REQUIREMENTS FOR PROTEIN MEALS FOR RUMINANT MEAT PRODUCTION IN DEVELOPING COUNTRIES

By

R A Leng*
Emeritus Professor, University of New England
Armidale, NSW
Australia

***Mailing Address**
26 Leichhardt Drive
Yandina Creek
Qld 4561
Australia

REQUIREMENTS FOR PROTEIN MEALS FOR RUMINANT MEAT PRODUCTION IN DEVELOPING COUNTRIES

By

R A Leng
Emeritus Professor, University of New England
Armidale, NSW
Australia

Abstract.

World meat and milk supplies must be increased considerably in the next 20-50 years if the predicted demand is to be satisfied. Development of poultry and pig industries are targeted as being the most likely to develop at a rate commensurate with the demand for meat. Developments of alcohol industries to provide oxygenate for inclusion in gasoline may take a large proportion of what was previously feed grain that is a requirement for industrial pig and poultry production. The demand for grain for alcohol may impinge on the availability of feed grain and may result in a short fall for these developments to occur.

This suggests that emphasis should be directed to ruminant production including cattle, sheep and goats that are capable of producing on feeds high in complex carbohydrates not usable in quantity by the monogastric meat producers.

A review of the literature, shows that with appropriate supplementation of the abundant crop residues and other fibrous materials that are fed to ruminants these can be used highly efficiently attaining reasonable production levels. Crop residues and wasteland or mature tropical grasses are mostly deficient in nutrients that are critical for the digestion of fibrous carbohydrates and efficient synthesis into products. Supplying these nutrients leads to significant improvement in productivity and when these supplementation strategies are applied together with management to attain high digestibility of the forage, high levels of production can be achieved relative to animals fed on for instance high quality temperate pastures.

Supplementation involves providing minerals and urea to satisfy requirements for efficient digestion by microbes in the rumen and augmenting the protein supply to the animal through feeding an escape protein meal. Protein meals appear to have differing roles: when fed at low increments the response in growth of cattle is apparently 4 fold greater than to similar increments of protein supplements above a critical level.

In dairy animals on forage based diets the response to supplements of protein meals depends on the genetic potential of a cow for milk yield. Cows on mature forage based diets and with high genetic merit will mobilise body reserves to produce milk and the benefits of increasing protein intake is often more apparent in decreasing live weight loss than a large stimulus in daily milk production. The prevention of live weight loss has large benefits in terms of reduced inter-calving interval and persistency of lactation.

As daily live weight gain increases with increasing levels of supplementation, the feed requirements to produce a fattened animal can be reduced to 20% of the feed required by a similar animal without supplements to fatten to the same weight.

The potential for ruminant production to be increased from poor quality forages is of the order of 5-10 fold without any increase in the demand for forage. To attain such increase in production there are associated needs. These include the need to supplement to increase fertility of the potential breeding herd and eliminate waste [death of animals], and to provide incentives for farmers to take up recommended strategies. The latter requires the establishment of infrastructure for slaughter, distribution and marketing of meat at equitable prices

Introduction

It is predicted that in the foreseeable future there will be a greatly increased and continuing demand for protein foods for human consumption in most developing countries particularly in Asia [Delgado et al 1999].

Purchasing power often limits the amount of meat and milk consumed by people and as disposable income increases, people tend to consume more of these commodities. At the same time there is an enormous moral need to provide protein in deficient diets of resource-poor people who do not have the capacity to purchase meat or milk on a regular basis.

Protein under-nutrition or malnutrition in early life of humans may lead to small stature and developmental retardation [see Waterlow, 1998] and in recent years it has been recognised that a balanced diet supports an efficient immune system and promotes resistance to parasites and disease even into adult life.

Rice, the staple food [calories] of much of Asia has the lowest average protein content of all cereal grains [6% CP]. In the form it is mostly consumed as polished grain, it is also the least nutritious of the traditional staples. Most countries are, however, self sufficient in staple foods. The desirable developments for future food production, from a welfare viewpoint, would seem therefore to emphasise meat production to meet the demand for protein that accompanies increased family incomes and education. This, in turn results in increased awareness, mainly by women, of the benefits to the family and to young children in particular, of balanced diets.

The options for increasing meat production are many, depending on the country, the availability of feed resources, the presence of infrastructure for slaughter, distribution and marketing of products, the endemic diseases of livestock , climate and socio economic factors such as the religious taboos against for instance consumption of pig meat..

In overall terms the major issues that determine meat supply and availability are:

- which species is best supported by the available resources
  - Pig
  - Poultry
  - Ruminants
- Which production system is appropriate to the country
  - Industrial scale,
  - Backyard systems
  - Or combinations of the two that suit the particular country.

The increased demand for meat in developing countries is a direct result of the increasing middle class that insists on a balanced diets and good eating value of the meat. This has been used to suggest that greater emphasis must be directed to production of poultry in Muslim countries and pig and poultry in countries where pig meat is acceptable. This does not eliminate any other developments but places emphasis on replication, in the developing countries, of the industrial methods currently in use in most developed countries.

Feed grain cost and availability in the future

Industrial livestock production in Western countries has been supported and encouraged by the availability of inexpensive grain and the opportunity provided by the size of production units to minimise the number of workers who have a relatively high income. As a generalisation, grain has been relatively inexpensive as a feed resource in industrialised countries for many reasons including subsidisation of its production by governments.

Access of producers to affordable feed grain is a pivotal requirement for development of industrial scale pig, poultry and beef production in the countries with emerging economies. The development of range or scavenging systems for poultry production is also assisted by inexpensive grain that is often fed as a supplement. Diet components often have to be imported, for example approximately 80% of concentrates have to be imported into countries such as Bangladesh to raise poultry under intensive and modified backyard production systems. The scavenging systems, however, are not necessarily dependent on grain availability and there are a number of opportunities for providing alternative sources of feed.

In a number of developing countries, the village chicken producers are often or mostly women that have access to small loans for this purpose, and the family benefits in two ways.

- The increased income that results from raising poultry
- The ability of the women poultry producers, with their improved income, to siphon off a proportion of their production for the family, increasing the protein intake of, in particular young children in a family, at a cost equal to that of production.

Where labour costs are low, the majority of the costs of production of industrial pig and poultry reside in the cost of feed. Relative to average income, chicken and pig meats produced in " modern systems" are mostly unaffordable for a large proportion of the urban and rural poor. Nevertheless, the increasing pressure for meat production to meet the demand of the urban middle class will see these and industrial scale production systems increase in developing countries so long as feed costs are reined-in.

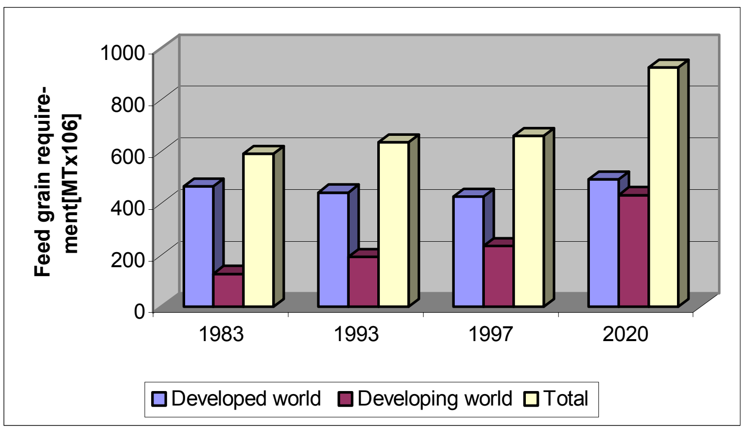
Many arguments can be made against the use of grain for livestock production based on concerns for the environment, soil fertility, soil erosion and salinity and socio economic questions. In marketing grain the high costs of land degradation in some areas, has not been factored into prices. Grain production is inextricably linked to fossil fuel inputs through the use of water, fertilisers, pesticides and fungicides and the need for traction engines and future prices will be heavily dependent on the cost of fuel [see Pimentel

2001]. Many of these factors in relation to future grain prices have been discussed by Delgado et al [1999] and are not developed further here.

Delgado et. al. [2002], predict that the increased demand for meat will be mostly met from industrial pig and poultry production with a huge increase in the requirements for grain [see Figure 1]. The major question here are:

- will such quantities of grain be available for this purpose?
- is it necessary to depend on industrial pig or poultry since the potential to increase ruminant production from biomass is so large?

Figure 1 The trends in requirements for feed grain to meet the anticipated demand for meat by 2020 [Delgado et al 2002].



If grain prices rise substantially, then smallholder livestock raising on locally available resources with recycling of wastes has the potential to become the most environmentally sustainable of all major farming systems world wide. There are obviously an enormous number of factors involved in such an evolution [revolution] that would need to be addressed and the concept is not taken further here, except to suggest that in the future, pressures that have not applied up to the present time may have substantial effects on the availability and price of feed grain.

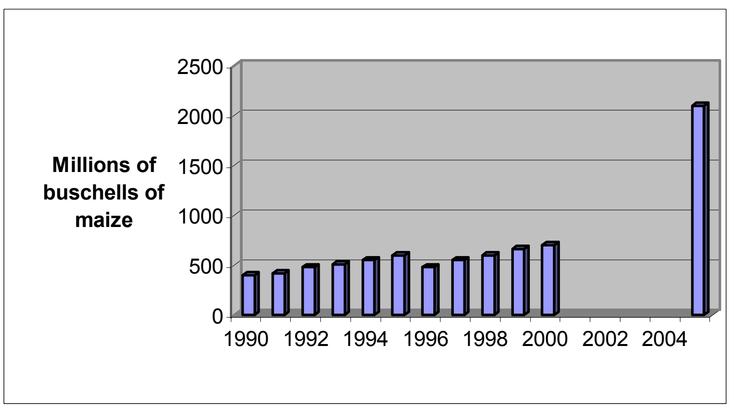
Alcohol production from grain and grain availability

World grain availability has been affected in the past, mostly by the demand for food for humans and feed for livestock. Grain for livestock, will have to compete with increasing demand for grain to produce industrial alcohol. The latter arises from the demand for industrial alcohol as an oxygenate to add to gasoline for use in automobiles.

The oxygenate in gasoline is required to lower the levels of many compounds in motor vehicle exhaust gases that pollute the atmosphere of high population density cities, such as Los Angeles. In 1999 legislature was introduced in the USA to enforce the addition of oxygenates into gasoline to more completely remove ozone, carbon monoxide, particulate matter and oxides of nitrogen and potential carcinogens such as benzene and 1,3 butadiene found in car exhaust emissions.

A compound derived in the fractionation of oil was first used [methyl tertiary-butyl ether, MTBE] for this purpose. Because of its affinity with water, MTBE polluted the ground water sufficiently to create alarm, gave water a pungent odour and made it undrinkable The extent of contamination of ground water led to its replacement by alcohol, which is higher in oxygen and produces less pollutants[alcohol and aldehydes] when co-combusted with gasoline. Alcohol for these purposes is predicted to increase industrial production to a minimum of 5 billion gallons annually within 3 years and utilise over 2000 million bushels of maize or 21% of current production in the USA, potentially removing world surplus grain [Pearse Lyons & Bannerman, 2001].

Figure 2. Past and future use of grain for industrial alcohol production in the USA to meet the requirements for the inclusion rate of alcohol into automobile fuel [Pearse Lyons T & Bannerman [2001] see also Renewable Fuels Association 2001].



California, the potentially largest market for industrial alcohol in the USA, for purposes of reducing emissions from vehicles, needs to produce between 600 and 700 million gallons of alcohol annually and is considering the development of industries for production of alcohol from biomass, but this seems to be some time into the future. [California Energy Commission, 1999].

A huge demand for grain, or the transfer of land into production of other potential feedstock for alcohol production such as sugar cane, may result in a world scarcity of grain. It will be remarkable if the increased market demand does not increase the price of grain on international grain markets. If this is the case then any grain dependent animal production must necessarily become relatively more expensive. Thus such developments are certainly unlikely to benefit the poor, other then providing cash through the jobs that may be generated. Even these will be minimal if industrialised farming is promoted at the expense of small farmer operations. It is likely that a reliance on industrial sized development will actually reduce employment because of the economies of scale required and the demise of the small producer is predictable where these strategies are adopted.

Potential spin-off benefits from development of an alcohol industry based on grain.

The production of alcohol from grain yields a by-product that is low in carbohydrate but high in protein and fibre; gluten meal [where isolated starch is the feed stock] or spent distillers grains [where ground cereal grains including maize are the feed stock].
This is highly suitable as a supplement for ruminant animals, particularly those dependent on poor quality feeds such as crop residues [see below]. The consensus is that these by-products meals are high in escape protein content that can be used directly as an amino acid source by ruminants.

The yield of protein meal to maize grain fermented is roughly 300kg protein meal /ton of grain with about 90 gallons of alcohol output.

The future role of ruminants in meat production in developing countries

Undoubtedly industrial poultry/pig production delivers the high quality meat with good eating value that the middle class demands. There is, however, a clear moral issue for any agency to direct development so that the resource poor may share in the outcomes, whether it is from increased income and nutrition or both.

It is also unwise to "put all the eggs in one basket" when there is a massive under-utilised resource of ruminant animals, in most developing countries, that are producing at a fraction of their potential. The low level of production of large ruminants results from a number of factors, such as;

- the fact that their major feed resources are poor quality crop by products with no supplementation
- they are mainly kept as a hedge against disasters when cash flow becomes a problem and they can be sold
- they are mainly kept for work or religious purposes

In all cases efficient production is not necessarily a priority concern as it has little impact on the animals value

Meat from ruminant animals can be produced inexpensively from low cost [low quality?] forages resources by efficiently harnessing the fermentative digestion of ruminants. Cattle, buffaloes, sheep and goats can be produced in smallholder farms from waste forages [often regarded as a free resource] that are dispersed widely and therefore do not easily meet the requirements of intensive systems. The production systems are not dependent on large volumes of resources of carbohydrate or protein that are directly usable by either the human population or in pig and poultry production.

Over the past 20 years, ruminant nutrition has developed to the extent where efficient production of meat and milk [also wool and hair] is possible from forage resources such as crop and agro-industrial by products and biomass from fallow and waste lands. Ruminant production from these products hold a major hope for meeting the demand for large quantities of medium to high quality protein for human consumption at relatively low cost. This is not a new concept and the efficiency and level of ruminant production that is achievable on such diets has been debated for a number of years [see Preston & Leng 1986]. Development of such production systems provide major opportunities for upgrading many smallholder farming and agroforestry systems in large areas of Asia and increasing income of small and even landless farmers many fold.

Using crop residues for ruminant productivity.

Crop residues, agro-industrial by products, and weeds/grasses from wasteland and fallow cropping land, foliage of trees and shrubs and forage/tree crop foliage produced as an intercrop, are the basal feed resources of ruminants in developing countries. Crop residues such as straw are by far the greatest available biomass.

Straw is considered by most scientists to have little nutritional value because of its low metabolisable energy [ME] content that is predicted to support little more than maintenance of ruminant animals. Uninformed farmers regard it as a poor feed because cattle generally loose weight when fed it without supplementation

In 1990, this author challenged the description of crop residues as being of low quality and preferred to relate to them as imbalanced forages. The point is that with small additions of supplementary nutrients to these forages, large responses in animal production can be achieved. The levels of production achieved with appropriate low level supplementation are not predicted from the ME content of the mixed diet.

The concepts that were developed are more applicable in developing countries, for instance, to increasing milk yield in cows fed high forage diets in India [NDDB records quoted in Leng [1997]. Industrialised countries normally have little or no dependency on poor quality forages for ruminant industries except where there are large landmasses mainly suitable to production of grazing ruminants

Poppi and McClennan [1995] concluded, however, that large increases in productivity, through small amounts of supplements of protein meals were not attainable in cattle on low quality forages. However, as will be discussed below, a small error in analysis of results from cattle growth trials, has disguised important aspects of the response of ruminants to supplements on low quality forage diets. A re-examination of the available data from feeding trials with cattle on a variety of poor quality forages in various countries has major implications for the potential of using these abundant resources highly efficiently for ruminant production. The examples will be drawn from growth trials with cattle but the general conclusions are applicable to other species of ruminants

Chemical composition of crop residues and the need for supplements when fed to ruminants

Mature, dried foliage and stems of grasses, are normally low in protein [<3% CP] and have been variably leached of soluble components, including minerals, proteins, sugar and starchy carbohydrates. Mature dry forage, is therefore mostly complex or structural carbohydrates intermingled with the plants cement, lignin. The content of soluble materials is critical since it can change the overall digestibility of forage by up to 10 units and also reduce the need for supplemental minerals and urea for its efficient fermentative digestion. Thus managing the harvest of forage is critical to ensure its potential feed quality.

Supplementation requirements for optimum use of low digestibility forages by ruminants.

For efficient digestion of forage, irrespective of its content of solubles, the microbes in the rumen require a medium balanced with minerals and a source of ammonia. Once these are provided, the extent of digestion is then limited by the structural nature of the plant fibre and the extent to which this fibre is embedded in or surrounded by lignin.

Ruminant nutritionists have established the requirements for essential nutrients for microbial growth in the rumen and efficient methods are available for ensuring that no deficiencies of minerals or ammonia occur in animals feeding on mature forage diets [for example provision of multi-nutrient blocks [see IAEA 1991]. Supplementation of the animal to ensure an efficient digestion of forage in the rumen usually improves digestibility and intake and increases productivity. This is the first step in combating the low productivity when cattle are fed these forages [Leng 1984].

Improving protein nutrition is the second strategy for increasing production in ruminants with a high protein requirements. These include young animals following weaning, cows in the last trimester of pregnancy and also lactating cows. Here the question arises for immature animals on poor quality forage, to what extent can growth be increased by providing nutrients for the rumen and extra protein for absorption?

The provision of more protein for absorption in a ruminant on a straw-based diets can be achieved by a number of methods that include:

- Ensuring no microbial growth factors are deficient in the diet and microbial growth is optimised.
- Providing a protein meal that is relatively slowly degraded by microbial action and a proportion of the dietary protein enters the intestines for digestion [termed escape protein].
- Manipulation of the microbial ecosystem to minimise inefficiencies brought about by protozoa that prey on bacteria and reduce protein flow to the intestines [defaunation /oil drenching].

A discussion of various factors involved in the amounts of microbial protein entering the intestines or the extent to which a protein meal escapes to the lower gut is not warranted here [see Preston & Leng 1986 for a discussion of these factors in ruminants fed mature forages].

In practice, escape protein for supplementing ruminants is sourced from oilseed meals, in particular cottonseed meal [solvent extracted], hulled cotton cake [pressure extracted], copra meal, gluten meal or soybean meal. Numerous experiments have been done in various areas of the world to evaluate strategies of supplementation to increase growth of cattle and efficiency of resource use of mature forages from dry season pasture and crop by-products.

Practical aspects of the use of supplementation strategies to alleviate low production in cattle given low digestibility forage.

What to supplement and how much to give and the likely response in growth of young cattle are major economic considerations for livestock production from mature forages, which are the staple of most ruminants in developing countries. For instance, in Bangladesh the forage fed to large ruminants comes approximately 50:50 from rice straw and forage gathered from wastelands or fallow. Despite a potentially large short fall in forage requirements as animal feed in Asia, in most countries a considerable amount of the annual straw crop is either wasted or used for purposes other then feeding to livestock

Benefits of providing protein supplements to cattle consuming poor quality forage.

Mature forages from grasses such as cereal and pasture have an ME content rarely more than 5 Mj ME /kg dry matter. The requirements tables predict that such feed will probably maintain young animals provided nitrogen and mineral deficiencies are corrected.

The concept that straw is too low in ME to support growth often leads to recommendations to replace it with more energy-dense and/or increase the ME content by treatment with alkali such as ammonia. Treatment with urea or ammonia to increase straw digestibility is a highly recommended procedure as it increases the use of the basal low cost resource In addition it also corrects the N deficiency in the rumen. The increased digestibility of straw consumed often increases growth of cattle by up to 300g/day. This is, however, often below the cost of treatment [see Chenost & Kayuli [1997]. This leads again to recommendations to feed a cereal grain to enhance the intake of energy even where there is considerable biomass available. From published results, however, it appears that productivity of ruminants is limited by the balance of nutrients derived in digestion in the rumen. By providing more protein to be digested in the intestines, through supplementation with an escape protein source, the overall efficiency of use of absorbed nutrients is improved. The more efficient use of the ration results from the closer balance of nutrients absorbed to nutrients required and a greater intake of basal feed and so increased total nutrient availability.

This concept has been challenged by Poppi & McLennan [1995] who concluded that the benefits of supplementation of low protein feedstuffs for ruminants is largely an effect of the increased nutrients supplied [ME]. The same authors also concluded that the ME of straw underestimates production levels because the amount of forage that can be consumed by ruminants is much higher than has previously been reported. This is too simple because the measurement of ME per kg of forage [M/D] is used to predict production without reference to feed intake. In most situations ME is predicted from an *in vitro* digestibility measurement with obvious associated errors.

Response to escape protein of young ruminants given low digestibility forage

Credit for the discovery of the need for escape protein in the diets of producing ruminants is most difficult to assign as it slowly evolved from basic observations when ruminant nutrition was in it's infancy [see for review Broderick et al 1991].

The need for escape protein by young cattle to achieve high growth rates was most clearly demonstrated in feeding trials with high energy, low protein, non-conventional feeds such as liquid molasses. Preston and his coworkers [see Preston & Willis 1974] demonstrated that replacement of urea with fishmeal in a diet for young cattle based on molasses had marked stimulatory effects on growth and most importantly on efficiency of feed utilization.

Even on high quality grain based diets fed to lambs, where part of the protein in grain is likely to escape digestion in the rumen, Orskov et al [1973] showed that providing fish meal in a way that caused it to bypass the rumen stimulated growth of lambs and increased the efficiency of feed utilization even when cereal grain intake was optimised[Table 1].

Numerous publications have shown that cattle growth rate on straw based diets could be stimulated by increasing supplementation with a protein meal [see reviews by Preston & Leng 1986, Chenost& Kayouli [1997] and Leng 1990].

Table 1 Live-weight gain and efficiency of feed utilization to body weight gain by lambs fed pelleted, crushed grain [containing urea and minerals] supplemented with additional urea in the pellet, or fish meal post ruminally [after Orskov et al 1973].

Diet	Feed intake [g pellet/d]	Live weight gain[g/day]	FCR [g feed/g gain]
Pelleted crushed barley	1078	230	4.3
Pellet+1%urea	1062	224	4.3
Pellet+17gfish meal*/day	1190	300	3.5
Pellet +34g fish meal/day	1196	326	3.2
Pellet plus 57g fish meal/day	1241	332	3.0

*Fish meal was given mixed with water by sucking on a bottle to preserve the esophageal grove reflex so that it bypassed the rumen.

Research on the mode of action of supplements on growth of young cattle are difficult to rationalize, as in some studies the escape protein supplement was found to stimulate forage intake whereas in other studies, forage intake was unchanged or reduced when protein supplements were included. The studies where straw intake by cattle was stimulated when supplemented with escape protein were usually undertaken in hot climates. This suggested that forage intake of ruminants may be lower on mature forages such as straw at times when humidity and environmental temperature induce a intolerable thermal load on the animal and that supplementation with escape protein was able to ameliorate the effects of a thermal load [Leng 1990].

Energy versus protein supplements to improve growth ratesof cattle given poor quality forage

Fermentative digestion in the rumen, when uncompromised by deficiencies of nutrients, converts feed components to volatile organic fatty acids [VFA] and microbial cells[that are 40-60% protein] in a fairly constant ratio. Therefore on diets where rumen microbial growth is optimized, it is difficult to alter the protein to energy ratio in the nutrients absorbed, by feeding supplements that are digested in the rumen. In other words there is no such thing as an energy supplement for ruminants.

Only if supplements are degraded by microbial action in the rumen, at a rate that allows some to leave in the digesta to the lower tract, do they increase the balance of protein to VFA nutrients absorbed. Protein [amino acids] relative to energy in the nutrients absorbed may be altered by supplementing with a meal high in protein that has:

1. a structure relatively resistant to microbial attack, or
2. been protected from microbial action by chemical or physical treatments, or
3. in mastication comes in contact with materials that protect it from microbial action [this often occurs when secondary plant compounds are in high concentrations].

Degradable protein, as compared to an equal weight of fermentable carbohydrate, produces a lower yield of microbial cells with a higher amount of VFA produced. The reason for this is that there are less high-energy phosphate bonds available to microbes when protein is converted to VFA and ammonia than when carbohydrate is fermented to VFA. Thus cell yields on protein substrate are about half that on carbohydrate and supplementation with fermentable protein can actually reduce protein nutrition and production of ruminants.

Examples of protein meals that are relatively resistant to rumen microbial degradation and provide protected or escape protein when fed to ruminants include those that:

- have been chemically processed with formaldehyde or xylose [treated vegetable protein meals e.g. xylose-treated soybean meal]
- have been through a process of heat treatment in solvent or pressure extraction process for oil. [e.g. cottonseed meal, cotton cake and copra meal]

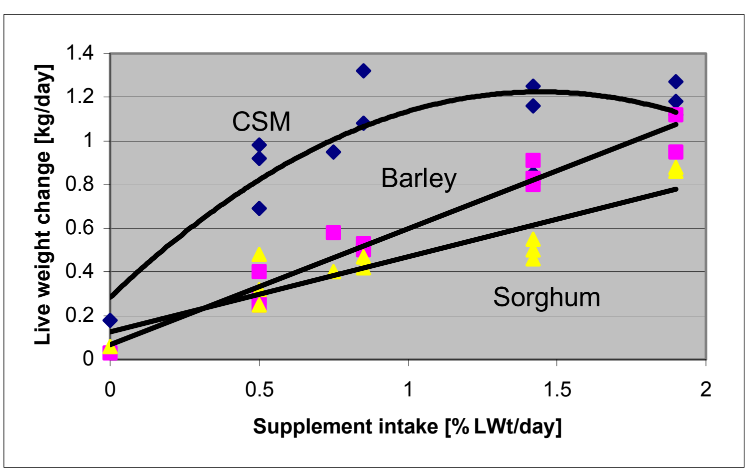
- are associated with relatively low levels of secondary plant compounds that bind proteins [e.g. some leaf protein in tree foliages, some vegetable protein meals]
- have a high degree of sulphur amino acids with considerable cross linkage in the amino acid chains [e.g. gluten meal and dried distillers waste from grains]

South African, fishmeal is possibly the best form of bypass protein and is usually flame dried and treated with formaldehyde to prevent decomposition [see Silva et al [1989] for response in cattle]. Cottonseed meal appears to be one of the better protected vegetable protein meals possibly combining protection from heat treatment and protection by secondary plant compounds.

The benefits of feeding supplements to young cattle on poor quality forage diets where the supplements are regarded as an energy source [barley or sorghum] or a source of extra protein at the intestines [cottonseed meal, CSM] is shown in Figure 3.

At the higher level of supplementation of cattle shown in Figure 3 the 'supplement' becomes the major dietary source of ME. In practice, a supplement, that is usually considerably more expensive then the basal feed, should rarely fed at above 0.5% of the animal's live weight. This requires emphasis since in cattle fed mature forage, the efficiency of conversion of the supplement to live weight gain with increasing amounts of cottonseed meal is some 4 fold greater as the increments are increased progressively to 0.5%of live weight as compared to the efficiency of conversion above this levels [see Figure 4]. For economic evaluation, it is important to define the early part of the response curve to supplements of protein meals in young cattle on poor quality forages [see Dolberg & Finlayson 1995]

Figure 3. The effects of supplementation of a low quality pasture hay with cottonseed meal, barley or sorghum grain. Young cattle were given a poor quality pasture hay and minerals and then given graded amounts of the various supplements according to their live weight [McLennan et al 1995]



Supplementation strategies for young cattle on low quality forage.

Large numbers of experiments have demonstrated the benefits of supplementing protein meals to ruminants fed poor quality forage. Most of these studies recognize the need to provide for an efficient rumen in these animals by providing minerals and urea in the diet. Only some experiments have included sufficient levels of protein meals to provide response relationships for both predictive purposes and economic evaluation. Exception to this are in research reported by Elliott & O'Donovan [1971],Creek et al [1983] Saadulah [1984], Wanapat et al [1986], Perdoc [1987], Zhang Weixan et al [1994], Finlayson et al [1994], see also Dolberg and Finlayson [1995] and Mclennan et al [1995]. However,in some of the feeding trials there was no control group fed only the basal diet and unfortunately therefore the data from these trials cannot be incorporated in the analysis below.

Where a large number of results from research conducted in different sites can be drawn together some very useful generalizations can be developed and used as " rules of thumb" and as guides to the likely economics of developing cattle fattening on straw. This is an alternative approach to using ME content of the available feeds to design diets for ruminants.

The results of a number of studies of the live weight response of cattle on low quality forage or at pasture during the dry season, to supplements of protein meals are shown in Figure 4. Inorder to take out some of the variability of weight of animals used in different experiments and the differences of quality of protein meals the intake of supplement is expressed in, g crude protein intake per kg body weight per day [gCP/kg LWt/d] and the response is calculated as the increase in live weight gain [kg/d] over that of un-supplemented animals. Much of the data were originally compiled by Poppi& McLennan [1995] and this has been combined with more data from trials where straw has been the major feed resource, as indicated in the reference listed above.

An oversight by these authors is apparent in the original analysis, as they fitted a linear regression to the data despite having already corrected the data for the live weight change of the control, unsupplemented group. This disguised the initial and higher response to feeding protein supplements to young cattle on these feeds. Figure 4a shows the relationships as fitted by Poppi and McLennan [1995]and that forced through the origin. The latter is a very poor fit to the data [R^2=0.22] as compared with the former [R^2=0.74]

A polynomial appears to more accurately describe the response but may underestimate the growth response at high levels of protein meal inclusion in the diet. On the other hand a logarithmic relationship appears to best describe the data with the highest amount of the variability taken out by the regression [see Figures 4b,4d].

In practice it could be more correct to use two independent relationships, as it is plausible that a protein meal supplement to cattle may have differing roles at low compared to higher levels of inclusion in a forage diet. In addition, in practice it is likely that the rate of supplementation will be restricted for economic reasons. It is suggested that the most logical approach for this to be used as a guide for farmers is to represent the data as two linear response relationships as shown in Figure 4c. The different response relationships may be attributed to:

- an initial effect of an increased protein supply and a more balanced array of nutrients for efficient live weight gain [the response in a 200kg steer is 1.2 g gain / 1g cottonseed meal consumed], and

- at higher intakes a lower response per unit of supplement, to the increasing availability of nutrients in a balanced array through the fermentation of a proportion of the protein meal and digestion of escape protein [0.32 g gain per 1g cottonseed meal consumed] with more nutrients, with a higher ratio of protein to energy [VFA], becoming available then would have been realized from the quantity of forage it replaces.

Figure 4 The effects of supplementing young cattle given low quality forage with protein meals.
A number of equations have been fitted to the data which have been collated mostly by Poppi and McClennan [1995] and includes results from McLennan [1995] , Smith & Warren [1986ab], Hennessey et al [1983], Perdoc& Leng 1990. Data of Zhang Weixian et al [1994] and Saadulah[1984] are also included.

Figure 4a The data are fitted to a linear regression with an intercept as done by Poppi & McLennan [1995] or through the origin.

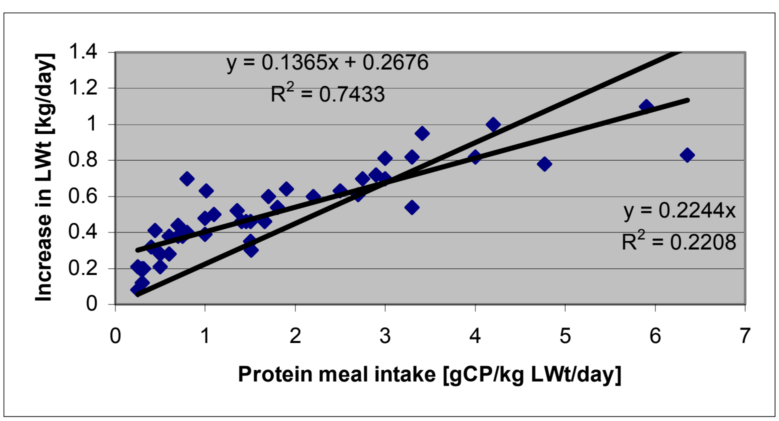


Figure 4b. A polynomial fit through the origin. This appears to be unacceptable as it there is a down turn in the benefits of supplementation at high rates that appears to be biologically incorrect

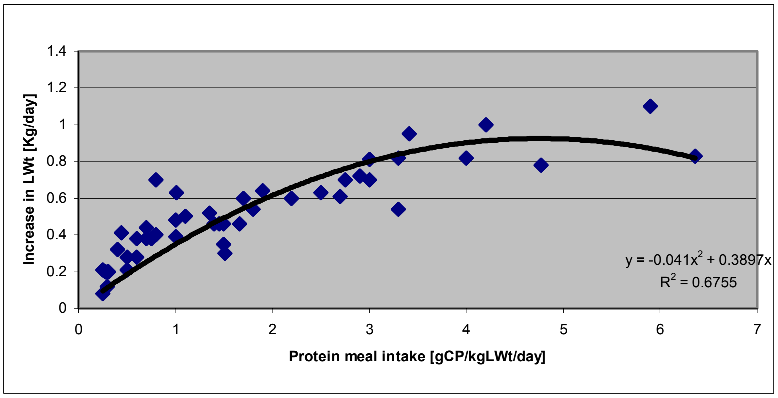


Figure 4c. The potential to describe the results as two distinct sets of data described by independent linear regressions. These regressions are intended to provide prediction equations relatively easily understood.

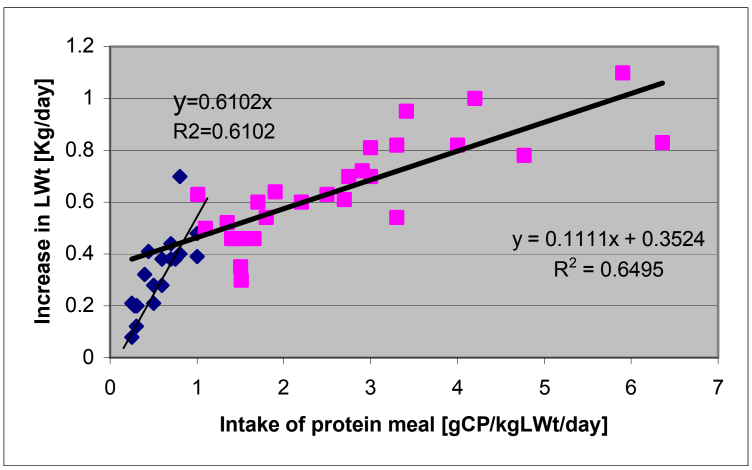
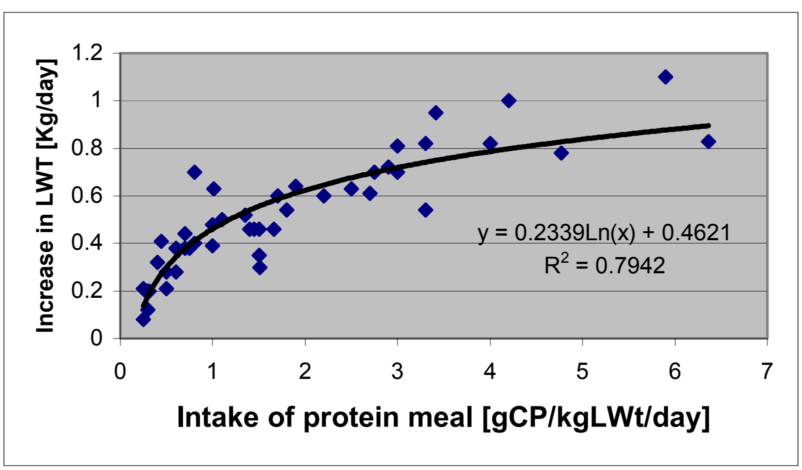


Figure 3d The most appropriate description is probably a logarithmic linear relationship shown below.



The important issue is that at low supplementation rates [i.e. the early part of the response curve] the returns in live weight gain are approximately four fold greater than at higher levels of supplementation [i e in the later part of the response curve].

Summary of growth trials with young cattle on mature forage supplemented with protein meals.

The effect of supplementing young cattle [200kg live weight] grazing dry pasture or straw with an escape protein meal such as cottonseed meal can be summarized as:

- up to 0.7kg/day of cottonseed meal the response in live weight gain would be approximately 0.84 kg /day or a conversion efficiency of supplement to live weight gain of 1.2 g LWt /g cottonseed meal consumed
- above this level of supplementation the improvement is approximately 0.35g LWt gain /g cottonseed meal supplemented.

Thus small inputs of a bypass protein have a "catalytic" effect on the utilization of a low quality forage but the level of production that can be achieved depends on the 'quality' of the forage. From the literature some generalizations can be drawn:

1. straw diets fortified with urea and minerals and fed to cattle support live weight changes from –200 to +100g/head/day
2. treated straws with balanced nutrients for the rumen organisms support growth rates that may vary from about maintenance to about 300g/head /day.

The greater the digestibility of a forage the higher the intake and the higher the growth rate without supplementation [see for discussion Chenost& Kayouli [1997]].

In most situations the growth rates of cattle achieved by feeding treated straw as compared with untreated straw are not economically attractive, unless production levels are boosted with supplements which reduce the time to market and the total feed requirements.

Digestibility of a basal straw diet by cattle supplemented with urea/minerals depends on a wide number of factors including:

- cereal variety
- soil fertility
- climatic conditions particularly those between harvest of grain and storage of straw
- storage conditions
- method of drying prior to storage particularly for wet season rice straw
- other forages mixed with the straw including higher digestibility grasses.

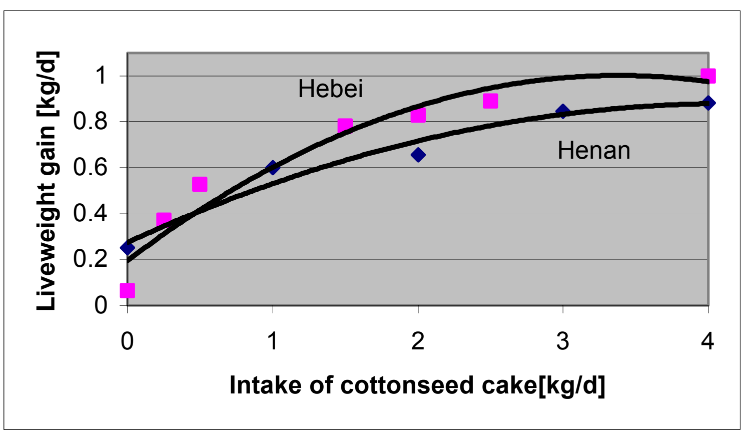
Attention to timing of straw harvest relative to the harvest of grain and also drying processes and storage processes have large effects on the feeding value of straw.

Essential a major loss of nutrients can occur in pre and post harvest management of straw and for optimum use of straw it is essential to minimize this loss of soluble nutrients.

Dolberg and Finlayson [1995] reported on studies undertaken within an aide project to introduce the use of urea ensiled or ammoniated wheat straw as a basal diet for fattening cattle in two provinces in China[Figure 5]. Cottonseed cake was the available protein source and response curves in live weight gain of young cattle to the level of cottonseed cake supplementation were developed. These studies are included in Figure 4 but despite a higher growth of cattle on the basal feed resource in Henan province there was a much higher stimulation of live weight gain in the lower levels of supplementation in the animals in Hebei province. However, as supplementation increased above the level where the catalytic response ceases [about 0.7 kg cotton seed cake/day] the responses were approximately the same per unit of cottonseed meal consumed.

It appears that the catalytic response in growth of young cattle to low inputs of protein meals was not observed because supplementation rates were above the cut off in the catalytic level of supplementation in the trials in Henan province. Similar effects are also apparent in studies where young cattle were fed ammoniated straw with supplements in Thailand, however, there were no unsupplemented cattle in the reported trial [Wannapat et al 1986].

Figure 5. The response of Yellow cattle given urea ensiled wheat straw[in Hebie] or ammoniated wheat straw[in Henan] as a basal diet to increasing levels of supplementation with cottonseed cake [after Dolberg & Finlayson 1995].



Implications for future meat production

National production of meat and milk is influenced by both the reproductive efficiency of the herd and the production levels achieved by the cattle being fattened. A generalized statement based on experience in a large part of south east Asia indicates that cows maintained by small farmers that rely on the locally available forage and do not strategically supplement their animals, probably have their first calf at 4-5years of age and produce a calf there after at intervals of a minimum of 2 years. Under the harsh conditions a high proportion of the calves succumb soon after birth and many cows barely replace themselves within their life-time.

The cow's maintenance is often justified in order to provide replacements for working bullocks and as an insurance against crop failure where a working bullock is incapacitated at critical times for crop production and the cow is then used for work. The cow, also produces small amounts of milk for the calf and the family. Sharing of the milk and/or early weaning of the calf are causes of ill thrift and early death of calves

The supplementation strategies discussed above, can[could] have remarkable effects, as increased growth of young animals by better feeding management can reduce breeding age to 2 years and in older animals the maintenance of live weight by the same approach can reduce inter-calving interval to 1-1.5 years. The overall improvement in animal health and body condition is accompanied by increased survival of young animals prior to weaning and reduced death rate among cows at calving. The effects on reproductive efficiency alone can more then double the availability of young animals for fattening.

A major benefit of the introduction of multi-nutrient block and bypass protein supplementation of lactating cows in the Cooperative Milk Unions under the auspices of the National Dairy Development Program in India was attributable to improved reproductive efficiency of the supplemented cows leading to a greater number of cows in milk at any one time and also the stimulation in both lactation length and improved daily milk yield [Leng and Kunju 1990].

Ruminant production and forage availability.

Improved reproductive function leads to increased mouths to feed and immediately the objection is made "where is the extra feed to be generated?"

The point that needs stressing here is that the amount of feed needed to turn off an animal is related to its growth rate. The higher the growth rate the lower the feed requirements per unit of live weight produced. The clearest indication of this comes from the research in China [Table 2] where without increasing forage resources but providing the necessary supplements to ammoniated straw it is possible to increase meat from ruminants by 10-13 fold. Depending on the cost of the protein meal the most economic response is likely to be at low protein inputs where production from a unit of straw maybe increased by about 5-6 fold. The conversion of concentrate into live weight gain is far ahead of that of pigs and poultry when the supplementation levels allow a catalytic response in gain, which occurs at less then 1kg of protein concentrate per day.

Table 2. The potential of balanced supplementation to increase meat production from young cattle fed low quality crop residues treated to increase digestibility. The calculations are based on the data from research in Hebei, China as reported by Dolberg & Finlayson 1995. The growth rates of the cattle were fairly accurately predicted from the regression shown in Figure 4d

Cottonseed supplement fed [kg/day]	0	0.25	0.5	1.5	2.0	2.5
Live weight gain [kg/day]	.063	.370	.529	.781	.829	.892
Straw consumed to produce 100kg live weight [tonnes]	6	1.1	0.92	0.56	0.48	0.46
Cottonseed cake consumed [tonnes] to produce 100kg live weight	0	.1	.1	.14	.22	.24
Number of animals that can achieve an extra 100kg of live weight on 6 tonnes of straw	1	5+	6+	10+	12+	13+
Protein meal requirements [tones] to allow 100g live weight gain per group of animals fattened	0	.5	.6	1.4	2.6	3.1
Conversion of protein meal to live weight [g Lwt gain/g feed concentrate]	-	1.2:1	0.93:1	0.48:1	0.26:1	0.31:1

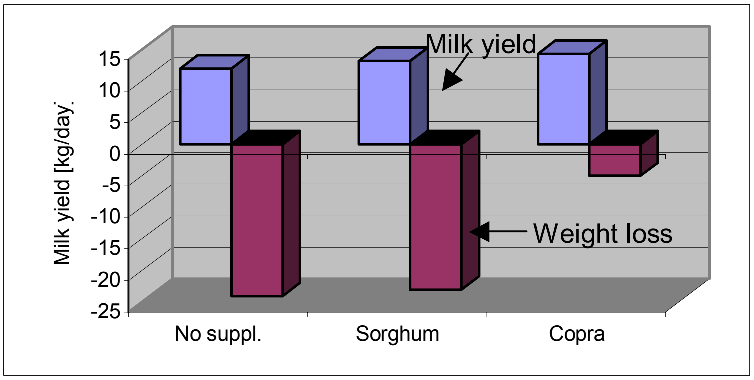
Responses to escape protein in dairy cows.

The response to protein intake by forage -fed dairy cows has not been so well defined as for young growing cattle. In milking cows on basal feed resources of mature forages, supplementation with high protein meals has major effects on live weight change, often reducing live weight loss in lactation. As there is a high correlation between live weight and the ability to breed in lactating cows, then supplementation with protein meals during lactation often, reduce time to first oestrus, reduce inter-calving interval and improves overall reproductive efficiency.

The major effects of supplying escape protein as compared with traditional concentrates for dairy cows fed mature forages appears to be to reduce the need by the cow to draw on body reserves to maintain milk production. Supportive evidence for this statement is shown in the data given in Figure 6 and Table 3.

Higher genetic potential for milk production is linked to the ability of the good [high yielding] cow to mobilise body reserves as against a poor cow that does not have this capacity [Bines & Hart 1978] and therefore the benefits of supplementing cows with a high genetic potential for milk production is more effective in reducing inter-calving interval.

Figure 6. The effects of feeding grain [3kg/day]or copra meal [3kg/day] to dairy cows on pasture. Supplementation with protein seems to be more beneficial in reducing body weight loss[kg in 12weeks] in dairy cows and milk yield [kg/day] is stimulated to a minor extent [Ehrlich et al 1990].



Definition of the amount of escape protein needed to attain the point at which the change of roles of the protein meal supplement occurs is clearly needed in lactating cows.

The concept is that the initial supplement protein source needs to be highly protected for maximum efficiency of use but after this response is achieved, a protein meal being partially protected appears to be a positive in that the requirements for amino acids to other nutrients appear to be closely balanced for additional production from such a source. Perhaps in this case there is good synchrony of nutrient supply [carbohydrate ammonia and minerals] from the feed for optimal fermentation of the feed in the rumen

Table 3. Effects of replacing balanced concentrates [20%CP] with a concentrate high in escape protein [30%CP] on live weight change and milk yield of Jersey x Kankrej cows [after Leng & Kunju [1990]. Note that the 'balanced concentrate'was given at about twice the rate of the protein concentrate

	Crude Protein in supplement [%]	Supplement given [kg/day]	Milk Yield [kg/day]	Live weight change [[kg/day]
Group 1	20	4.7	8.0	-0.21
Group 2	30	2.6	8.8	0.20

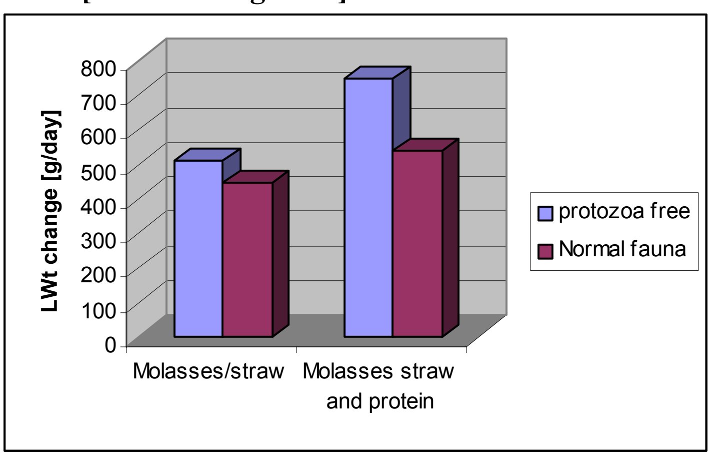
Minimising the need for escape protein

The definition of the growth response curves to feeding protein meals in a diet of straw given to cattle may be used to predict growth rates of cattle and from economic analysis, to establish priorities for the ruminant industries.

Research to minimise protein meal requirements is a priority since these are usually expensive and often in short supply. The most appropriate way would seem to be to more completely protect the protein in a meal [for example cottonseed meal protein is estimated to be between 40 and 60% protected] to maximise the initial response and then feed the untreated meal for the most economic level of production.

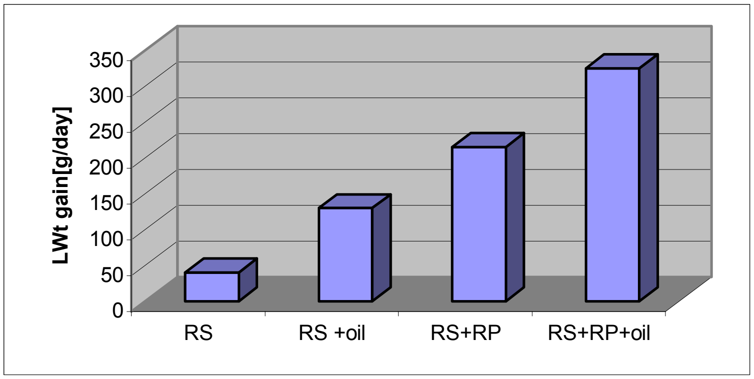
One way of partially reducing the initial high requirement for escape protein in cattle on forage diets is to increase the net flow of bacterial cells to the lower tract by removing the predatory protozoa from the rumen [defaunation]. Bird and Leng [1979] first showed that defaunation of the rumen improved growth of cattle on low protein diets [see Figure 7]. Wool growth response in sheep to defaunation indicated that more protein was delivered from the rumen of fauna free as compared to normal sheep [Bird et al 1980]. This was confirmed by Veira et al [1984] who demonstrated that introduction of protozoa into the rumen of sheep that were raised without rumen protozoa, reduced microbial protein flowing to the intestines. The work of Ushida et al [1986] indicated that in the absence of rumen protozoa more dietary protein, in addition to bacterial protein moved to the lower tract in sheep. It appears that the consensus is that protozoa in the rumen reduce total protein flow to the intestines and therefore lower the protein availability from the feed consumed by ruminants.

Figure 7. The effects of the defaunated state on growth of cattle fed straw /urea/molasses based diets supplemented with sub-optimal levels of escape protein meals [Bird & Leng 1979].



The potential is thus there to minimise protein requirements of ruminants on low protein diets by manipulation the rumen to exclude and maintain the animal free of protozoa. Until recently, no methods have been discovered that can be easily applied to existing farming systems.

Figure 8. The effects of a single oil drench at the beginning of the fattening period on the growth rate of young cattle fed rice straw and supplements [Nguyen Thi Hong Nhan et al 2001].



Young cattle were given rice straw with grass[RS] or rice straw/grass with a supplement of 1kg/day rice polishing[RS +RP] one group in each feeding system was drenched with 5ml vegetable oil/kg live weight [+oil] at the beginning of the feeding trial

Nguyen Thi Hong Nhan et al [2001] working in Vietnam showed that treating young cattle fed on rice straw with an oil drench increased their subsequent growth rate. For the first 20 days after drenching the rumen appeared to be free of protozoa and the response was attributed to the absence of protozoa in the rumen. The results are shown in Figure 8. Subsequent studies by Mom Seng et al [2001] showed that rumen protozoa appeared to be eliminated initially but returned within two weeks with a changed population mix of protozoa. The very large protozoa that usually make up a small proportion of the numbers but are often a large proportion of the total biomass returned to only a fraction of their population density pre-drench. A slow recovery of these large protozoa has been previously observed where fauna free sheep were naturally infected, when returned to a flock of normal grazing sheep [Hegarty et al 2000].

The amount of rice polishing [15%CP] that had to be fed to get the same response as drenching once with oil, was about 0.5 kg/day.

Conclusions

It is argued in the paper by Delgado and co-authors [1999,2002] that the relative price of grain will not rise significantly in the next 50 years and grain surplus to human requirements can be used to provide the basis for an industrialised pig and poultry industry to expand in developing countries to meet the growing demand for meat.

Legislation for the inclusion of alcohol [an oxygenate] in gasoline for motor vehicles in order to lessen the hazards of chemical smog in major cities of the USA is likely to have a major impact on the economics of feed grain. The production of alcohol is set to monopolise surplus US maize grain by 2005. In addition the lobby for development of industrial alcohol as a fuel is also likely to increase the demand for grain for these purposes. This is despite the fact, that on balance, greater amounts of gasoline are utilised in the production of corn and conversion to pure ethanol than in the alcohol produced [see Pimentel [2001] for a complete discussion of the net energy balance of the alcohol industry based on corn.]. Whilst these developments will have repercussions for livestock industries in all parts of the world, a major benefit will be the considerable quantities of fibrous high protein by-products that will become available and are most suited to supplementation of ruminants given low digestibility forage.

It seems likely that the development of alcohol industries will also be implemented in a number of countries increasing the use of starch and sugar based crops for this purpose In the future there will also be considerable effort to use biomass [urban, forest and agricultural waste] for the same purpose but the technology has yet to be refined to support economic production [California Energy Commission, 1999]. A world short fall in feed grain will adversly effect intensive animal production industries and limit the production of meat.

It appears that the development of ruminant industries has the potential to meet any short fall in meat as the feed base of cellulose biomass is abundantly available and inefficiently utilised at present. The use of poor quality forage, un-supplemented for ruminant production, is realising less than 20% of the potential and it is relatively easy to provide technology to increase meat from these resources by more than 5 fold without finding new sources of basal feeds. However it will be necessary to identify and prioritise protein meals that are required as supplements to increase the efficiency of production to levels that are economic.

Protein concentrates may be more efficiently used for meat [and milk] production from ruminants when combined with forage from such sources as crop residues, which in many developing countries are regarded as a free resource.

The wide distribution of ruminants in general, and cattle, in particular, among rural farms where the forage is a by-product of crop production is highly advantageous. However, to be successful in encouraging the development of such dispersed, small production units the necessary supplements must be made available and suitable slaughtering facilities and an equitable marketing system are essential.

These requirements are well demonstrated by the success of the Milk Cooperatives in India that have shown that dispersed systems for milk production from indigenous cows or their crossbreds and local feed resources, can be highly economic where the necessary supplements are made available and where there is a guaranteed and equitable marketing of milk to the cities where the wealthy are concentrated.

Small farm systems appear to be best operated outside of any industrial frame-work which then ensures that the farmer benefits directly as against indirectly as is the case with workers in industrial enterprises. The marketing of supplements [multi-nutrient mineral urea mixes and concentrates high in escape protein], provision of slaughter houses and packaging plants and a guaranteed market, together with some form of time payment to ensure a regular income, are all considerations for the introduction and success of such a development.

The overall development could realise the potential of a five or more fold increase in meat production from ruminants, particularly in those developing countries with vast areas of crops.

Reports that have indicated that relatively high levels of meat production are possible on these resources have been often ignored or maybe it is that the reports are merely unbelievable because of the preconceived concept that such feeds are poor quality rather than simply being deficient in some nutrients.

The trials summarised here indicate that cattle growth rates and milk production from mature forage with appropriate supplementation can often approach the same levels as are obtained on high quality temperate pastures. Growth rates of young cattle of the order of 0.75kg/day are relatively regularly reported for cattle fed treated and untreated straws with appropriate supplementation. It should be emphasised that this growth rate of cattle is translated to 280 kg of live weight per year. The small ruminants also respond to the same magnitude relative to their size.

The feeding trials reviewed indicate that cattle on a diversity of mature low protein forages, respond very similarly to supplementation despite a wide divergence of local climates and different management. The source of supplements is often a key factor and is not necessarily dependent on packaged supplements, for instance tree foliages/sown grasses or other plants that can be grown may be sources of minerals and escape protein and/or where they have a high digestibility a source of biomass to increase the digestibility of the diet. The point to be made is that the requirements for essential nutrients deficient in straw or other low digestibility feed maybe sourced wherever possible and the above discussion is intended to provide " rules of thumb" that have to be applied in developing such feeding systems

Meat production will continue to be diversified in all countries amongst the three major species in extensive and intensive systems. However, for the ruminant industries to develop it will be necessary to identify and to provide the resources that are needed to improve productivity.

The need is for education of farmers to

- improve their management of the harvest of straw
- manage or treat roughage appropriately to increase its digestibility
- blend or harvest forages to provide essential nutrients and to improve digestibility of the total forage diet.

The second need is for the relevant industry groups in both public and private sectors to find and make available the essential supplements to ruminants fed on poor quality straw or other forages to

- ensure no deficiencies of essential nutrients for microbial growth in the rumen

- provide a source of escape protein to be fed at optimal rate
- provide options of drenching with a vegetable oil at the beginning of a fattening period

Research is needed on all the above points but in particular, if better harvesting methods could be established to retain the feeding quality of straw after harvest so that treatment with ammonia becomes unnecessary to achieve high growth rates with minimum supplements.

The last point, but perhaps the one to have greatest impact is the requirement for infrastructure to support marketing of ruminant meats to ensure farmers receive fair and equitable prices

References

Bird S & Leng R A [1978] The effects of defaunation of the rumen on the growth of cattle on low protein high-energy diets. British Journal of Nutrition 40, 163.

Bird S J, Hill M K & Leng R A [1979] The effects of defaunation of the rumen on the growth of lambs on low protein high energy diets. British Journal of Nutrition 42, 81.

California Energy Commission. December [1999] Evaluation of Biomass-to-Ethanol Fuel Potential in California. http://www.energy.ca.gov/reports/1999-12-22_500-99-022

Chenost M & Kayouli C [1997] Roughage utilisation in warm climates. FAO Animal Production and Health Paper 135, FAO, Rome

Creek M J, Barker T J & Hargus W A [1983] An evaluation of the use of anhydrous ammonia to treat rice straw.UNDP/FAO Beef Industry Development Project. EGY/82/007.Field Document No.8 FAO Rome.

Delgado C, Rosegrant M, Steinfeld H, Ehui S &Courbois C [1999]. Livestock to 2020; The Next Food Revolution. Food, Agriculture,and the Environment Discussion Paper 28.International Food Policy Research Institute. Washinton DC

Delgado C L, Rosegrant M W& Meijer S [2002] Livestock to 2020.The Revolution Continúes. In World Brahman Congress, Rockhampton, Australia, April 2002.

Dolberg F & Finlayson P [1995] Treated straw for beef production in China. World Animal Review 82, 14.

Ehrlich W K, Upton P C, Cowan R T & Moss R J [1990] Copra meal as a supplement for grazing dairy cows. Proceedings of the Australian Society of Animal Production 18, 196.

Elliott R C & O'Donovan M W [1971]In 'Report of the Henderson Research Station.,1971. Harare Zimbabwe.

Finlayson P, Zhang Weixian, Chuan Xue, & Dolberg F [1994] Economic aspects of utilising fibrous crop resdidues for beef production in China. Research for Rural development 6[3] **http://www.cipav.org.co/lrrd/lrrd6/3/4.htm**

Hegarty R S ,Shands C,Harris C & Nolan J V [2000]Productivity and pasture intake of defaunated crossbred sheep flock Australian Journal of Experimental Agriculture 40, 655.

Hennessy D W, Williamson P J, Nolan J V, Kempton T J & Leng R A [1983] The roles of energy- or protein –rich supplements in the sub tropics for cattle consuming basal diets that are low in digestible energy and protein. Journal of Agricultural Science 100, 657.

IAEA [1991] Proceedings of international Symposium on Nuclear Related Technologies in Animal Production and Health .Vienna 1991 IAEA

Leng R A [1990] Factors effecting the utilisation of poor quality forages by ruminants particularly under tropical conditions Nutrition Research Reviews 3, 277.

Leng R A [1984] The potential of solidified molasses-based blocks for the correction of multi-nutritional deficiencies in buffaloes and other ruminants fed low-quality agro-industrial by products. In The Use of Nuclear Techniques to Improve Domestic Buffalo Production in Asia. IAEA Vienna 1984 STI/PUB/684

Leng R A [1989] Dynamics of protozoa in the rumen .In J V Nolan, R A Leng & D Demeyer [eds] The Roles of Protozoa and Fungi in Ruminant Digestion. Penambul Books, Armidale, Australia Page 51.

Leng R A [1997] Tree foliage in Ruminant Nutrition. FAO Animal Production and Health Paper 139 FAO Rome

Leng R A & Kunju P J G [1990] Feeding strategies for improving milk production from milch animals owned by small farmers in India .In Domestic Buffalo Production in Asia. International Atomic Energy Agency ,Vienna

Mom Seng, Preston T R, Leng R A & U ter Meulen[2001] Effect of a single drench of cooking oil on the rumen ecosystem and performance of young local "yellow cattle" fed rice straw and cassava foliage. Livestock Research for rural Development 13 [4] [http://www.cipav.org.co/lrrd13/4/seng134.htm]

McLennan et al.1995 quoted in Poppi & McLennon[1995]

Nguyen Thi Hong Nhan, Nguyen Van Hon, Ngu N T, Preston T R & Leng R A [2001]Practical application of defaunation of cattle on farms in Vietnam: Response of young cattle fed rice straw and grass to a single drench of ground nut oil. Asian-Australasian Journal animal Science 14{4] 485.

Orskov E R ,Fraser C& McHattie I[1973] The effect of bypassing the rumen with supplements of protein and energy on intake of concentrates by sheep. British Journal of Nutrition 30 361.

Pearse Lyons T & Bannerman J[2001] The US Fuel Ethanol Industry from 1980 to 2001: Lessons for Other Markets . In " A Time for Answers". Proceedings of Alltech's 15th Asia –Pacific Lecture Tour. 115.

Poppi D P & McLennan S J. [1995] Protein and energy utilisation by ruminants at pasture. Journal of Animal Science 73, 278.

Saadulah M [1984]Studies on the utilisation of rice straw by cattle. PhD Thesis Royal Veterinary University. Copenhagen, Denmark.

Silva AT, Greenhalgh J F D & Orskov E R [1989]Influence of ammonia treatment and supplementation on the intake, digestibility and weight gain of sheep and cattle on barley straw diet. Animal Production 48, 99.

Smith G H & Warren B [1986a Supplementation to improve the production of yearling steers grazing poor quality forage.1The effects of forage type and cottonseed meal supplement. .Australian Journal of Experimental Agriculture 55 389.

Smith G H & Warren B [1986b] Supplementation to improve the production of yearling steers grazing poor quality forage.2The effects of oats, supplementary nitrogen, lupins and cottonseed meal. Australian Journal of Experimental Agriculture. 26, 7.

Perdoc H B [1987] Ammoniated Rice Straw as a Feed for Growing Cattle. PhD Thesis, University of New England, Armidale, Australia

Perdoc H B & Leng R A [1990]Effect of supplementation with protein meal on the growth of cattle given a basal diet of untreated or ammoniated rice straw. Asian –Australasian Journal of Agricultural Science 3, 269.

Pimentel D [2001] Biomass utilization,limits of. In Encyclopedia of Physical Science and Technology. Third Edition Vol 2 pages 159.

Preston T R & Leng R A[1986] Matching Livestock Systems to Available Resources in the Tropics and Sub Tropics..Penambul Books ,Armidale, Australia

Preston T R & Willis M B [1974] Intensive Beef Production. Pergamon Press, Oxford

Renewable Fuels Association .[2001] One Massachusetts Avenue, Suite 820, Washington DC 20001, **http://www.ethanolrfa.org**.

Ushida K, Jouuany J P, Lassalas B&Thivend P [1984] Protozoal contribution to nitrogen digestion in sheep. Canadian Journal of Animal Science 64,[suppl.],20.

Veira D M, Ivan M & Yui P Y[1984] The effect of ciliate protozoa on the flow of amino acids from the stomach of sheep. Canadian Journal of Animal Science 64, 22.

Wannapat M, Duangchan S, Pongpairote, S,Anakewit T, & Tongpanung P [1986]Effectsd of various levels of concentrates fed with urea-treated rice straw for pure bred American Brahman yearling cattle. In "Ruminant Feedinng Systems Utilizing Fibrous Agricultural Residues" [R M Dixon ed]IDP.Canberra. Page 149.

Waterlow J C [1998] with contributions by Tomkin A M& Grantham-McGregor. Protein-energy malnutrition. Edward Arnold, London

Zhang Weixian,Gu Chuan Xue,Frands Dolberg,& Peter M Finlayson [1994] Supplementation of ammoniated wheat straw with hulled cottonseed cake Livestock Research for Rural Development 6[1] [http://www.cipav.org.co/lrrd/lrrd6/1chna l.htm