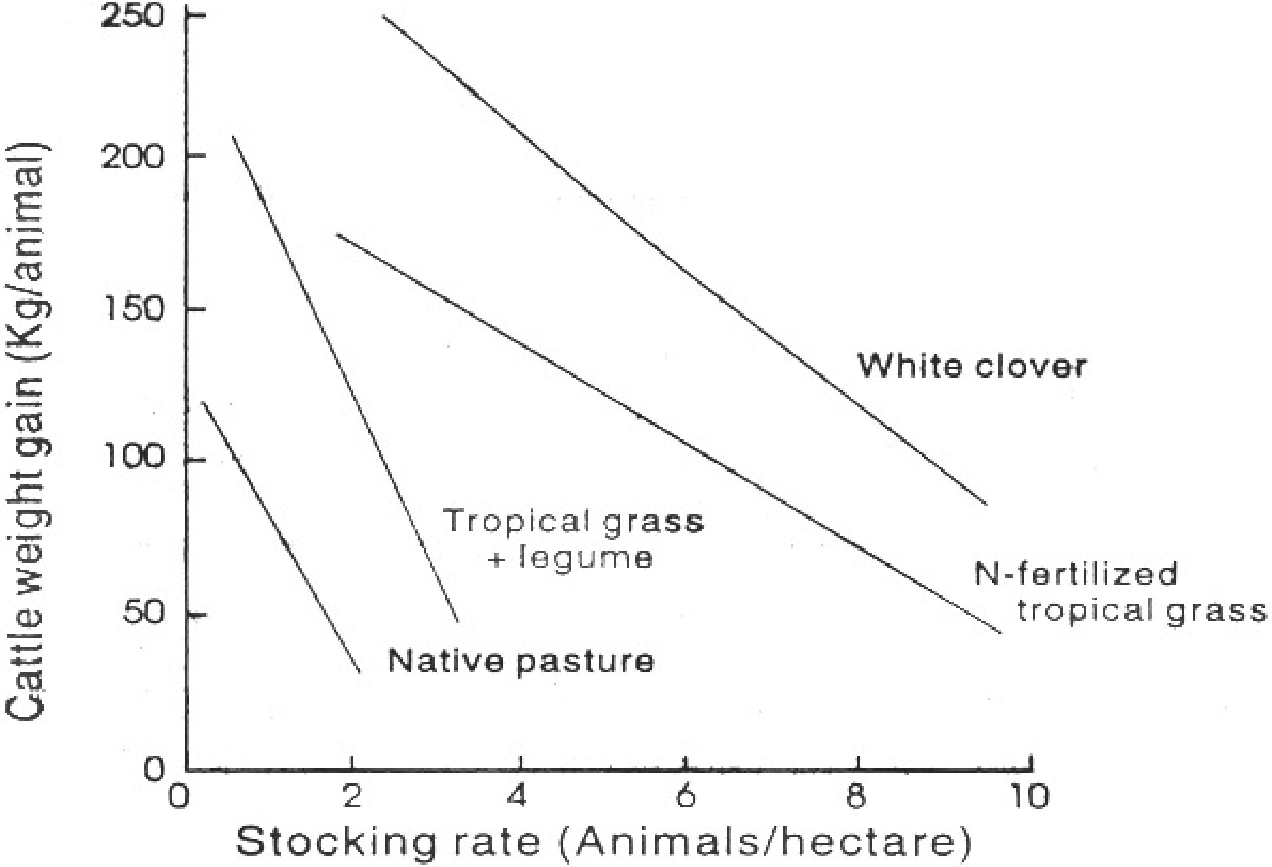
Introduction of legumes into pastures has generally improves animal production even without fertilizer inputs. Growth rates are often increased by 50–100% (see Clatworthy & Hollen, 1979; Stobbs, 1966, 1969). Fertilizer application to legume pastures has

increased animal production to even greater degrees and importantly, this has often led to improved cattle reproduction in the tropical areas (Holroyd *et al.* 1977) possibly through improved phosphorus nutrition. Productivity is improved through individual liveweight increases plus the increased stocking rate that such practices then allow. The influence of various treatments of pasture on individual animal productivity with stocking rate is shown in Figure 4.3 on the following page (Walker, 1987).

Legumes also improve animal productivity from grass lands by increasing total edible biomass. The production increases can also be related to the high mineral concentrations in legumes and to higher protein levels in the associated grasses. In addition their seeds contribute significant concentrated nutrients in the form of protein and carbohydrate and are highly digestible if crushed in chewing. Many of the responses to legumes are similar to the responses seen from feeding MUMB and are

undoubtedly attributable to supplementation of the rumen microbial ecosystem, ensuring an efficient fermentative digestion.

Figure 4.3: ***Cattle growth on pasture is a function of pasture type, fertilizer application and legume concentration. Productivity per unit area is maximized for the different pastures at different stocking rates: 89 kg/ha for native pasture, 223 kg/ha for tropical grass with legume, 682 kg/ha for tropical grass with fertilizer and on temperate pasture (clover) 1051 kg/ha (Source: Walker, 1987).***


Cattle weight gain (Kg/animal)
250
200
150
100
50
0
White clover
Tropical grass
+ legume
N-fertilized
tropical grass
Native pasture
0
2
4
6
8
10
Stocking rate (Animals/hectare)

The ability of MUMB to lift animal productivity and production of animal products per hectare is associated with an increased efficiency of utilization of the available forage through improved rumen conditions. Whilst legumes may have a similar rôle, there is also the additional benefit on the total forage availability. The proportion of the benefits from improved efficiency and improved biomass is not clear. Operative questions arising are:—

- **is it more economical to feed MUMB or equivalent to increase productivity than to sow legumes into pasture and manage them?**

- **is it more appropriate to find high yielding grasses such as *Eragrostis* spp. (love grasses) that grow rapidly in response to showers of rain and use MUMB supplementation to achieve higher levels of animal production from that biomass?**

The same questions must similarly be asked of the use of tree foliages. Whether some forage legumes contain secondary plant compounds that protect their protein is uncertain--many of the tanniniferous legumes are sustained in pasture and are unpalatable but are eaten to some extent in the dry season when the pasture protein is low.

The potential for using bypass protein from forages to increase productivity of ruminants is evident where concentrated bypass protein supplements such as cottonseed meal (see Figure 4.1 on page 46) have been fed to ruminants on basal poor quality forages. There has been no major research attempt to develop tree or legume forages high in bypass protein, perhaps because most effort has gone into the agronomic aspects of the forages/trees in association with pastures. Some efforts have been made to grow legume forages as protein banks which can then be used to supplement low quality forages for cattle.

Tree foliages have essentially the same rôle in the nutrition of ruminants as legume forage. Trees, however, have a number of attributes which are advantageous or disadvantageous to either the pasture or the animal. These include:—

- **their deep rooted nature, which allows them to continue to grow often well into a dry season, whereas forage legumes although often adapted to pasture, may dry off earlier as they are mostly more shallow rooted than trees. Deep rooted trees, following their establishment, often produce more biomass than pasture in the semi-arid or arid regions.**

- **their regeneration after harvesting or grazing. They must be managed and each tree species requires a different management system. Trees in the wet tropics do not necessarily compete for soil nutrient with pasture.**

- **their growth in hedge rows or alleys between crops as**

protein banks where they are easily harvested. They can be grown as plantations where they are the sole objective of the production system. Often, strategic cutting of trees, particularly *Leucaena* at the end of the dry season, produces considerable extra foliage into the dry season.

- **their importance for control of soil erosion-their extensive root systems bind soil when pasture has dried off and the earth may be exposed. Trees also reduce the direct effects of wind erosion.**

- **their provision of shade that is invaluable in the tropics when animals may be heat stressed.**

- **their leaves, which are often richer in secondary plant compounds than forages. These compounds can make them unpalatable to grazing herbivores or allow the protein to escape fermentative digestion when consumed by ruminants.**

> These secondary compounds may be advantageous in that they may be toxic for a single group of rumen organisms and may favourably manipulate the microbial mix within the rumen ecosystem. For example, some secondary plant compounds (some saponins) are toxic to rumen protozoa (Leng *et al.* 1992)

The plates of Figure 4.4 on the following page and Figure 4.6 on page 62 show some protein banks of *Gliricidia sepium*. Figure 4.4 has also the shrub (*Pachecoa venezuelensis*) growing for supplementary feeding of both large and small ruminants in Venezuela (Combellas, 1994). Figure 4.5 on page 61 and Figure 4.7 on page 65 show solitary fodder trees growing in Queensland, Australia.

Fodder trees may be used to feed ruminants where high protein feed resources are scarce or unavailable. They should be planted where they have advantages over more conventional forage

crops. In general, it is not economic to grow trees as a high biomass crop to provide a basal diet for ruminants. An exception to this is in parts of Central Queensland and particularly The Kimberley area of Australia where *Leucaena leucocephala* is being grown under irrigation for grazing by cattle. Growth rates even at 20% C.P. in the foliage are about 800 g/day (Rowe, J., personal communication[6]). However, *Leucaena* and grasses under irrigation can support high stocking rates (e.g., 6–8 cattle/ha).

There are circumstances, particularly on large ranches, where the establishment of legume trees as a total diet could be condoned, but, in general, the costs of establishment of plantations will preclude such strategies. Exceptions to this might be where timber or fuel are the major salable product or where the fruit or the pods are harvested as a concentrate source for ruminants and the tree require little maintenance throughout the year. An example of the latter is with *Prosopis*

juliflora plantations in semi-arid areas of the tropics where the trees in conjunction with Buffel grass pastures have transformed parts of the Sertao of Brazil from cactus and scrubby grazing country to easily managed tree plantations with undergrowth of grasses. In Australia, systems of biomass production for grazing cattle using *Leucaena leucocephala* have evolved, but these enterprises are in the dry areas where the high cost of establishment of *Leucaena* are offset against market opportunities arising when unfinished cattle from extensive areas can be fattened by grazing this resource (Quirk *et al.* 1990).

[6] Professor J. Rowe, Department of Animal Science, University of New England, Armidale, New South Wales 2351, Australia.

The overall conclusion is that the rôle of tree foliages is seen in the same light as forage legumes. Tree foliage allows efficient utilization of the basal feed resource and they have environmental and other advantages (see Chapter 1) but the

nutritional rôle of the forage tree is often unknown or at least not considered by farmers and scientists alike.

Figure 4.4: ***Tree fodders (protein banks) for cattle production in the tropics:*** **Gliricidia sepium** ***plus*** **Pachecoa venezuelensis** ***growing in Venezuela*****.**

4.11 Improvements in productivity of cattle from supplementation with tree foliage

Undoubtedly the inclusion of tree foliages in diets for cattle and sheep given low quality forages or grazing tropical pastures has improved both production per head and production per hectare. Stocking rates are generally increased where fodder trees are included in pastures.

Two operative questions arise:—

1. **at what rate of inclusion of tree foliages in a diet is the production response maximized**

2. **are the responses brought about through an improved rumen or an improved efficiency of utilization of the diet through the provision of bypass protein, or both?**

4.12 Responses of cattle to supplementation of forage based

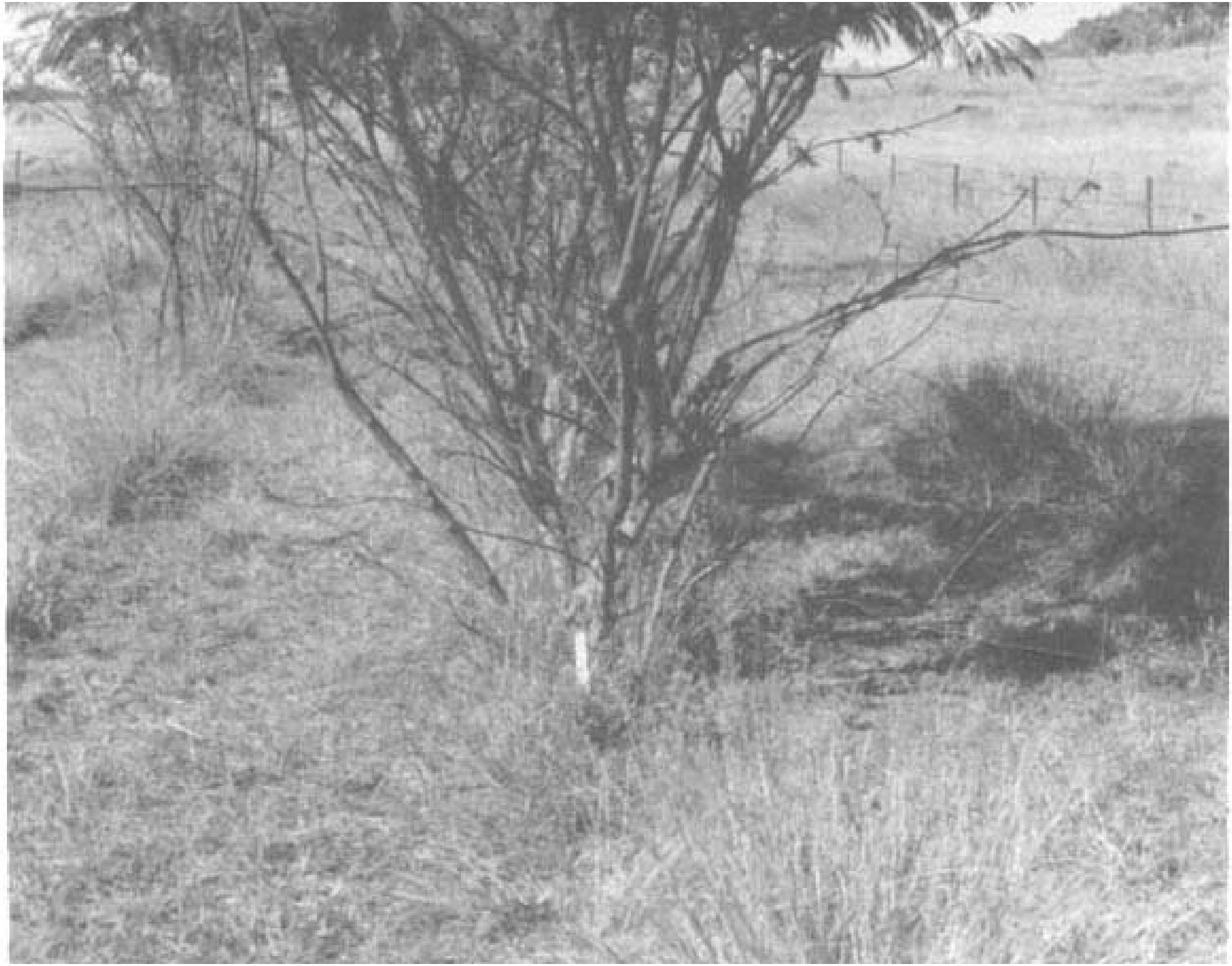
diets with tree foliage

Unfortunately no research studies to the knowledge of the writer have set out to compare responses to supplements of tree foliages with those from:—

- **MUMB**
- **an equivalent amount of bypass proteins or**
- **a combination of MUMB and a known bypass protein.**

In terms of bypass protein requirements, a cottonseed meal at 44% CP with 75% of the protein potentially escaping the rumen (i.e., 33 g bypass protein/100 g cottonseed meal DM) requires to be fed at between 1 and 2 kg per day to have optimal economic effect on growth rate of cattle fed a poor quality roughage (see Figure 3.4 on page 43).

Figure 4.5: ***Tree fodder for cattle production in the tropics*****:** **Leucaena pallidum** ***growing at Gayndah, Queensland***



In making such comparisons, it is important to recognize that urea is a concentrated source of ammonia for the rumen: 100 g urea provides about 45 g of ammonia N. Tree foliage or other forages with say, 24% crude protein (CP) in the dry matter can supply only 6 gN/100 g forage dry matter (DM). To provide the same NPN as 100 g urea requires 750 g DM of a tree foliage—approximately 3.65 kg of fresh plant material would be required to replace 100 g urea as a rumen ammonia source. In a steer of 250 kg liveweight consuming forage at a rate of 2.5% of its body weight, this represents 12% of its total dry matter intake. The amount of NPN required from such a source, however, would need to be adjusted for the crude protein content of the basal diet.

To obtain the same amount of bypass protein from a protected leaf meal at 20% CP in its dry matter, 1.65 kg DM must be fed or

8.25 kg wet leaf material. So if all the NPN and bypass protein has to be provided by the leaf meal, a 250 kg steer fed straw would need 2.4 kg DM or 12.0 kg of wet leaf material if there was a 50:50 contribution of dietary protein to NPN and bypass protein. Thus it is necessary to feed at a minimum 38% of the total feed intake as foliage to potentially balance a poor quality forage based diet.

Figure 4.6: ***Tree fodders (protein banks) for cattle production in the tropics:*** **Gliricidia sepium** ***growing at Maracay, Venezuela*****.**

There are obvious opportunities for combining tree foliage with

MUMB and tree foliage with bypass protein or both supplements. These are the areas for a major nutritional research thrust.

Table 4.2: *Effects of feed supplementation on liveweight gain of cattle (6 per group) grazing on green* Brachiaria decumbens *pastures in the wet season (with mineral supplements) with liquid molasses/urea 10% or* Gliricidia *foliage (Source: ICA 1988)*.

Treatment	**Rumen Ammonia (mgN/l)**	**Initial Wt (kg)**	**Final Wt (kg)**	**LWt gain (g/d)**
No supplement	50	194	244	580
+ *Gliricidia*	170	204	266	717
+ Molasses/Urea	250	203	269	751

4.13 Evidence for tree foliages as sources of rumen ammonia and minerals

In the ensuing discussion only a small number of examples are

given. A full review of the literature is not warranted because the majority of experiments have only set out to test whether a tree foliage will improve productivity of ruminants and not to examine the mechanism by which these benefits are delivered.

Supplementation of cattle on green *Brachiaria decumbens* pasture with either urea/molasses or foliage of the fodder tree *Gliricidia* resulted in similar increases in production (see Table 4.2); research from Cuba has shown that *Leucaena leucocephala* in pastures produced the same live weight gain as cattle on pasture supplemented with MUMB (Table 4.4 on the following page). Seijas *et al.* (1994), however, obtained some evidence for a better result on production of cattle grazing pasture with *Gliricidia* compared to pasture with MUMB, but there was a trend for both supplements together to produce the best response (Table 4.3 on the next page) These few experiments indicate that the value of a high protein tree forage is the same or only slightly higher than supplements aimed at improving the rumen

fermentative capacity.

Table 4.3: *Liveweight gain and intake by growing cattle grazing* Cynodon nlemfuensis *with no supplement, with* Gliricidia, *with MUMB or* Gliricidia *plus MUMB (Seijas* et al. *1994)*

		Supplement		
	Control	***Gliricidia***	**MUMB**	**MUMB + *Gliricidia***
LWt gain (kg/d)	0.20	0.36	0.28	0.40
Gliricidia intake (kg)	0	0.46	0	0.51

4.14 Foliage of fodder trees as mineral supplements

Undoubtedly, for animal production purposes, the mineral composition of tree foliages is superior to that of tropical grasses. Norton (1994a) has reviewed the mineral content of a range of tree forages as shown in Table 4.5 on page 66. There is little information on the range of trace elements but if the tree is healthy then an array of trace elements in the foliage can be

expected.

Table 4.4: *Effects of feeding MUMB to cattle at pasture in relation to the effects of having* Leucaena *within the pasture system. Pasture was star grass in the dry season (Diaz, 1994)*

	Leucaena + pasture	**Pasture + MUMB**
No of animals	12	8
Stocking rate (hd/ha)	3	2
Liveweight gain (g/d)	0.45	0.45

Tree foliage is likely to be a significant source of minerals when fed in high amounts but animals are likely to require supplementation where dry feeds deficient in minerals are the basal diet and tree foliage makes up 20–30% of the total dry matter intake. Goodchild & McMeniman (1994) attributed increases in ruminant production to leaf foliage included in the diet as being due mainly to its mineral content and therefore the

supply of minerals to the animal and the rumen microbiota.

Figure 4.7: ***Tree fodder for cattle production in the tropics:*** **Albizia chinensis** ***growing at Gayndah, Queensland***

4.15 Tree foliage as potential sources of bypass proteins

It appears from the literature that tree foliages in general provide a mixture of soluble N, minerals and vitamins. An exception to this has been reported recently. Palmer & Schlink (1992) found that fresh *Calliandra calothyrsus* was readily eaten by sheep. However, dried material was less edible and this fitted with a higher *in sacco* digestibility of the fresh material when compared to the same material dry, wilted or freeze dried.

When *Calliandra* forage was fed in increasing levels to groups of sheep given a basal diet of hay, both liveweight gain and wool growth were stimulated, indicating that considerable amounts of the protein was apparently bypassing the rumen (see Table 4.6 on page 67).

Table 4.5: *Concentration of some minerals in the foliage of some forage tree legumes (see Norton, 1994a for reference source*).

	Range of mineral components (g/kg DM)

	Range of mineral components (g/kg DM)						
Species	**N**	**S**	**P**	**Na**	**K**	**Ca**	**Mg**
Acacia	11–36	1.2–1.4	0.4–2.3	3.8	7.9	9.2	1.9
Albizia	24–46	1.8–2.8	1.4–2.1		14		
Cajanus	25–34		2.2–2.4		8		
Calliandra	34–37	2.0	1.5				
Chamaecytisus	28–36	1.3	1.2–1.7	0.5–0.8	5–9	4.5–5.1	1.7–2.6
Entrolobium	27–40	2.7	1.4–1.7			6.7	
Gliricidia	37–44	1.7–2.0	1.2–2.8	0.5–1.6	27–33	10.5–13.8	4.0–4.4
Leucaena	32–	2.2–	1.6–		13	5–23	6

Sesbania	45 16–42	2.6 2.7	2.9 2.4–4.7	0.7	18	1.3–2.8	

***Calliandra* leaf contains condensed tannins which are implicated somehow in reducing digestibility of *Calliandra* foliage when wilted. Palmer & Schlink (1992) demonstrated that 6 hours' wilting may reduce *Calliandra* foliage digestibility for ruminants by 80% and there appears to be an increase in condensed tannins by as much as 80% (Tangendjaja *et al.* 1992, cited in Palmer *et al.* 1995)) possibly arising from the polymerized tannins in the leaf.**

A possible explanation is that the binding of tannins to proteins under anaerobic conditions in the rumen are weaker than protein and tannins together under the aerobic conditions of drying. However, in drying it may be possible that other reactions, such as mild Browning reactions protect the protein from ruminal microbial degeneration and also from irreversible binding with

tannins. To add confusion to the area Norton (1994b) (see Table 5.3 on page 77) found that *Calliandra* leaf material that was dry increased the growth rate of goats as compared to similar animals fed the fresh materials. This points to differences between goats and sheep in the use of browse in the rumen.

There is a need for major research here to explain the differences, but in practice such foliages are of little benefit unless grazed by animals so that they are consumed fresh. These discussions do not exclude a range of other possibilities, such as binding of critical nutrients in wilting, thereby making them unavailable in the rumen (e.g., S, P or Mg) or the production of toxic compounds to specific groups of rumen microbes.

Supplements of tree foliage can increase growth rates of cattle above that of a supplement of urea. This has been shown in studies where tree foliage has been fed with ammoniated straw

which could be anticipated to oversupply rumen ammonia on these diets. However, it does not rule out the correction of other deficiencies by minerals in the tree foliage, such as sulphur.

Table 4.6: *Liveweight gain and wool growth in sheep fed* ad libitum *hay supplemented with various levels of fresh* Calliandra *leaf over 65 days (Source: Palmer* et al. *(1995)).*

Supplement (% DM intake)	LWt gain (g/d)	Wool growth (mg/100 cm^2/d)
0	-35	30
16	6	55
28	41	70
35	70	95

A study in Indonesia (Table 4.7 on the next page) has shown good increases with replacement of natural tropical grasses in the diet with dried *Leucaena* forage. These responses appear to

be in line with *Leucaena's* being a source of bypass protein. Both total dry matter intake and digestibility was increased when *Leucaena* forage became an increasing proportion of the total forage fed. Also, the production and efficiency of production was increased when *Leucaena* supplied 40–60% of the total dry matter intake. However, in other results from Indonesia, cattle on tropical grasses (green) supplemented with MUMB have improved productivity by over 100% (Chapter 3) and the cattle have higher rates of growth than those recorded by Wahyuni *et al.* (1982). This then leaves unresolved the rôle of the protein in *Leucaena* when fed in a grass based diet.

The two overall effects of using *Leucaena* as a supplement to ruminants seem to be that:—

1. **there is little substitution of the basal crop residue by the tree foliage at low intakes**

2. **total digestible feed intake is increased.**

Some of the increase in productivity of ruminants on crop residues to supplements of *Leucaena* have been attributed to a mineral response (Goodchild & McMeniman, 1994). Rumen ammonia levels are increased, and improved digestibility and P/E ratio in the nutrients from the rumen are probably responsible for the extra production without invoking a bypass protein effect (Table 4.8 on page 69). Goodchild & McMeniman, (1994) concluded that the responses of sheep to supplements of browse are to extra N and minerals in the rumen and the organic matter in the foliage which enhances the overall fibre digestibility of the diet. However, supplementation with any dry browse seems to have an additional effect similar to adding a bypass protein.

Table 4.7: *Effects of increasing levels of* Leucaena *forage in a diet of tropical grass fed to cattle (Wahyuni* et al. *1982).*

%	%	DM intake g/kg	DM dietary	LWt gain

% grass	% *Leucaena*	DM intake g/kg LWt/d	DM dietary digestibility (%)	LWt gain g/d
100	0	20	42	-20
60	40	26	44	290
40	60	29	46	540
20	80	29	44	590
0	100	22	51	310

The results of feeding *Leucaena* (not dried) to sheep (mature) fed sorghum roughage (± urea) are shown in Table 4.8 on the next page.

4.16 Nutritional ecology of ruminants

The nutritional and metabolic strategies that small ruminants have evolved in the tropics to utilize herbs, shrubs or tree foliage high in secondary plant compounds appear to be associated with high fecundity, ability to breed twice in one year and high

capacity for milk yield.

Although scientists have, so far, not attempted to relate these strategies with nutrient availability, it appears logical that strategies for utilization of foliage high in secondary plant compounds also enable the animal to receive higher levels of dietary protein post-ruminally for digestion and absorption. Nutritional ecology of ruminants is a new area for study, involving considerable rationalization of the places of different species according to their metabolic strategies.

Table 4.8: *Effects of* Leucaena *foliage supplementation in a diet of sorghum straw with or without urea given to sheep (Goodchild & McMeniman, 1994).*

Level of *Leucaena* inclusion in diet	**Intake (g/kg LWt/d)**					
	Urea inclusion	**Sorghum straw OMI**	**Total OM**	**Digestibility OMI**	**OM Dig %**	**Rumen NH_4 (mg**

(%)						N/I)
0	-	12.9	13.1	3.9	30	32
	+	11.9	11.8	4.0	35	75
12	-	15.1	17.6	6.3	35	40
	+	16.9	19.8	8.0	39	84
22	-	14.0	18.9	8.2	44	71
		+16.0	21.2	10.0	47	83
34	-	16.5	25.3	12.4	49	75
	+	14.8	23.3	11.5	49	103

In small ruminants of tropical breeds there is an obvious positive relationship between the amount of fodder tree foliage in a diet and the level of protection, whereas the reverse is true where foliages are replaced by graminaceous species in the diets (Sánchez, M., personal communication[7]). It becomes imperative to recognize that research on small tropical ruminants may be quite different to that of temperate climate species (commonly

known as British breeds) and sheep that have developed on open grasslands in the arid subtropics or temperate areas (e.g., the Merino) and *vice versa*.

The choice of diets for ruminant production should involve looking at the dietary conditions under which the species evolved—in the case of small ruminants in tropical areas these are largely forests.

[7] Mr M.D. Sánchez, Animal Production Officer, Animal Production and Health Division, FAO Via della Terme di Caracalla, Rome 00100, Italy.

4.17 Overall

There is little point in going further in attempting to illustrate the supplemental rôle(s) of tree foliages here, since the research necessary has yet to be done. Norton (1994*b*) has reviewed the

effects of various foliages of trees on the digestibility of forage diets, the voluntary intake of tree foliages and their influence on production of cattle/sheep and goats.

4.18 Conclusions on the use of trees as fodder for ruminants

The above discussion defines the potential strategies to provide two types of supplements from tree foliage that are required for optimal efficiency of utilization of low quality forage by ruminants in areas with scarce resources of nitrogen or protein. The strategies must be to find forages, seeds or pods that are high in protein and minerals. These materials can then be used as catalytic supplements to provide for either the rumen soluble protein and minerals, or (after treatment to protect the protein), as a bypass protein source. They can also be used in combination with a MUMB when the leaf protein is protected and/or as a source of locally available soluble protein with a bypass protein meal when the leaf protein is unprotected.

Legume tree forages have a major rôle, as their extensive root system fixes N_2 and the trees grow throughout the dry season.

The enormous biological diversity within tropical trees provides a bank of materials that can be used for animal feeding, yet only some 20–30 species have been used and out of those *Leucaena*, *Gliricidia*, *Erythrina* and *Acacia* species have predominated. In fact the use of *Leucaena* may have been accepted more widely than others despite establishment difficulties and problems with insect pests, because of the wide publicity it received when scientists found the cure to its toxic components (see Jones & Lowry, 1990). The toxicity of *Leucaena* was only a problem where ruminants were isolated from the micro-organisms that degraded the toxic breakdown products of the alkaloid, mimosine. These organisms are present in the rumen of animals where *Leucaena* has been a component of their diets. This has resulted in many agricultural advisers knowing of the value of *Leucaena* because of the publications surrounding this very important breakthrough

in understanding. However, this has led to neglect of other adapted trees found locally. Unfortunately infestation of *Leucaena* with thrips has at times killed *Leucaena* in large areas where it has been introduced. However, *Leucaena* grows apparently unaffected by these thrips in Cuba where the thrips originated, indicating some form of biological control. Considerable work is proceeding in this area.

The wealth of potential fodder trees is enormous and the agronomic work has begun on a variety of species. Future developments must use an integrated approach which not only involves biomass and crude protein production of trees in relation to biomass from other plants (e.g., grasses) but also studies the optimum use of the tree foliages. To be able to take advantage of this enormous genetic resource, animal nutrition research should be focussed on:—

- **studying the mechanisms of binding of proteins and tannins**

- **identification of secondary plant compounds and how they are influenced by environment and grazing or harvesting**
- **developing ways of neutralizing anti-nutritional effects of tannins**
- **conversely, finding ways to utilize the potentially beneficial effects of condensed tannins which bind protein in the rumen and protect it from rumen degradation**
- **increasing the availability of the N in the rumen and/or amino acids for absorption in the intestine**
- **protecting the dietary proteins by processing for feeding to ruminants.**

The nutrition research must, of course, be undertaken in the light of agronomic research that has solved the problems of how and where to grow the tree.

Chapter 5
Bypass proteins from tree foliages

5.1 Introduction

There are several opportunities for using tree foliage high in protein to provide bypass protein to supplement a low protein forage diet given to ruminants. These include:—

- **using the natural capacity of certain endogenous secondary plant compounds to bind with proteins and protect them from microbial attack. These complexes must then dissociate** under acidic or alkaline conditions in the lower tract to provide digestible protein to the host.

- drying tree foliages under prescribed conditions. This is independent of whether tannins are present: other mechanisms may be active, e.g., a Browning reaction in the presence of reducing sugars in the leaf material

- harvesting plant foliages and treating them with chemicals and/or heat in order to produce a bypass protein through insolubilization of the leaf protein. Pelletting after treatment would be extremely advantageous.

5.2 Natural protection of leaf proteins

The literature has few references to the rôles of foliage protein as sources of fermentable N or escape or bypass protein.

Table 5.1: *Liveweight gains (LWG) of cattle grazing grass pasture*

either with or without access to* Leucaena *forage (Jones, 1994)

	LWG (kg/head/d)		
Pasture	**Nil**	**+ *Leucaena***	**Access to *Leucaena* foliage**
Native pasture	0.59	0.70	25% *Leucaena* on area basis
Native pasture	0.22	0.39	4 hours/day
Native pasture	0.18	0.33	25% *Leucaena* on area basis
Native pasture	-0.15	0.16	25% *Leucaena* on area basis
Native pasture	0.23	0.51	6% *Leucaena* on area basis
Native			25% *Leucaena* on area

pasture	0.25	0.35	basis
Native pasture	0.25	0.56	100% *Leucaena* on area basis
Cenchrus ciliaris	0.60	0.60	10 or 20 hours/week
Brachiaria	0.49	0.64	4 hours/day
Hyparrhenia rufa	0.27	0.35	10% *Leucaena* on area basis
Cynodon	0.29	0.41	4 hours/day
Dichanthium	0.21	0.50	20% *Leucaena* on area basis
Pennisetum	0.07	0.34	3 hours/day
Panicum	0.52	0.67	30% *Leucaena* on area basis
Panicum	0.18	0.37	30% *Leucaena* on area basis

Leucaena foliage has been reported to contain approximately 6.6% condensed tannin (Wheeler _et al_. (1995) and from Barry's work (Barry & Manley, 1984; Barry, 1983) with a forage legume, _Lotus_, these tannins could be expected to protect the proteins. This was confirmed in studies with sheep with re-entrant cannulae in the intestines where dietary protein from fresh _Leucaena_ forage substantially escaped degradation in the rumen (Bamaulim _et al_. 1984). However, in these studies it was not determined whether this protein was available to the animal or whether it had been bound such that it avoided digestion in the small intestinal and the lower gut. Growth studies with cattle fed a variety of pastures with or without access to _Leucaena_ (Jones, 1994) are surprisingly similar to results of supplements with MUMB to cattle on tropical pastures (see Table 5.1 on the preceding page and Chapter 3). These growth rates on pasture of cattle supplemented with _Leucaena_ foliage are below those expected from a good quality bypass protein meal such as cottonseed meal fed to cattle on ammonia treated straw (see

Figure 3.4 on page 43).

In all probability, *Leucaena* leaf protein (after drying) has some properties of both escape protein and fermentable N. Studies are required to understand these rôles in order to develop strategies that will promote substantial increases in cattle growth. A similar conclusion is also apparent for dried forage legumes such as lucerne (see Figure 5.1, page 75).

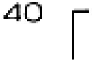
Jones (1994) also summarized the effects of supplementation with *Leucaena* foliage to dairy cows grazing pasture. Between 2 and 33% increase in milk yield apparently occurred in response to the cows' having access to *Leucaena*. Feeding MUMB to dairy cows at pasture in the tropics is summarized in Chapter 3 and similar milk yields (1 to 39%) were noticed.

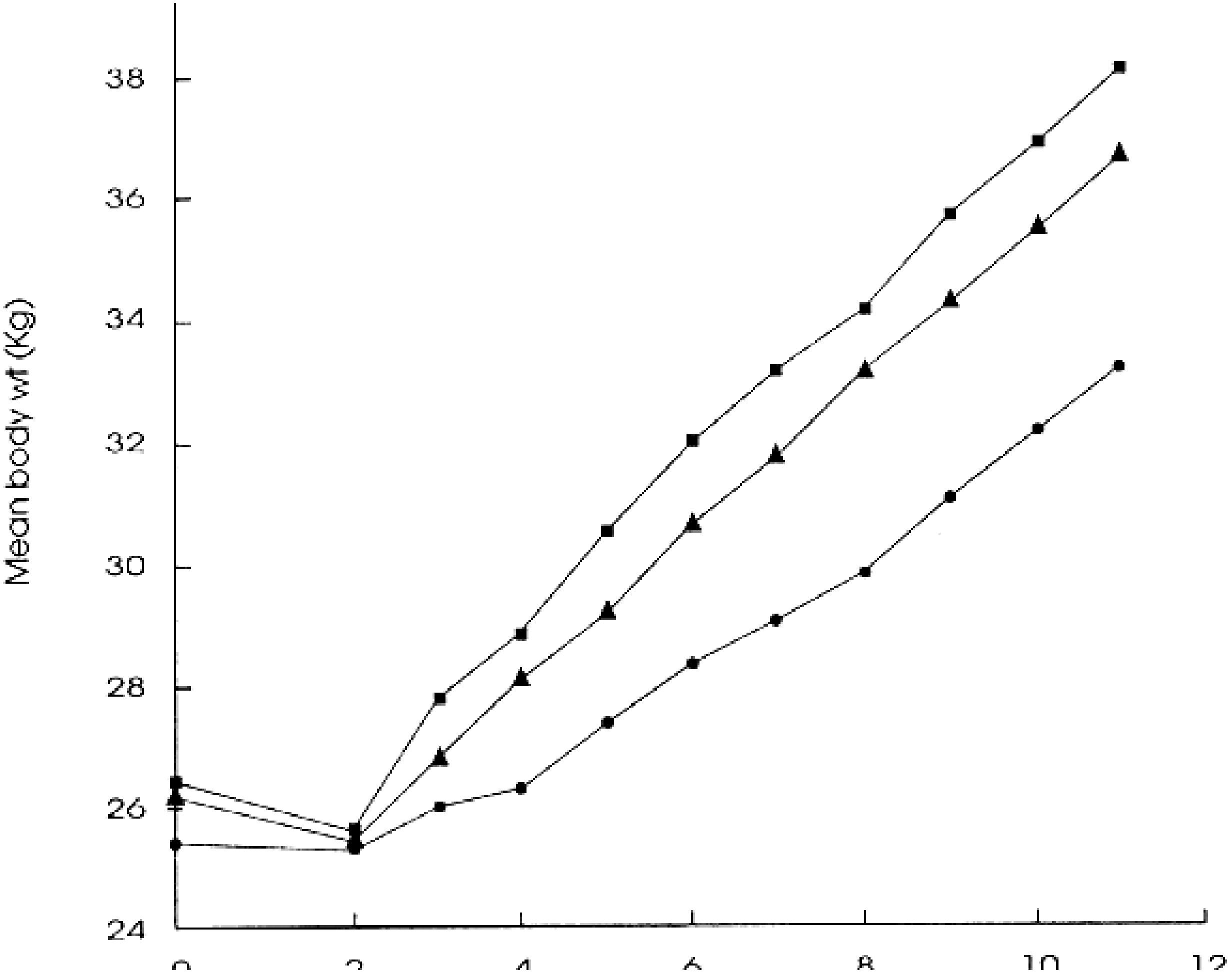
The similarity in these results indicate that fresh *Leucaena* in tropical pastures possibly acts as an ammonia and mineral

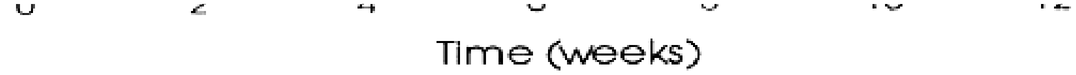
source to the rumen microbiota and that if the tannins do protect a proportion of the protein, this protein may not be available for digestion in the intestines. There seems to be little evidence that fresh tree leaf proteins provide escape or bypass protein with the exception on *Calliandra* spp. for supplementation of sheep, where a bypass protein response was apparent (see Table 4.5, page 66).

Similarly, *Erythrina poeppigiana* foliage was reported to have 42% crude protein and only 49% of this was soluble. However, it was dried before analysis.

Figure 5.1: *Effects of supplementation of lambs fed oaten chaff without supplements (•), or with 25% lucerne that had been sprayed with 1% xylose and dried before feeding (■), or untreated (▲) (Ball & Leng, 1994, unpublished)*.




Mean body wt (Kg)
38
36
34
32
30
28
26
24
0
2
4
6
8
10
12



In some *Erythrina* species a greater percentage of the nitrogen is linked to acid detergent fibre suggesting extensive bypass protein in these species (Kass, 1994) but the question remains: is the protein that is protected in the rumen totally or partially available or unavailable to the animal? Where tree foliages after drying have been fed to goats on a basal diet of Napier grass, growth rate was stimulated over the use of the fresh foliage, but additional benefits have occured when protected soyabean meal was also supplemented with the dry foliage (Table 5.2).

Table 5.2: *Effects of supplement of dry foliage and/or protected protein (formaldehyde treated soyabean meal [SBM]) source on growth rate of goats fed a basal Napier grass diet (Norton 1994b, after van Eys* et al. *1986)*.

Napier grass intake (g/kg	**Supplement (g/kg**	**LWt gain**

LWt/d)	LWt/d)	(g/d)
33.4	0	-1
29.4	4.1 *Gliricidia*	20
29.1	4.2 *Leucaena*	22
26.1	3.9 *Leucaena*	
	+ 2.7g (SBM)	45
30.2	4.1 *Sesbania*	20
33.6	3.8 *Sesbania*	
	+2.7g (SBM)	52

5.3 Effects of drying fodder tree foliage

Supplementation with dried foliages from 5 tree species all produced greater liveweight gains in goats on a basal diet of poor quality forages than the same quantity of foliage fed fresh (see Table 5.3 on the next page). This is the type of response that might be related to a change in the solubility of the protein

increasing the bypass protein content of the leaf meal. The reduction of anti-nutritive factors, however, might also have occurred. The former explanation seems more plausible, since the level of tannin would be quite different in the different species that were fed. A further possibility is that, in drying, the leaf meal undergoes a mild Browning reaction with the reducing sugars that would be invariably present in leaf materials and the protection has little to do with secondary plant components. However, that tannins may be implicated was shown by Ahn (1990); extractable tannin content of *Gliricidia* leaves was zero after drying and when dried leaf meal was fed to sheep, straw intake increased and feed and N digestibility together with N balance were also increased. Recently, Dalzell (1996) has reported that drying reduces extractable condensed tannins to 25% that obtained from freeze dried samples.

Table 5.3: *Comparison of the effect of tree foliage supplements fed fresh or after drying to goats (Norton, 1994, after Robertson, 1988)*.

Supplement	Forage intake (g/kg LWt/d)				
	Tree foliage				
	Fresh	Dry	Basal forage	Dry matter digestion (%)	Growth rate (g/d)
Albizia chinensis	7.5		18.5	51	0
		7.5	16.5	44	54
Calliandra calothyrsus	7.5		18.5	47	24
		7.5	18.5	44	48
Gliricidia sepium	7.5		18.5	56	12
		7.5	15.5	47	42
Leucaena leucocephala	7.5		15.5	49	-18
		7.5	18.5	47	0
Sesbania sesban	7.5		14.5	53	0
		7.5	17.5	52	54

If the concept that tannin-protein complexes were too strongly cross-linked in dried materials to provide a digestible bypass protein at the intestines is correct, then a mild Browning reaction in drying catalyzed by sugars in the leaf could make more protein available to the animal. A similar concept was recently promulgated by Broderick (1995) for forage legumes when dried. Drying might also remove anti-nutritive factors (Ahn, 1990; Norton, 1994), including the condensed tannins. That goats on low quality diets supplemented with fresh foliage respond to a source of bypass protein is clearly indicated in Table 5.2, page 76.

It may be costly to dehydrate or pellet leaf meals, and sun drying is a more acceptable and feasible alternative. However, application of heat might increasingly protect tree leaf meals as apparently occurs when lucerne meal is dehydrated at temperature increasing from 65°C to 160°C (Table 5.4, page 78).

5.4 Effects of adding chemicals

A number of chemicals when added to protein meals insolubilize the protein, thus protecting it from microbial degradation in the rumen. The best known of these is formaldehyde but the potential of formaldehyde to affect the health of humans or to produce carcinogens precludes its use in many situations, particularly in small rudimentary feed mills. In recent times the only alternative to formaldehyde is xylose which is found in acid waste from paper manufacture or is produced inexpensively from wood. Xylose is also readily produced by mild acid hydrolysis (e.g., steam pressure) from hemicellulose sources such as sugar cane bagasse or cottonseed hulls.

Table 5.4: *Effect of drying temperature on solubility and digestibility of N and N balance in lambs fed dried, chopped lucerne hay (Goering & Waldo, 1974).*

Drying temp (°C)	Solubility of N (%)	N digest (%)	N balance (%)

65	43	49	6.0
130	40	68	7.4
160	40	66	6.9
180	34	52	3.4

Molasses is a source of fructose and glucose that will react with the lysine of proteins to give a protected protein when the two are heated together. Molasses is potentially usable provided temperatures are not excessive, since glucose and fructose may easily produce a strong Browning reaction. However, xylose has much more potential as it forms a weak bond with lysine that is unlikely to produce over-protected proteins.

Lewis *et al*. (1988) demonstrated that mild heat with a small amount of xylose is very effective in protecting soyabean meal protein for cattle (Table 5.5) The effects of protecting lucerne forage protein with xylose on liveweight gain and wool growth of sheep is shown in Table 5.6, page 80.

Table 5.5: *Effects on liveweight gain of cattle of supplementing a basal forage/concentrate based diet with soyabean meal or soyabean meal treated with the xylose in sulphite liquor (SL) at 200° F for 2 hours (Lewis et al. 1988).*

	LWt gain (g/d)
No supplement	591
+ 7% soyabean	673
+ 9% soyabean + 10% SL	823
+ 8% soyabean + 5% SL	841

In more recent work chopped lucerne hay treated with 1% xylose (prepared by hydrolysis of sugar cane bagasse) showed improved nutritional value when the lucerne was mixed at a rate of 25% of an oaten chaff diet (+ 1% urea and minerals) fed to lambs (Figure 5.1 on page 75).

5.5 Tree foliages as supplements or as basal diets

The developing countries in the tropics have, in general, little land for ruminant production *per se*, as crop production for human consumption is given the first priority. It is inconceivable that large tracts of land could be set aside for tree pastures where the trees exclude other forms of biomass. There are however, niches where this might be tolerated but it would be on either the farms of the rich (often absentee landlords), in the countries with low population densities, or where the fodder tree has multiple rôles which make it economic to produce. Australian farmers and farmers from a few other countries have some wide experience with using *Leucaena* as a component of pasture and also as the main harvestable biomass. Where such pasture have been established there seems to be real potential to grow cattle at around 200 kg/hd/year (about 700 g/head/day) with free access to *Leucaena* (Quirk *et al*. 1990). This is typical of, say, growth rates of cattle on good quality rye grass pastures under New Zealand farming conditions and/or irrigated pastures in Australia.

Table 5.6: *Liveweight gain and wool growth of sheep fed oaten chaff*

Table 5.6: *Liveweight gain and wool growth of sheep fed oaten chaff supplemented with either 220 g/d lucerne, lucerne treated with 0.5% xylose (Arreaza et al. 1994)*.

Supplement	**Oaten chaff Intake (gDM/d)**	**LWG (g/d)**	**FCR (g/d)**	**Wool growth(g/d)**
Nil	690	44	22	9
220 g lucerne	693	50	20	9
220 g treated lucerne	795	69	16	11

In Central America, trials with foliage from the fertilized mulberry as a feed for goats and a supplement for dairy cows have been very impressive, with growth and milk yields at high levels and cows achieving up to 18 litres of milk/day on forage supplemented with fresh mulberry foliage. However, under these circumstances mulberry must be cut and carried and fertilizer requirements are high (200 kg N/ha/yr) but this can be supplied as manure or green mulches (Benevides, 1994). To place this in

perspective, the production rate on high intakes of tree foliages such as *Leucaena* and mulberry are only as good as those of cattle on straws treated with ammonia to increase digestibility and supplemented with 1–1.5 kg/d of cottonseed meal.

5.6 High density forage production from *Leucaena*

A recent major development with *Leucaena* shows great promise both for biomass production and for industrial processing of *Leucaena* leaf meal (Funes *et al*. 1996).

The development uses high density seeding rates (20 kg/ha) of *Leucaena* planted in a well prepared seed bed in rows at 0.50 metres apart. The seed is first heat treated and inoculated with a specific rhizobium.

The *Leucaena* is cut first at 10–15 cm above soil level when it has grown to a height of 1.2 metres. Thereafter 4–6 cuts can be taken

per year when the plant reaches a height of 1 metre. The approximate yield under Cuban farming conditions without irrigation or fertilization is 12 tonnes DM/ha with 22–25% crude protein. In some experimental conditions 20 tonnes DM/ha have been achieved.

The forage may be fed fresh, or after sun-drying. There is great potential to fractionate the plants after drying into leaf meal (30% protein) and stems. The leaf meal then could be treated with molasses, hydrolyzed bagasse (xylose) or formaldehyde to protect its protein from microbial degradation in the rumen.

The combination of *Leucaena* in pasture and protected *Leucaena* leaf meal can be expected to have spectacular effects on animal productivity. The responses are relatively easily monitored using the established technology discussed later, i.e., measuring the milk yield and by purine excretion.

Figures 5.2 and 5.3 on the next page show high-density-forage: *Leucaena* growing in the tropical areas—Queensland and Cuba.

Figure 5.2: *Tree fodders (protein banks) for cattle production in the tropics*.

A. Leucaena leucocephala, *growing at Biloela, Queensland. Tracks have been left during planting to facilitate grazing*.

5.7 Assaying the nutritional value of protein in leaf foliages or meals

The operative questions that have arisen consistently throughout these discussions have been:—

1. **how can the level of bypass protein in leaf meal be assessed?**

2. **when are the rumen micro-organisms efficient in growth and digestion of forage?**

Figure 5.3: ***Tree fodders (protein banks) for cattle production in the tropics*****.**

B. Leucaena, ***high density plantings in Cuba. Used as cut and carry forage for goats. The*** **Leucaena** ***is allowed to grow to 1 metre before harvesting. About 6 cuts are taken annually*****.**

Both these questions are now able to be resolved, at least in the laboratory. There have been many attempts to predict the mechanisms of utilization of leaf proteins, including chemical analysis of acid detergent-N, protein solubility in buffers and ammonia production when the leaf meal is incubated with rumen fluid. The best that can be concluded from these studies is that they give an indication of the form of the protein. However, a major problem is apparent for any analytical approach: drying causes unknown changes in many leaf meals from different sources.

In the last few years it has been apparent that wool production (in sheep with a good capacity to grow wool) and milk yield (in high yielding dairy cows or goats) can be used as a bio-assay of amino acid absorption in ruminants. Essentially, these animals, on a diet of high digestibility forage and with a rumen provided with all microbial nutrients, will respond in wool/milk production to inputs of extra protein. Response curves to a standard

protected protein can be used as the control and the response to an input of leaf meal will be indicative of the level of bypass protein.

Purine excretion in urine has long been viewed as a potential microbial marker. It is now known that the amount of microbial biomass digested in the intestines is highly correlated with total purine excretion. Thus, purine excretion in urine, combined with the protein assay using wool growth or milk yield will give an estimate of the extent of bypass of the protein and any improved production of microbial cell biomass.

The assay system would appear to be simple when working with animals in pens but quite difficult to apply to grazing animals. The intake of forage is critical under the latter conditions and there are no methods for satisfactorily measuring forage intake from mixed pastures or silvipastoral systems.

The wool growth assay appears to be quite a logical one where wool growing sheep are available. The basis of the assay is that wool growth is highly dependent on the protein digested in the intestines and therefore the amino acid supply to the animal (Leng *et al*. 1983). However, its weakness is that, more correctly, wool growth is highly dependent on the S-amino acids in the mixture of amino acids absorbed; but this should not be a major constraint as S-amino acid contents of leaf meals do not vary greatly. An assay with cows using milk yield would be quite costly to establish, but the use of goats, particularly those that breed all year round should be quite possible.

An approach to such an assay might be as follows:—

Experimental animals

These should be sheep or goats adjusted to a basal low protein diet (chopped forage with 55–60% digestibility) supplemented

with minerals/urea. Minerals/urea may be best given as a multinutrient block to which the animals have been previously trained to consume small amounts at regular intervals.

The animals are then divided into groups (minimum 4 but optimum 6–10) on an equal mean live weight basis, animals that consume less than 90% of the average intake of forage are excluded.

Treatments

The following feeding trials are then undertaken:—

Treatment	Diet
2.	Diet-C + 100 g leaf meal
3.	Diet-C + 150 g leaf meal
4.	Diet-C + 200 g leaf meal
5. Control	

	Diet-C + 200 g of the same chopped forage

The animal intake is restricted to a level that is 200 g below the average intake of all animals.

Parameters

Wool growth can be measured using a small area on both sides of the animal that is clipped after three weeks on the diet and then again three weeks thereafter. Similarly a dye band can be placed on the wool at the surface of the skin at these times. At the end of the six week feeding period and over one week, total urine collection will be made daily and purine analysis determined on the accumulated sample to provide a mean daily excretion rate.

Any animal refusing feed for more than one day should be discarded from the statistical analysis.

Comments

The same experiment could be carried out with lactating goats or cows, but using initial two week period on the basal (control diet) as a covariance to adjust milk yield over the three weeks following transfer to the treatment groups.

Simultaneous studies with freshly harvested or dried foliages would quickly resolve some of the questions associated with responses to dried *versus* fresh foliage. a major problem here is that there can be substantial differences between the goat and sheep because of the former's major ability to detoxify secondary plant compounds.

5.8 Conclusions

Although low levels of condensed tannins in tree leaf protein consumed by ruminants appear to increase dietary protein

entering the intestines, there must be considerable doubt about its quantitative significance in terms of extra protein available to the animal. Most studies with *Leucaena* as a supplement to ruminants on poor quality forages appear to support growth rates in cattle that are similar to those recently reported for the use of MUMB with cattle on tropical grasslands. This suggests a major rôle of the leaf meal supplement in stimulating rumen fermentative digestion and the efficiency of forage utilization. If this is tested and found to be true then the effectiveness of *Leucaena* or other tree fodders to improve cattle production from forages resides in its ability to provide the critically deficient nutrients required by the rumen microbiota. It is probably necessary to harvest and process tree foliage to meet the second rôle, i.e., the need for extra dietary amino acids by the animal once the rumen conditions have been optimized. However, where tree plantations under the prevailing climate, produce more biomass than pasture this will be a key feature for the acceptance of forage trees as a sole biomass feed. This will

hardly be economic in most developing countries in the tropics even where the tree has multiple rôles.

Heat or drying appear to produce bypass proteins from the soluble proteins of tree foliages but the mechanisms by which this occurs is still not clear and may not necessarily involve reactions with tannins.

There appears to be considerable potential to develop bypass protein concentrates from leaf meals using simple low temperature drying in the presence of reducing sugars.

5.9 Postscript

The use of trees as components of diets is a widespread practice in many tropical countries. In Sri Lanka, for instance, some 200 tree foliages are fed to both large and small ruminants in an *ad hoc* way when available.

Tree foliages have assumed only slight importance in animal nutrition in developing countries, except where only browse is available. The largely undirected use of tree foliage is perhaps the main reason for the obvious lack of development of trees as feed for ruminants. In some cropping areas, other, more easily obtainable resources preclude their use, whereas the difficulties of managing plantations, harvesting and storage make them difficult to accept by pastoralists. Without education of the small farmer, tree foliages are not likely to be used extensively unless the foliages are produced in the appropriate form and provided as packages to farmers for their animals.

A case in question is the use of *Prosopis* pods in Brazil. Use of these in animal production has been only stimulated by the development of strategies to organize collection, marketing and processing of the pods. Trees will assume a much greater significance in the future because of the associated environmental advantages of planting trees. There should be a

greater use of tree foliages as supplements to ruminants, particularly as the demand for animal products increases in the developing countries. Research and extension is needed to ensure their rational use, particularly as supplements to crop residues, which will be the major resource in the future for ruminants in developing countries.

Chapter 6
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