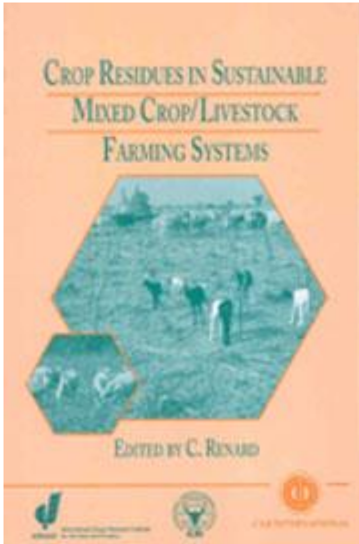

The Influence of Socioeconomic Factors on the Availability and Utilization of Crop Residues as Animal Feeds

Timothy O. Williams[1], Salvador Fernández-Rivera[1] and Timothy G. Kelley[2]
[1]*International Livestock Research Institute, ICRISAT Sahelian Center, BP 12404, Niamey, Niger*
[2]*International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India*

Abstract

The fibrous by-products resulting from crop cultivation constitute a major source of nutrients for animal production in developing countries. On small farms, they form the principal feed of ruminant livestock during the dry seasons. Concerns about inadequate utilization of available feeds have led to the establishment of research programmes to improve the nutritive value and utilization of crop residues as ruminant feed. Despite this, farmer uptake of research findings has been limited. This paper explains why. It argues that the importance of crop residues as feed differs between production systems. Differences in production goals, resource endowments and socioeconomic conditions create different opportunities for the use of crop residues. Consequently, in designing research and extension projects that seek to improve use as livestock feed, it is pertinent to identify the main livestock production systems, farmers' production objectives and resource endowments, and determine the appropriate crop-residue-based diet for each system.

Introduction

Among the constraints facing livestock production in developing countries, poor animal nutrition and productivity arising from inadequate feed supplies stands as the most important. Growing concerns about this problem have prompted researchers and development planners to search for ways to promote the more efficient utilization of available feed resources. Crop residues—the fibrous by-products which result from the cultivation of cereals, pulses, oil plants, roots and tubers—represent an important feed resource for animal production in developing countries. These residues provide fodder at low cost since they are by-products of existing crop production activities. They are important adjuncts to natural pastures and planted forages and are often used to fill feed gaps during periods of acute shortage of other feed resources. In most parts of Africa, Asia, Latin America and the Caribbean, ruminants are dependent for at least part of the year on diets based on crop residues. Sandford (1989) reported that in various parts of semiarid sub-Saharan Africa, cattle derive up to 45% of their total annual feed intake from crop residues, and up to 80% during critical periods. Thole *et al.*(1988), in a village survey carried out in western Maharashtra, India, found that sorghum stover contributes between 20 and 45% of the total dry-matter (DM) feed provided to dairy animals by small-scale farmers. Similarly, McDowell and Hildebrand (1980) indicated that, in three livestock production systems found in Latin America, crop residues contribute 30-90% of ruminant feed. Parra and Escobar (1985) highlighted the importance of crop residues as feeds in different livestock production systems of Latin America and the Caribbean, from the integrated crop/livestock systems of Central America and Caribbean countries to the ranching systems of Mexico and Venezuela and the feedlot operations of Peru.

Nonetheless, there is still a perception that the potential of crop residues as livestock feed has not been fully exploited, particularly given the expansion in arable land that has taken place in many countries. This is partly due to the fact that crop residues have low nutritive value, i.e. low contents of metabolizable energy and crude protein. Consequently, many governments in both developed and developing countries have launched research programmes to improve the nutritive value and utilization of crop residues. Emphasis in much of this work has been on improving crop residue intake and digestibility in ruminants through upgrading and/or supplementation (Sundstol and Owen, 1984; Doyle *et al.,* 1986; Little and Said, 1987; Kiran Singh and Schiere, 1993). Despite impressive animal production responses on the experiment station, farmer uptake of research findings has been minimal, partly because much less effort has been put into identifying the socioeconomic factors limiting greater utilization of crop residues and adoption of new feeding systems by smallholder farmers (Owen, 1985; Owen and Jayasuriya, 1989; Devendra, 1991, this proceedings, p. 241).

The purpose of this paper is to review and summarize the information currently available on the utilization and management of crop residues at farm level in order to identify the constraints that have hindered the practical application of research results and to identify opportunities for greater utilization of crop residues as livestock feed. It is argued that the potential for such utilization differs from one production system to another. The substantial diversity that exists between production systems in resource endowments, availability of different feeds and type and level of animal production creates different opportunities for the use of crop residues as feeds. Consequently, it is important to identify the major livestock production systems and farmers' production goals and to determine what type of crop residue-based diet is appropriate for each system.

In what follows, the relative importance of crop residues in different ruminant production systems is examined. The social and economic factors that can influence crop residue availability at the farm level are discussed, as well as the opportunities and constraints to the adoption and utilization of technologies designed to improve the feed value of crop residues. A description of emerging socioeconomic trends and their likely influence on crop residue use as livestock feed concludes the paper.

Importance in Different Production Systems

Numerous livestock production systems can be found in developing countries. Their multiplicity necessitates a system of classification to order and group similar systems for the purpose of identifying opportunities and constraints to livestock development. In a recent multi-donor initiative coordinated by the Food and Agriculture Organization of the United Nations (FAO), a classification system based on three criteria was developed: (i) the agroecological environment; (ii) the level of integration of livestock with crop production; and (iii) the availability and type of land used for livestock production (Seri *et al*., 1995). The study identified 11 livestock production systems involving monogastrics and ruminants, but the emphasis in this paper is on the nine ruminant production systems relevant to developing countries. This emphasis is justified because ruminants, with their ability to digest low-quality feeds and roughages, can utilize crop residues much more effectively than monogastrics.

Table 2.1 considers ruminant production systems in the context of the feed resources they use. These systems can be found in varying proportions in different developing regions of the world. The table indicates that the role of crop residues as livestock feed differs considerably between systems. Crop residues usually play a minor role in grass/rangeland systems, but are very important in mixed crop/livestock systems.

For analytical purposes, and to obtain a better understanding of the relative availability of other productive resources within these systems, they have been regrouped into three management systems as shown in Table 2.2. The grass/rangeland systems constitute the extensive grazing systems. Land is the principal resource in such systems, but its quality and productivity vary greatly between regions. Mixed crop/livestock systems are found in some of the most populous locations in the world. Potential labour availability in these systems is relatively high, but land and capital are less plentiful. The specialized production systems are made up of intensive enterprises, including the beef feedlots and dairy farms found in some developing countries, particularly near large urban centres. These systems are characterized by high capital inputs.

Table 2.1. Ruminant production systems and feed resources in selected countries and regions.

System	Region[1]	G/R[2]	FCs	CRs	CCs
Livestock/grassland (temperate zones, tropical highlands)	Mongolia, Parts of China S America E Africa	xxx			
Livestock/grassland (humid/subhumid tropics)	LAC (lowlands)	xxx			
Livestock/grassland (arid/semiarid tropics)	Parts of SSA WANA	xxx		x	
Mixed crop/livestock (rainfed; temperate zones, tropical highlands)	NE Asia Parts of E Africa Andean LAC (Ecuador, Mexico)	x	xx	xx	x
Mixed crop/livestock (rainfed; humid/subhumid tropics)	SE Asia LAC SSA	x	x	xxx	x
Mixed crop/livestock(rainfed arid/semiarid tropics)	WANA W Africa S Asia NE Brazil	xx	x	xxx	x
Mixed crop/livestock (irrigated; temperate zones, tropical highlands)	E Africa Parts of China	x	xx	xx	x
Mixed crop/livestock (irrigated; humid/subhumid tropics)	Parts of SE Asia (Philippines, Vietnam)		x	xxx	
Mixed crop/livestock(irrigated; arid/semiarid tropics)	WANA S Asia Mexico		xx	xxx	

[1]SSA = sub-Saharan Africa; LAC = Latin America and the Caribbean; WANA = West Asia-North Africa.
[2]G/R = grassland/rangeland; FCs = forage crops; CRs = crop residues; CCs = concentrates. The number of crosses under each feed resource indicates its relative importance.
Source: Based on Seré *et al*. (1995).

Classified in this way, it is clear that livestock production systems differ in terms of their resource availability and potential to adopt and use technologies that demand different resource inputs. The relative availability of labour and capital compared with land, the existence of other feeds and the alternative uses to which crop residues can be put are some of the factors that determine the usefulness of crop residues as feeds within a production system (Giaever, 1984). Thus, in designing research and extension projects that will seek to improve the utilization of crop residues as livestock feed, it is important to identify what sort of system is being targeted and so to determine the resources available to support the changes to be introduced.

Table 2.2. Relative resource availability in ruminant production systems of developing countries.

Management system	Relative availability of:		
	Land	Labour	Capital
Extensive grazing	High	Low	Low
Mixed crop/livestock	Low	High	Low
Specialized production	Low	Low	High

Factors Influencing Availability

Having identified the production systems where crop residues can be utilized as livestock feed, it is important to determine the amounts of different residues available within the various systems. The availability of crop residues at the farm level depends not just on production levels but also on a variety of social and economic factors. Land, crop and animal ownership patterns, cultural practices, the use of modern crop varieties and the opportunities for market and non-market exchanges all influence a farmer's access to the residues that are locally produced. Seasonal and inter-year variations in crop residue production can also have a marked effect on availability at particular times of the year. These factors are usually ignored in national and regional assessments of crop residue production. Yet they are important not only for arriving at a realistic estimate of what is available but also for identifying the constraints that might limit improved utilization.

Land Tenure and Access Arrangements

A farmer’s access to crop residues depends on the amount of land he or she owns and the institutional arrangements that exist for sharing or exchanging residues. Customary arrangements for sharing vary from country to country. In parts of sub-Saharan Africa where population pressure is low, privately cultivated fields revert to communal use after harvest so that crop residues can be freely grazed by village animals or collected by those who need them. This evens out inequality in land ownership and crop production within a village. But in areas where population density is high, access to crop residues is tightly controlled. Where farmers rely on animal manure to maintain soil fertility, they often enter into exchange relationships with pastoralists whereby the latters’ animals graze the crop residues on their fields in exchange for the manure they deposit. In Asia, where share-cropping is widely practised, different arrangements exist for sharing the grain and fodder outputs. For example, in India the share-cropper takes the entire fodder output if he or she provides the bullocks used in field work, but shares the output with the landowner on an agreed basis if the latter supplied the draught animals (Parthasarathy Rao, personal communication).

Seasonality of Production

Crop residues are seasonally produced. Most become available only after grain harvest. If they are not used immediately they have to be conserved until needed. The difficulties of handling and storing crop residues have not been given adequate attention by researchers (Hilmersen *et al*., 1984; Owen and Aboud, 1988). Devendra (1982) showed that exposure to weather decreased the nutritive value of rice straw. Other problems include pest infestation, moulding and fire risk. The combination of seasonality and storage problems creates an annual cycle of brief peaks in crop residue availability followed by long periods of scarcity. This is the case in many parts of semiarid sub-Saharan Africa, where crops are planted with the first rains in May or early June and harvesting occurs from September to November. Crop residues are plentiful for just 3 months, between December and February. By the end of the dry season, in April, they are often extremely scarce. Where the rainy season is longer or irrigation is available, farmers have much more flexibility in choosing when to grow crops. Planting is often phased to even out labour demands. As a result, a variety of crop residues may be available throughout the year.

Inter-annual fluctuations in rainfall can also affect crop residue yield, which may in turn affect the ratio between edible and non-edible fractions within residues. In northern Nigeria, van Raay and de Leeuw (1971) found a negative correlation (r = -0.92) between total crop residue yield and the edible fraction of sorghum. This was because high residue yields were associated with thicker and less edible stalks. Thus, inter-year variations in crop residue yields caused by rainfall may be partially offset by changes in the edible/non-edible ratio (Sandford, 1989).

Cultural Practices

The management practices used in the production, harvesting and processing of crops can affect the quantity and quality of crop residues. Shortage of labour often prevents farmers from harvesting crop residues. Where harvesting is done it is mainly carried out after grain harvest. Delayed harvesting can lead to greater loss of leaves and leaf sheaths—the most digestible parts of cereal straws—with a consequent reduction in nutritive value.

These factors taken together affect not only the quantity and quality of crop residues available to the farmer, but also the uses to which he or she decides to put those residues.

Alternative Uses

Besides serving as animal feed, crop residues have several other uses. In South Asia they are used as compost and mulch for crop production, bedding for livestock, a substrate for growing mushrooms, fibre for paper manufacture and as fuel. In semiarid sub-Saharan Africa, they are used to control wind erosion and in the construction of roofs, fences, granaries, beds and doormats. Research has also shown that annual incorporation of millet stover into the sandy soils of this region increases soil pH, organic matter content and exchangeable cations, and—most important—crop yields (Pichot *et al.,* 1974; Bationo *et al.,* 1995). In discussing the alternative uses of crop residues, the quantities used for these other purposes and the relative returns to different uses are important issues that need to be considered.

Few estimates are available of the amounts of crop residues used for these other purposes. Data from village surveys carried out in the dry and wet zones of western Niger showed that farmers collect on average 33 and 90 kg ha^{-1} of millet stover for non-feed use. These amounts represent approximately 2.5 and 3.5% of the average millet stover yields in the two zones respectively (Baidu-Forson, 1995). In South Korea, Im and Park (1983) reported that about 66% of the rice straw produced annually (about 7 million t $year^{-1}$) was used as a soil amendment or as fuel.

What are the relative returns to these different uses of crop residues? McIntire *et al.* (1992) modelled the "competition" between animals and crops for crop residues in Niger, Nigeria and Ethiopia, representing the semiarid, subhumid and highland tropics respectively, with varying soils, population densities and degrees of mechanization. Cattle were used in the model in

Niger and Nigeria, while cattle, draught oxen and sheep were used in Ethiopia. The results indicated that, in Niger, shifting from grazing crop residues to using them as mulch would reduce income because the yield response of pearl millet to crop residues is weak. In Ethiopia too, shifting to mulching would reduce income. In Nigeria, in contrast, it would increase income, because the yield of crop residues is high and crop response to them appears stronger. Field visits by the authors confirmed that feeding crop residues to livestock is the predominant use.

These few observations indicate that large quantities of crop residues are available for feeding to animals, but that there are other competing uses which need to be considered when promoting increased use of this resource as livestock feed.

Feeding Methods

Farmers use various methods to feed crop residues to their animals. Arranged in increasing order of labour requirements, these methods include: (i) open access to whole residues on harvested fields; (ii) harvest and removal of stalks, with subsequent open access to stubble on harvested fields; (iii) harvest and removal of stalks, with subsequent restricted access to stubble on harvested fields; (iv) transport and storage for feed or sale; and (v) harvest of thinnings from cultivated fields for selective feeding before the main harvest (McIntire *et al.,* 1992*).*

The pattern of residue use is often dictated by population density, herd management practices and level of transport and marketing infrastructure. Open access to residues occurs in areas with low population densities and where animals are herded communally. In densely populated and heavily stocked areas, farmers restrict access to crop residues. The availability of labour, large livestock populations and easy access to markets encourage the removal of crop residues from fields. Direct grazing, through either open or restricted access, allows farmers to use residues as feed without incurring storage and processing costs. This method of feeding results in low utilization rates due to trampling and spoilage, but allows for the consumption of most nutritious plant parts and the return of nutrients to the soil (Klopfenstein *et al.,* 1987*).* Methods of residue feeding that involve harvesting (i.e. cut-and-carry systems) are more demanding in terms of labour, transport and storage facilities. The returns to these methods have to be reasonably high before they appeal to farmers.

Socioeconomic and Technological Constraints

Apart from the socioeconomic factors discussed above, there are other limitations to the use of crop residues as livestock feed. In many sub-Saharan African countries, inappropriate pricing policies and overvalued exchange rates have encouraged the use of imported grains and concentrates at the expense of locally produced feeds such as crop residues (Williams, 1989*).* Another major limitation is that crop residues have low contents of metabolizable energy and crude protein, so their intake by ruminants is low. This nutritional constraint has led to the development of various technologies to improve the quality and utilization of crop residues as feed. These include: (i) crop management practices (Bartle and Klopfenstein, 1988); (ii) variety selection (Orskov, 1991); (iii) chemical (Sundstol and Owen, 1984*),* physical (Riquelme-Villagran, 1988*)* and biological (Burrows *et al.,* 1979; Latham, 1979; Kamra and Zadrazil, 1988*)* treatment; (iv) supplementation (Preston and Leng, 1987; Dixon and Egan, 1988); (v) feeding strategies, such as excess feeding or selective grazing (Owen and Aboud, 1988); (vi) genetic manipulation of rumen microbes (Armstrong and Gilbert, 1985;Ørskov and Flint, 1991; Wallace, 1994); and (vii) selection of animals better suited to the utilization of fibrous by-products (Coombe, 1981; Ørskov, 1991). Reviewing the scientific principles underlying these technologies is not within the scope of this paper. However, their potential impacts are listed in Table 2.3.

Despite positive results achieved on the experiment station, the adoption of these technologies by farmers in developing countries remains low. Table 2.4 shows some of the constraints that have hindered adoption. In many cases, high labour and/or capital requirements have been the main deterrent. The difficulty of accurately predicting animal responses to the treatment and/or supplementation of crop residues has also been cited (Owen and Jayasuriya, 1989; Jayasuriya, 1993). In general, it appears that considerable efforts have been devoted to developing technologies and not enough to investigating the resource requirements of these technologies at farm level-a major determinant of their profitability and adoption. In most cases, the economic benefits of the new technologies have not been convincingly demonstrated to farmers (Devendra, this proceedings, p. 241). Economic evaluation has too often been regarded as a secondary activity to be carried out after the technical experiments have been conducted (Potts, 1982).

Table 2.3. Technologies available for improving the yield, quality and use of crop residues, and their potential impacts.

Technology	Impact
Crop management:	
Fertilizer application	Higher yield and quality
Planting density	Higher yield
Timely harvesting	Lower losses, higher quality
Selective harvesting	Improved availability, quality
Plant breeding	Improved yield, quality
Physical treatment (chopping, grinding, etc)	Higher intake, slight decrease in digestibility, less waste
Chemical treatment	Increased digestibility, intake
Biological treatment	Increased digestibility
Supplementation	Increased digestibility, intake, nutrient supply
Residue management:	
Excess feeding	Greater selectivity (quality)
Selective grazing	Greater selectivity (quality)
Livestock selection (species and breeds)	Animals better adapted to low-quality feeds
Genetic engineering of rumen microbes	Uncertain (technology under development)

Table 2.4. Potential constraints to the adoption of technologies for improving crop residues.

Technology	Constraints		
	Labour	Capital	Other

Crop management:			
Fertilizer application	xx	xxx	Availability
Planting density	x		More nutrients needed
Timely harvesting	xx		
Selective harvesting	xxx		
Plant breeding		x	Potential trade-offs
Physical treatment	xxx	xxx	Uncertainty of animal response
Chemical treatment	xxx	xxx	Uncertainty of animal response, safety concerns, environmental pollution
Biological treatment	xxx	xxx	Variability in animal response, high technical skills needed
Supplementation	x	xxx	Availability, variability in animal Response
Residue management:			
Excess feeding	xx		Residue availability
Selective grazing	xx		Higher management skills needed
Livestock selection		xx	Multiplication of superior animals

Early economic evaluation can identify problems that might prevent adoption. Such evaluation needs to go beyond simple cost/benefit analysis of new technologies. It must identify farmers' production objectives and resource endowments, including available quantities of different feeds. And it must determine whether farmers are reluctant to adopt new technologies because these are too labour demanding, too risky, or simply not profitable enough compared with other investment opportunities.

Future Trends

Livestock production systems evolve in response to population and income growth, urbanization, and improvements in transport and marketing infrastructure. Projections for human population growth up to the year 2010 indicate an average annual growth rate of 1.4% in Asia, 1.6% in Latin America and the Caribbean, 2.2% in West Asia-North Africa and 3.1 % in sub-Saharan Africa (Alexandratos, 1995). As population pressure increases on a finite resource base, extensive grazing will become less feasible. Rapid population growth and increased demand for food will provide strong incentives for the expansion of mixed crop/livestock systems.

Most of the population increase in developing countries will occur in cities. According to projections by the World Bank (1992), urban population growth over the period 1990-2030 will average 1.6% in Latin America, 3% in Asia and 4.6% in sub-Saharan Africa. Over the same period, average annual per capita income in real terms for the developing countries as a whole is expected to more than triple, from US$ 750 to US$ 2500. However, substantial regional differences will persist, with the figure ranging from a mere US$ 400 in sub-Saharan Africa to US$ 5000 in Latin America (World Bank, 1992). Where they occur, rapid urbanization and higher incomes will encourage the consumption of livestock products and stimulate demand for higher-value products. This should spur a general increase in animal production, together with the development of more specialized production units.

In countries where inappropriate sectoral and macroeconomic policies have inhibited the growth of the livestock sector in the past, structural adjustment and macroeconomic reform can be expected to provide a boost to the sector soon, especially as price distortions and trade barriers are removed and misaligned exchange rates are corrected. The resulting increase in livestock production will increase the demand for feeds, including crop residues. The removal of government subsidies on imported feeds should stimulate demand still further, by promoting the use of local feed resources. At the same time, similar policy reforms in the crop subsector are likely to discourage food imports and encourage domestic production, increasing the availability of crop residues.

The rate at which livestock production systems intensify will vary between countries, just as it will between regions. Specific trends are difficult to predict. What is clear is that the demographic and economic changes predicted for the developing countries generally will ensure the continuing utilization of crop residues as livestock feed. The shift towards mixed crop/livestock systems that these changes are expected to create will stimulate the demand for different types of crop residues, both treated and untreated. It will then become essential to identify what type of crop residues will fit best into a particular system.

In the longer term, as economic growth progresses and transport and marketing improve, mixed crop/livestock systems will gradually evolve into more specialized production systems (McIntire *et al.,* 1992). These specialized systems will require animals of higher genetic potential and feeds of better quality to achieve higher milk yields or animal growth rates. Under these conditions, the use of low-quality crop residues will diminish. Nevertheless, there is evidence that crop residues can be a suitable feed in specialized beef (Ward, 1978; Klopfenstein *et al.,* 1987) and dairy (Klopfenstein and Owen, 1981) enterprises, particularly during phases when animal nutritional demands are lowest.

Conclusions

The greatest potential for the use of crop residues as animal feeds exists in the mixed crop/livestock systems of the semiarid and subhumid tropics. The demographic and economic changes expected in these regions will generally reinforce the importance of crop residues as feeds. However, as production systems become more specialized, crop residues are likely to be included in ruminant diets in lower proportions or only at phases of production with lower nutritional requirements. This implies varying opportunities for the use of crop residues as feeds. As a result, recommendations on feeding crop residues, and especially on upgrading their quality, should be developed for each production system only after careful consideration of the opportunities and constraints inherent in that system. The potential of crop residues as a feed resource will only be fully realized if their use proves to be economically beneficial and compatible with the resource endowments and production goals of farmers.

References

Alexandratos, N. (1995*) World Agriculture Towards 2010: An FAO Study.* John Wiley & Sons, Chichester, UK.

Armstrong, D.G. and Gilbert, H.J. (1985) Biotechnology and the rumen: A minireview. *Journal of Science, Food and Agriculture* 36: 1039-1046.

Baidu-Forson, J. (1995*)* Determinants of the availability of adequate millet stover for mulching in the Sahel. *Journal of Sustainable Agriculture* 5: 101-116*.*

Bartle, S.J. and Klopfenstein T.J. (1988) Nonchemical opportunities for improving crop residue feed quality: A review. *Journal of Production Agriculture* 1:356-362*.*

Bationo, A., Buerkert, A., Sedogo, M.P., Christianson, B.C. and Mokwunye, A.U. (1995) A critical review of crop-residue use as soil amendment in the West African semiarid tropics. In: Powell, J.M., Fernández-Rivera, S., Williams, T.O. and Renard, C. (eds), *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of sub-Saharan Africa, vol. 2:* Technical Papers. Proceedings of an International Conference, *22-26* November *1993,* International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia, pp. 305-322.

Burrows, L, Seal, K.J. and Eggins, H.O.W. (1979) The biodegradation of barley straw by *Coprinus cinereus* for the production of ruminant feed. In: Grossbard, E. (ed.), *Straw Decay and its Effect on Disposal and Utilization.* John Wiley & Sons, Chichester, UK, pp 147-154.

Coombe, J.B. (1981) Utilization of low-quality residues. In: Morley, F.W.H. (ed.), *Grazing Animals.* World Animal Science, B1. Elsevier, Amsterdam, The Netherlands, pp. 319-334.

Devendra, C. (1982) Perspectives in the utilization of untreated rice straw by ruminants in Asia. In: Doyle, P.T. (ed.), *The Utilization of Fibrous Agricultural Residues as Animal Feeds.* University of Melbourne, Parkville, Victoria, Australia, pp. 7-26.

Devendra, C. (1991) Technologies currently used for the improvement of straw utilization in ruminant feeding systems in Asia. In: Romney, D.L., Ørskov, E.R. and Gill, M. (eds), *Utilization of Straw in Ruminant Production Systems.*Proceedings of a Workshop, 7-11 October 1991, Natural Resources Institute and Malaysian Agriculture Research and Development Institute, Kuala Lumpur, pp. 1-19.

Dixon, R.M. and Egan, A.R. (1988) Strategies for optimizing use of fibrous crop residues as animal feeds. In: Dixon, R.M. (ed), *Ruminant Feeding Systems Utilizing Fibrous Agricultural Residues.* Proceedings of the Seventh Annual Workshop of the Australian-Asian Fibrous Agricultural Residues Research Network. International Development Program of Australian Universities and Colleges (IDP), Canberra, pp. 11-26.

Doyle, P.T., Devendra, C. and Pearce, G.R. (eds) (1986) *Rice Straw as a Feed for Ruminants.* International Development Program of Australian Universities and Colleges (IDP), Canberra.

Giaever, H. (1984) The economics of using straw as feed. In: Sundstol, F. and Owen, E. (eds), *Straw and Other Fibrous By-products as Feed.* Elsevier, Amsterdam, The Netherlands, pp. 558-574.

Hilmersen, A., Dolberg, F. and Kjus, O. (1984) Handling and storing. In: Sundsttel, F. and Owen, E. (eds), *Straw and Other Fibrous By-products as Feed.* Elsevier, Amsterdam, The Netherlands, pp. 25-44.

Im, K.S. and Park, Y.I. (1983) Animal Agriculture in Korea. Mimeo, the Asian Australasian Association of Animal Production Societies, Department of Animal Sciences, College of Agriculture, Seoul National University, Korea.

Jayasuriya, M.C.N. (1993) Use of crop residues and agroindustrial by-products in ruminant production systems in developing countries. In: Gill, M., Owen, E., Pollott, G.E. and Lawrence, T.L.J. (eds), *Animal Production in Developing Countries.* Occasional Publication No. 16, British Society of Animal Production, pp. 47-55.

Kamra, D.N. and Zadrazil, F. (1988) Microbiological improvement of lignocellulosics in animal feed production: A review. In: Zadrazil, F. and Reiniger, P. (eds), *Treatment of Lignocellulosics with White Rot Fungi.* Elsevier Applied Science, London, UK, pp. 56-63.

Kiran Singh and Schiere, J.B. (eds) (1993) *Feeding of Ruminants on Fibrous Crop Residues: Aspects of Treatment,, Feeding, Nutrient Evaluation, Research and Extension.* Proceedings of a Workshop, 4-8 February 1991, National Dairy Research Institute (NDRI)-Karnal. Indian Council of Agricultural Research (ICAR), New Delhi, India.

Klopfenstein, T. and Owen, F .G. (1981) Value and potential use of crop residues and by-products in dairy rations. *Journal of Dairy Science* 64: 1250-1268.

Klopfenstein, T., Roth, L., Fernández-Rivera, S. and Lewis, M. (1987) Corn residues in beef production systems. *Journal of Animal Science* 65: 1139-1148.

Latham, M.J. (1979) Pre-treatment of barley straw with white-rot fungi to improve digestion in the rumen. In: Grossbard, E. (ed.), *Straw Decay and its Effect on Disposal and Utilization.* John Wiley & Sons, Chichester, UK, pp. 131-137.

Little, D.A. and Said, A.N. (eds) (1987) *Utilization of Agricultural By-products as Livestock Feeds in Africa.* Proceedings of the African Research Network for Agricultural By-products (ARNAB) Workshop, September 1986, Blantyre, Malawi. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

McDowell, R.E. and Hildebrand, P .E. (1980) Integrated Crop and Animal Production: Making the Most of Resources Available to Small Farms in Developing Countries. Working Paper, The Rockefeller Foundation, New York, USA.

McIntire, J., Bourzat, D. and Pingali, P. (1992) *Crop/Livestock Interaction in subSaharan Africa.* World Bank Regional and Sectoral Studies, Washington DC, USA.

Ørskov, E.R. (1991) Manipulation of fibre digestion in the rumen. *Proceedings of the Nutrition Society* 50: 187-196.

Ørskov, E.R. and Flint H.J. (1991) Manipulation of rumen microbes or feed resources as methods of improving feed utilization. In: Hunter, A.G. (ed.), *Biotechnology in Livestock in Developing Countries.* University of Edinburgh, pp. 123-138.

Owen, E. (1985) Crop residues as animal feeds in developing countries: Use and potential use. In: Wanapat, M. and Devendra, C. (eds), *Relevance of Crop Residues as Animal Feeds in Developing Countries.* Funny Press, Bangkok, Thailand, pp. 25-42.

Owen, E. and Aboud, A. (1988) Practical problems of feeding crop residues. In: Reed, J.D., Capper, B.S. and Neate, P J.H. (eds), *Plant Breeding and the Nutritive Value of Crop Residues.* Proceedings of a Workshop, 7-10 December*1987,* International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia, pp. 133-155.

Owen, E. and Jayasuriya, M.C.N. (1989) Use of residues as animal feeds in developing countries. *Research and Development in Agriculture* 6: 129-138*.*

Parra, R. and Escobar, A. (1985) Use of fibrous agricultural residues in ruminant feeding in Latin America. In: Preston, T.R., Kossila, V .L., Goodwin, J. and Reed, S.D. (eds), *Better Utilization of Crop Residues and By-products in Animal Feeding.* Proceedings of the FAO/ILCA Expert Consultation, *5-9* March *1984,* International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia, pp. 81-98.

Pichot, J., Burdin, S., Charoy, J. and Nabos, J. (1974) L'enfouissement des pailles de mil *Pennisetum* dans les sols sableux dunaires: Son influence sur les rendements et la nutrition minérale du mil; son action sur les caractéristiques chimiques du sol et la dynamique de 1'azote minéral. *Agronomie Tropicale* (Paris) 29: 995-1005.

Potts, G.R. (1982) Application of research results on by-product utilization: Economic aspects to be considered. In: Kiflewahid, B., Potts, G.R. and Drysdale, R.M. (eds), *By-product Utilization for Animal Production.* Proceedings of a Workshop on Applied Research, 26-30 September 1982, Nairobi, Kenya. International Development Research Centre (IDRC), Ottawa, Canada, pp.116-127.

Preston, T.R. and Leng, R.A. (1987) *Matching Livestock Production Systems to Available Resources.* Penambul Press, Armidale, New South Wales, Australia.

Riquelme-Villagrán, E. (1988) Feed processing technologies to increase nutritive values. In: *Proceedings of the Sixth World Conference on Animal Production,* 27 June-1 July 1988, Helsinki, Finland, pp. 72-84.

Sandford, S. (1989) Crop residues/livestock relationships. In: Renard, C., Vandenbeldt, R.C. and Parr, J.F. (eds), *Soil*, *Crop and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone.* Proceedings of an International Workshop, 11-16 January 1987, ICRISAT Sahelian Centre, Niamey, Niger. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, pp. 169-182.

Seré, C., Steinfeld, H. and Groenewold, J. (1995) World livestock systems: Current status, issues and trends. In: Gardiner, P and Devendra, C. (eds), *Global Agenda for Livestock Research.* Proceedings of a Consultation, 18-20 January 1995, International Livestock Research Institute (ILRI), Nairobi, Kenya, pp. 11-38.

Sundstol, F. and Owen, E. (eds) (1984) *Straw and Other fibrous By-products as Feed.* Developments in Animal and Veterinary Sciences 14, Elsevier, Amsterdam, The Netherlands.

Thole, N.S., Joshi, A.L. and Rangnekar, D.V. (1988) Feed availability and nutritional status of dairy animals in western Maharaashtra. In: Kiran Singh and Schiere, J.B. (eds), *Fibrous Crop Residues as Animal Feed.* Indian Council of Agricultural Research (ICAR), New Delhi, pp. 207-212.

van Raay, J.G.T. and de Leeuw, R.N. (1971) *Rural Planning in a Savanna Region.* The University Press, Rotterdam, The Netherlands.

Wallace, R.J. (1994) Rumen microbiology, biotechnology and ruminant nutrition: Progress and problems. *Journal of Animal Science* 72: 2992-3003.

Ward, J.K. (1978) Utilization of corn and grain sorghum residues in beef cow forage systems. *Journal of Animal Science* 46: 831-840.

Williams, T.O. (1989) *Livestock Development in Nigeria: A Survey of the Policy Issues and Options.* ALPAN Paper No. 21, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

World Bank (1992) *World Development Report 1992.* Oxford University Press, New York, USA.

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Sources:

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http://www.ilri.org/InfoServ/Webpub/fulldocs/CropResidues/TableofContents.htm