Practical technologies to optimise feed utilisation by ruminants

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INTRODUCTION

Rates of growth and milk production from ruminants in developing countries are generally low and often only 10% of the genetic potential of the animal. The reasons for low productivity are complex but in order of priority they appear to be:

- The imbalanced nature of the nutrients that arise from digestion of the available forage resources when these are fed without supplements
- The incidence of disease and parasitism
- The often harsh climatic conditions

The use of a high yielding genotype in these situations is often irrelevant because the primary constraint is poor nutrition. On the other hand, resistance of particular breeds to disease and high temperatures is an important overall consideration.

Nutritional research has shown that large increases in animal productivity and efficiency can be brought about by small changes in the balance of nutrients in the feed base (Leng, 1991). These increases are not restricted to laboratory studies and have been observed on a large scale at the small farm level (NDDB, 1989) and without alteration to the other management practices. This illustrates the large potential impact of feeding strategies in these environments.

Increased production of meat and milk is only one benefit. The improved body condition of animals also has an impact on reproductive rate. The age at puberty of heifers is lowered and the intercalving interval in mature cows is decreased.

Increased efficiency of forage utilisation by animals and improved reproductive rate together produce an increase in production of up to five fold without changing the basal feed resources. This is accomplished by identifying and providing critical catalytic nutrients that are deficient in the diet and therefore balancing nutrient availability with animal requirements.

In general, the supplements required are a source of fermentable N, minerals for the rumen organisms and a source of protein that is not readily degraded in the rumen but moves rapidly to the lower tract to improve the animal's amino acid supply.

In many countries, these feed supplements are available. In others, there is a need to identify alternative sources and provide them in the correct amounts and in an appropriate form.

In many pastoral areas of the world, the basic resource is pasture, which is generally low in total protein and fermentable N. Often a source of bypass protein is not available locally. Research and development is needed to produce supplements economically at the centres of high ruminant population densities. In the rangelands, particularly in the semi arid areas, tree forages, seeds and pods represent by far the greatest potential source of protein meals that can be used as supplements to provide soluble N, bypass protein and a source of minerals. When fed, they create a rumen environment more capable of fermentatively digesting poor quality forage. In addition, in the dry areas, these green supplements are a major source of Vitamin A.

FORAGE RESOURCES IN DEVELOPING COUNTRIES

Crop and livestock production in developing countries have more than doubled in the last 30 years; however, the demand for food has increased at an even greater rate, leading to an increase in food imports of approximately 10% per year. Increases in animal production in developing countries has been brought about through increases in animal numbers. Production rates per animal have remained low or have only increased to a minor extent (Jackson, 1981).

The demand for food for human consumption in Third World countries is likely to increase and, since cropping land is almost fully utilised at the present time, it appears that cultivated pasture is likely to become scarcer in these countries. The ruminant will therefore have to depend increasingly on forage biomass containing large amounts of complex carbohydrates which are not digested by intestinal enzymes and therefore require fermentative digestion. These include forage and crop residues which cannot be used by monogastric animals but can be used efficiently by ruminants. The ability of ruminants to convert otherwise waste materials into useful products or to accomplish work will ensure they remain important livestock species in the foreseeable future.

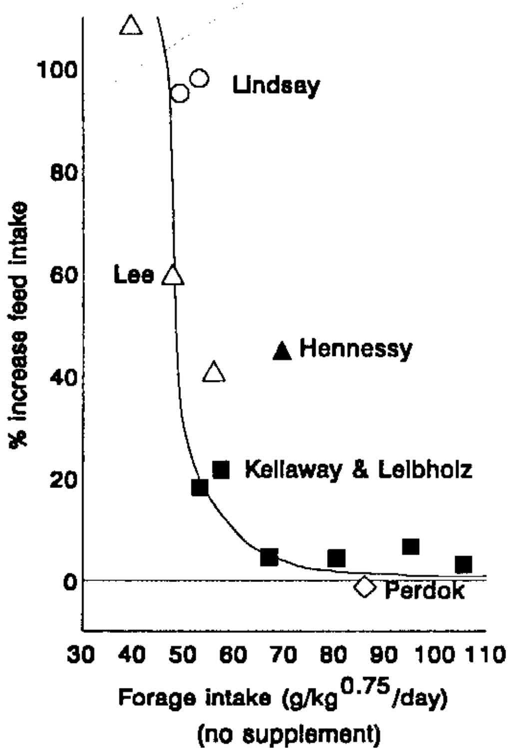
The increasing need for land for crop production indicates that ruminants will continue to use primarily crop residues, industrial byproducts and pastures from relatively infertile rangelands. The common characteristics of such feeds are low digestibility, low protein content and a low mineral components.

ANIMAL PRODUCTIVITY FROM AVAILABLE FEED RESOURCES

It has been a major misconception throughout the scientific literature that low productivity of ruminants fed on forages is a result of the low energy density (i.e., low digestibility) of the feed. This is very misleading. There is abundant evidence that low productivity in ruminants on forages results from inefficient utilisation of the feed because of deficiencies of critical nutrients in the diet. The deficient nutrients may be those critical to growth of rumen microbes which ferment or digest the feed or those nutrients required to balance the products of digestion that are absorbed to meet requirements. The evidence for these statements has been considered in detail recently by Leng (1991). Inefficient utilisation of nutrients is accompanied by an increase in metabolic heat which has important implications for ruminant production in the tropics. The often low intakes of poor quality forage by ruminants in tropical countries may be imposed by a combination of metabolic heat stress and high environmental temperature and humidity (Leng, 1989). Correction of a nutrient imbalance by feeding a bypass protein often (but not always) increases the intake of poor quality forages to between 80-100 g/kg$^{0.75}$/d, particularly in hot climates (Figure 1).

Cattle in the tropics may require less feed for maintenance as they do not have to combat cold stress. If they can process these nutrients that would otherwise be oxidised for maintenance of body temperature, they can be more efficient than animals in a cold climate. The energy spared, however, must be supplemented with protein to ensure an appropriate protein to energy (P/E) ratio in the nutrients absorbed for optimum efficiency of feed utilisation. For this reason the requirements for amino acids are higher in cattle in the tropics than in animals on the same feed in cool environments.

FIGURE 1. **Intake of low digestibility forages by cattle either unsupplemented or supplemented with bypass protein or bypass protein and urea (Lindsay and Loxton, 1981; Lindsay *et al.*, 1982; Hennessy, 1984; Perdok, 1987; Kellaway and Leibholz, 1981).**



IMPROVING RUMINANT PRODUCTION ON LOW DIGESTIBILITY FORAGES

The rationale and concepts on which the following discussions will be centred have been reviewed by Preston and Leng (1987) and Leng (1989, 1991). The basic concept is that ruminants fed low quality forages require supplementation with critically deficient nutrients to optimise productivity. The required supplements must:

- correct nutrient deficiencies for the rumen microbes, and
- increase the ratio of protein (absorbed amino acids) to energy (VFA) available from digestion so that it more closely corresponds to the animal's requirements.

Rumen fermentative digestion

Anaerobic fermentative digestion in the rumen provides microbial cells (which supply the protein (P) to the animal) and VFAs (E) (the major source of oxidizable substrate). The efficiency of microbial growth and therefore the P/E ratio will be low when nutrient deficiencies occur in the rumen. Thus a sub-optimal level of any nutrient required for microbial growth will result in low protein to energy (P/E) ratio in the nutrients absorbed. Ensuring a nutrient non-limited microbial digestion in the rumen by complete supplementation automatically improves the P/E ratio in the nutrients available to the animal.

Feeding a protein meal in which the protein has been made insoluble or otherwise not degraded by rumen microbes is a further major supplementation strategy to adjust the P/E ratio upwards. The P/E ratio appears to be the primary factor that controls the efficiency of feed utilisation and the partitioning of nutrients into various components of production (Leng, 1991).

The ratio of microbial protein to VFA produced and the effects of supplementation to provide an optimal environment for microbial growth efficiency is less important where dietary bypass protein is completely digested in the rumen (Table 1).

TABLE 1. The effects on P/E ratio in the nutrients absorbed of supplementation with a bypass protein to cattle with a poor or optimised (i.e., supplemented) microbial milieu in the rumen. The values are calculated for a steer digesting 4 kg DM in the rumen (Leng, 1982).

Rumen environment	Protein bypass (g prot/d)	Microbial cells produced (g/d)	Microbial protein (g/d)	VFA produced (MJ)	P/E* protein (g/MJ)
Deficient	0	830	500	41	12
Supplements	0	1630	1010	30	33
Deficient**	400	830	500	41	22
Supplements	400	1680	1010	30	47

* Ratio of microbial protein plus dietary protein to VFA energy

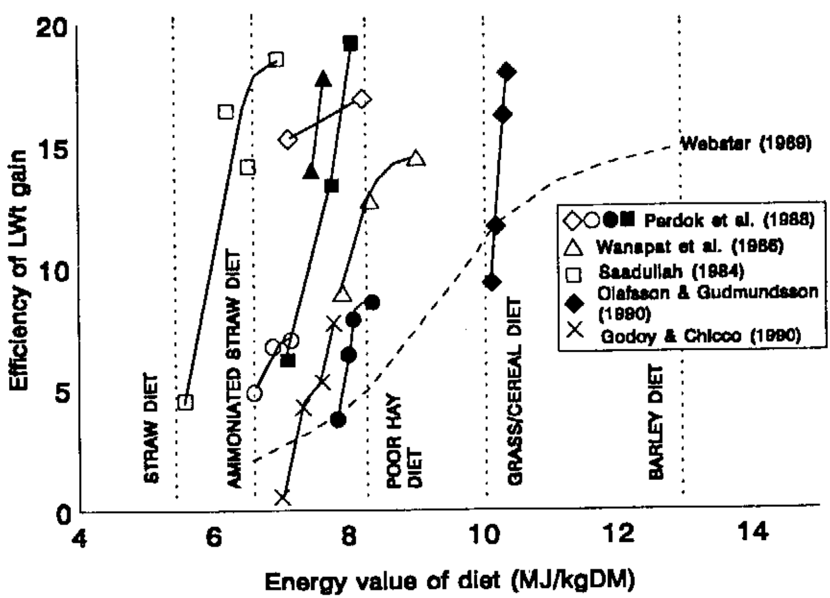
** Although the rumen environment is deemed not to change through the addition of protein meal, in fact it will have been improved but may not be optimized to the extent it would by feeding a molasses-urea block. P/E ration here is therefore underestimated.

The reason for discussing these theoretical calculations at this point is to emphasise the large variations that can occur in P/E ratio (from 12 to 50) in the nutrients absorbed by ruminants fed unbalanced diets and diets balanced with supplements at the same level of feeding. A further point is that, on a diet supplemented with a high level of bypass protein, the rumen microbes need not grow highly efficiently as long as the digestibility is optimised.

Feeding standards: are they realistic?

The relationship of P/E to the efficiency of feed utilisation has a very large effect on growth, milk yield and reproductive performance. The levels of production achieved when P/E is increased have been greatly superior to that predicted from present day feeding standards based on metabolisable energy of a feed (Figure 2). This illustrates the marked differences that result when supplements high in protein are given to cattle on diets of low ME/kg DM.

Figure 2: Schematic relationship between diet quality (metabolisable energy/kg dry matter) and food conversion efficiency (g live weight gain/MJ ME) (from Webster, 1989). The relationships found in practice with cattle fed on straw or ammoniated straw with increasing level of supplementation in Australia (Perdok *et al.*, 1988), Thailand (Wanapat *et al.*, 1986) and Bangladesh (Saadullah, 1984). Recent relationships developed for cattle fed silages supplemented with fish proteins (Olafsson and Gudmundsson, 1990) and tropical pastures supplemented with cottonseed meal (Godoy and Chicco, 1990) are also shown.



Except for temperate pasture, most forages consumed by livestock are relatively low in digestibility (55%). On most crop residues or tropical pasture, digestibility is 40-50%. The metabolisable energy in the dry matter (M/D) thus ranges from 4.8 to 7.5 MJ/kg DM. According to feeding standards, a metabolisable energy content in a feed of 7.5 will support a gain of approximately 2 g/MJ of ME intake in cattle. At

4.8MJ/kg DM cattle should be in negative energy balance (ARC, 1980; Webster, 1989). Contrast this with results of supplementary feeding trials based on balancing the nutrition of animals with urea/minerals and bypass protein, where cattle growth rates equivalent to 18 g/MJ of M/E intake have been achieved in cattle fed straw (Figure 2). Obviously the presently accepted feeding standards are misleading and should not be used to predict animal performance on these feeds.

The application of the basic concept of balanced nutrition, as referred to 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 on forage based diets in the tropics can be as efficient in converting feed to live weight gain.

The low productivity of ruminant livestock has been accepted in developing countries as an inevitable result of the poor feed base and a low feed conversion efficiency. This is no longer tenable and should give impetus to those developing animal production in Third World countries as the application of the new feeding technologies has carry-on effects of improved reproduction, increased percentage of a herd in production and an increased offtake from a herd. The benefit of improved reproduction may even outstrip the direct effects on live weight gain or milk yield *per se*. However, the remaining challenge is to develop the necessary supplements and to get these to the animals in the various production systems.

APPLICATION OF THE NEW FEEDING STRATEGIES

Even though the principles of feeding bypass protein to improve productivity have been known for many years, application has been slow and unspectacular. The application has been slowed by:

- The desire by many scientists to stand by the feeding standards that have been promulgated for twenty years and which appear to be totally inappropriate for most feeding systems
- The controversies surrounding the principal mechanisms of action of protein supplementation which has clouded the major issues

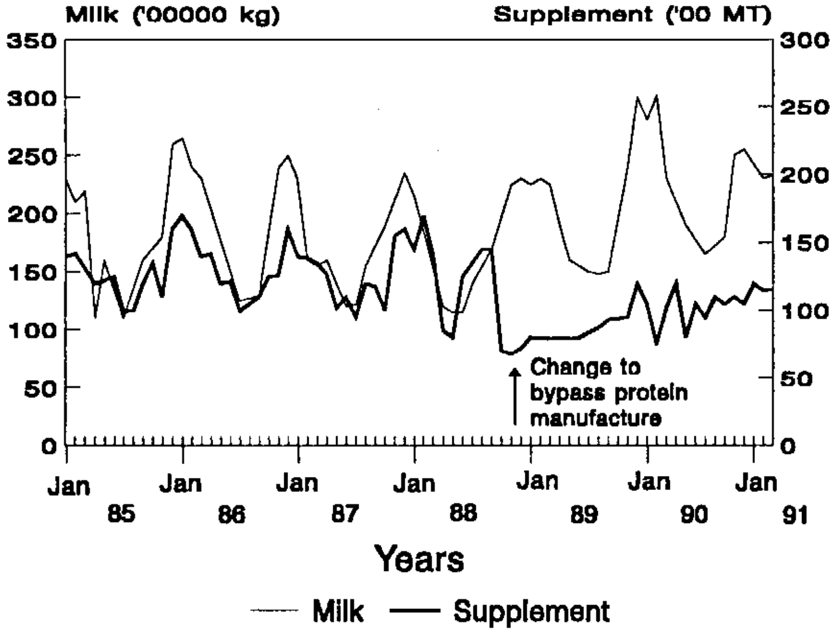
- The inability of research scientists to communicate with and be believed by applied technologists
- The unavailability of protein, minerals and non-protein nitrogen in the cattle producing areas

However, extensive application of the use of supplements high in bypass protein has occurred in India through the initiatives of The National Dairy Board of India (NDDB). For the same reasons as given above, progress was initially slow (the development started in 1980) but it is now accelerating at a pace which should see most feed mills in India dedicated to the production of bypass protein supplements within the next five years. At the present time, approximately 200 MT of bypass protein feed is being fed daily to dairy animals 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 collection is shown in Figure 3 for a dairy co-operative in the Kedah district of India that changed from feeding a traditional concentrate to a new supplement containing 30% protein with a high bypass capacity. The collection of milk is 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 milk collected, local research confirms that the responses in milk production to the new supplements are in agreement with observed increases in milk collected (Leng and Kunju, 1988).

The effects of the changed feeding strategies appear to be a 30-50% increase in milk production from 1 December 1988 to 1 December 1989. A further similar increase in production is apparent in 1989-1990 (unpublished observation). This increase probably represents a carry-on effect that would come from increased reproductive rate and the increased proportion of the herd in milk resulting from the improved feeding strategies.

FIGURE 3. **Milk collection records and the sale of supplements for a milk cooperative in the Kedah district of India when supplements were compounded on traditional concepts (1985-1987) and following (1st December, 1988) their replacement with a 30% C.P. bypass protein pellet (records provided by the NDDB of India).**



THE APPROPRIATE STRATEGY

To ensure maximum utilisation of local forage resources in developing countries, the appropriate supplements are:

- a combination of minerals and a source of nitrogen for rumen microbes.
- a supply of protein with a substantial proportion of bypass protein.

Meeting the requirements for appropriate supplements

In most areas of the world, it is not practical to identify the deficient micro and macro minerals in a basal roughage diet as these will vary from site to site and year to year. The practical approach is one of 'rules of thumb', that is to provide a 'best bet' or 'shot-gun mixture' of minerals as economically as possible. A concentrated plant extract such as molasses provides such mixtures and can be fortified for specific areas where local knowledge points to specific deficiencies. In this respect, molasses (both sugar cane and beet) and concentrated palm oil sludge offer useful sources of these minerals. They are also quite palatable to livestock and are useful in hiding less palatable nutrient sources in supplements. Where forages are mature and dry, a tree forage or other green forages may also provide deficient minerals.

Mineral salt mixtures are commercially available in most countries. They usually have a high content of salt and only minor quantities of the trace elements. In practice, fortified materials, such as molasses, will be superior to these mixtures as they present a greater coverage of all the minerals required and are also a valuable source of other nutrients (e.g., B vitamins) and a small amount fermentable energy. It should also be pointed out that, where protein meals are supplemented, these often provide adequate amounts of essential minerals such as phosphorus.

Supplying the rumen microbes with ammonia/urea

The other requirement is a non-protein nitrogen source for the rumen microbes, usually urea. Urea is commonly administered together with minerals and its concentration in such mixtures is controlled by safety concerns and the difficulty of incorporation, and therefore rarely exceeds 10-15% of such mixtures. However, this is usually sufficient to allow an intake of between 50 and 100g of urea by cattle from a molasses-urea block, which is sufficient to balance the rumen for ammonia on a low N roughage diet.

Results from India suggest that mineral-urea mixtures in, for example, molasses multi-nutrient blocks are best given free choice, allowing the animal some degree of selection. There are indications that the animal will learn to control the intake of urea to an optimal level. In Indonesia, the combined effects of NPN and minerals in molasses-urea blocks has a large effect on production of ruminants fed cut-and-carry green tropical pasture (Table 2) (Hendratno *et al.*, 1991).

TABLE 2. **Effects of UMMB supplements on growth rate of Friesian Holstein steers, Ongole steers, sheep and goats fed cut/carry pasture in Indonesia (Hendratno *et al.*, 1991).**

Animals	N	Growth rate		% Increase in production
	(g/day)	-UMMB	+UMMB	
Friesian-Holstein steers	156.3	210	560	166
	171.3	400	810	102
Ongole steers	161.0	333	526	57
	204.0	478	465	-2.7
	291.0	388	822	111
	110.0	183	403	120
Sheep (local)	30.4	36	67	86
	31.5	140	316	126
Goats (does)	31.7	40	88	120
(kids)	51.7	91	105	15

Based on data collected by West Java and Central Java Livestock Services.

Bypass protein supplements

Providing bypass protein to cattle owned by small farmers is often difficult and at times too expensive. 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 meal that has been flame dried (but not sun-dried fish meal or fish silage) and protein sources that have been heat treated, have some considerable 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 occurs (unpublished observations).

Identification of protein sources

Some countries are fortunate in having large amounts of crop residues high in protein, most of which have a fair degree of protection brought about by processing methods. 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.

In many countries, particularly in extensive grasslands or savannas, where major constraints to production of cattle are essentially the same as those for cattle fed crop residues, protein sources may not be readily available or the sources not so obvious or easily obtainable. Most legume forages, legume seeds, edible tree leaves, seed pods and seeds that are available in these areas contain highly soluble protein which is easily fermented in the rumen. These, when used as supplements, provide a valuable source of ammonia and minerals (they have, for example, 0.5-1% phosphorus). This increases production of cattle on a basal diet of low protein roughage but, when fed as a small proportion of the diet, they provide little bypass protein as the protein degrades rapidly in the rumen.

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 (Table 3). This indicates the value of a high protein tree forage as a rumen stimulator but illustrates that its effects are limited to the responses in the rumen.

TABLE 3. **The effects of feed supplementation on livestock 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.**

Treatment	Rumen Ammonia (gN/l)	Initial Weight (kg)	Final Weight (kg)	Live Weight Gain (g/day)
No supplement	50	194	244	580
+ *Gliricidia*	170	204	266	717
+ Molasses/Urea	250	203	269	751

Source: ICA (1988)

CONCLUSIONS ON SUPPLEMENTATION

The above discussion defines and highlights the potential strategies to provide two types of supplements required for optimal efficiency of utilisation of low quality forage by cattle 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 molasses-urea block when the leaf protein is protected and/or as a source of locally available bypass protein when the leaf protein is unprotected. Tree forages have a major role, as they are deep rooted and provide fresh forage particularly in the dry season.

Processing of local protein resources to provide bypass protein

There are a number of processing techniques that will effectively and adequately treat protein sources and render them non fermentable in the rumen but allow them to retain digestibility in the intestines. In general these include chemical treatments with agents which cross link with amino acids on the protein chain, including formaldehydes and aldehydes, tannins and simple sugars such as glucose and xylose. These reactions often require the protein source to be heated in processing. Heat alone will often denature the protein and effect protection. For instance, Goering and Waldo (1974) found significant effects of the temperature of drying lucerne on the subsequent animal production from that lucerne.

In general, the higher the temperature of drying the greater the retention of nitrogen by the animal. More recently Lewis *et al.* (1988) demonstrated that mild heat with a small amount of xylose is very effective in protecting soya bean meal protein (Table 4). Xylose can be readily produced by acid hydrolysis of many fibrous materials including bagasse and cottonseed hulls. The effects of protecting lucerne forage protein on productivity of sheep is shown in Table 5 (Arreaza *et al.*, unpublished).

TABLE 4. **Effects on live weight gain of cattle supplementing a basal forage/concentrate based diet with soyabean meal or soyabean meal treated with sulphite liquor at 200°F for 2 hours (Lewis *et al.*, 1988).**

	Live Weight Gain (g/day)
No supplement	591
+ 7% soyabean meal	673
+ 9% soyabean meal + 10% sulphite liquor	823
+ 8% soyabean meal + 5% sulphite liquor	841

There is a great need to research methods for protecting protein of forages, tree leaves, seeds and pods from local resources as these are potentially available in the pasture areas of the world but must be used in the most appropriate supplementation mode.

TREES AS A SOURCE OF PROTEIN AND SOLUBLE NITROGEN MINERALS IN THE RANGELANDS

A number of authors have pointed to the small percentage of pasture biomass that is actually consumed by grazing animals in the extensive arid and semi-arid rangelands (Ellis and Swift, 1988). Most tropical grasslands are highly leached and their pastures apparently have a low potential to provide ruminants with their required nutrients. The point to be stressed is that 10-30% of pasture biomass is often all that is used by grazing animals. Trees can produce considerable amounts of edible biomass. For example, the tree *Prosopis juliflora* produces up to 440kg of edible pods *per annum*. A more usual production is 200kg but, on average, it contains 16% crude protein (Riveros, F., personal communication). The protein in the pods is, in all probability, soluble. Compare this with the usable biomass of 250kg DM/ha from the poor native pastures of South America. The combination of trees and grassland would obviously be a desirable development and synergistic for cattle production.

TABLE 5. Live weight gain and wool growth of sheep fed oaten chaff supplemented with either lucerne of xylose-treated lucerne.

Treatment[*]	Oaten chaff intake (g/DM/day)	LWG[**] (g/day)	FCR[**] (g/day)	Wool growth (g/day)
LX0	690	44	22	9[a]
LX1	795	69	16	11[b]
LX2	693	50	20	9[a]

[*] LX0 = 220g DM/day lucerne, LX1 = 220g D</day lucerne treated with 0.5% xylose
LX2 = 220g DM/day lucerne treated with 1% xylose.
[**]LWG=Live Weight Gain; FCR=Feed Conversion Rate
[a,b] means with different superscripts are statistically different ($p < 0.05$).

GENERAL CONCLUSION

The research needs are obvious. Local research in centres of cattle density must initially identify actual or potential protein sources. They must then establish mechanisms for harvesting and processing the protein to concentrate it, if necessary, and protect it from rumen degradation. Finally, appropriate means for using both the processed and unprocessed protein/minerals to optimise the efficiency of animal production must be established.

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