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REVIEW

Use of crop residues as animal feeds in developing countries

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Summary

Development and application of modern technology for upgrading straw in Europe during the 1970's has stimulated intense interest in developing countries. Since 1980, twenty four international workshops have been held in Africa and Asia to consider research and development on crop residues as feed, with emphasis on improving their intake and digestibility in ruminants by treatment with ammonia generated from urea and/or supplementation. Despite much research and development at universities and experiment stations, farmer-uptake of the findings has been minimal. Reasons for this are manifold, but include difficulties of transporting and storing crop residues, insufficient trials at farmer-level demonstrating obvious economic benefits from treatment and supplementation, inappropriate technology and near-absence of agricultural extension services. The annual dry matter production of 2.0 t crop residue per 500 kg livestock unit in developing countries is a vast resource which is currently underutilised. Future population pressure in developing countries will require greater utilisation of crop residues as animal feed; hopefully ways of applying the recent research findings will be found.

Key words: crop residue — developing country — feed — research — ruminant — treatment — supplement — workshop

Introduction

'Crop residues' has become the used term in tropical research and development circles for describing the fibrous by-products of cereals, sugarcane, roots and tubers, pulses, oilseeds, oilplants, vegetables and fruits. With notable exceptions e.g. sugar beet pulp and citrus pulp, crop residues have in common the fact that they are of low nutritive value as feed for ruminants and have little or no feed value for non-herbivores.

Utilisation of crop residues as feed has been the subject of intense research and development worldwide since the mid 1970s. It began with technological developments for upgrading straw in Europe and North America and then moved rapidly to the developing tropics where something akin to a 'Residue Revolution' has taken place in the 1980's. Despite this there appears little evidence that the large research effort has resulted in greater utilisation of crop residues in developing countries.

The purpose of the paper is to examine why this is so and identify what needs to be done to achieve greater farmer-uptake of research findings. Developed-country technology is briefly reviewed along with developing-country research and development, in order to provide the historical background. Production of crop residues and their possible use as feed in developing countries are considered to illustrate the enormous feed-resource they represent. This is followed by a discussion of factors considered to have hindered the practical application of research and development findings.

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Developed-country technology for upgrading straw

The search for ways of overcoming the low nutritive value of cereal straw has a long history (e.g. Lehman 1891); and the fact that straw has a low feed value has been acknowledged for centuries. A practical method for treating straw with sodium hydroxide to improve its digestibility and intake was devised by Beckmann in Germany during World War One (see Homb 1984). The Bekmann Method was practised on farms in Europe during periods of acute fodder shortage due to war (1939–45) or poor grass-growing climate (e.g. in Norway 1940–1970). The 1970's revival of interest in straw upgrading followed publications by Lampila (1963) and Wilson and Pigden (1964). These described 'dry-treatment' of straw with sodium hydroxide which overcame some of the disadvantages of the Beckmann Method, in particular the high water-requirements and leaching losses. Commercial application of the improved sodium hydroxide-treatment-method occurred during the 1970s in Europe, especially in Denmark and the UK. Treatment was both on farms (Wilkinson 1984) and in industrial plants (Rexen and Bach Knudsen 1984; Wilson and Brigstocke 1977).

Research and development on treatment of straw with ammonia occurred from the mid-1970s, particularly in Norway (Sundstol *et al.* 1978; Sundstol and Coxworth 1984). Ammonia treatment of straw on farms became popular in many European countries in the 1980s. Compared to sodium hydroxide, ammonia is slightly less effective in improving digestibility, but its gaseous form eliminates the need for physical processing of straw to enable admixture with the chemical. Ammonia has a further advantage over sodium hydroxide in that it also improves the nitrogen content of the straw thus reducing the need for nitrogen supplementation when feeding it.

In vitro digestible organic matter contents (Tilley and Terry 1963) of barley and wheat straw are increased from around

Table 1 Developed-country Workshops/conferences on treating straws etc to improve their nutritive value for ruminants

Date	Venue	Reference/Organisation
1981	UK	OECD 1981
1981	UK	Stark & Wilkinson 1981
1982	UK	Anon 1982
1983	UK	OECD 1984
1984	UK	Anon 1984
1984	UK	MAFF 1984a
1984	Denmark	Carlesberg Research Centre 1984
1984	FRG	OECD 1985
1986	Belgium	Verstraete *et al* 1988
1987	France	Cost 84 bis*
1987	UK	Hartley *et al.* 1987
1988	UK	Cost 84 bis*

*EEC, European Scientific Technical Cooperation — Working group on use of cellulosic wastes as feed.

400 g/kg dry matter (DM) to 500–600 with sodium hydroxide treatment, and to 500–550 with ammonia treatment. Treatment also raises voluntary intake of straw by up to 80 and 30% in sheep and cattle respectively (Alderman and Mason 1984).

Straw utilisation and upgrading has attracted much research and development interest. It has been the subject of many conferences (Table 1) and reviews (Table 2), such that in Europe at least, it is an example of research and development culminating in practical application, as discussed by Greenhalgh (1983). Wilkinson (1985) highlighted the large number of commercial organisations in the UK marketing technical services for improving the utilisation of straw as feed.

However the extent to which straw is used as a feed and whether or not it is treated is variable because ultimately it depends on whether its use is economic (Giaever 1984). It is notable that in the USA, the research and development on straw upgrading has not gained practical application because of the availability of cheaper feeds (i.e. lower cost per unit of metabolisable energy).

It should be noted that in Europe, cereal straw is largely the only poor-quality crop residue available and therefore researched. This contrasts with the situation in the developing tropics and sub-tropics where a range of crop residues have been, and are, under consideration.

Table 2 Reviews on treating straws etc to improve their nutritive value for ruminants.

Author	Year
Owen	1976
Balch	1977
Jackson	1977
Jackson	1978
Klopfenstein	1978
Owen	1979
Greenhalgh	1980
Huber	1981
Wilkins	1981
Greenhalgh	1984
MAFF	1984b
Sundstol & Owen	1984
Doyle *et al.*	1986a
Riquelme-Villagran	1988

Developing-country research and development

As noted earlier, interest in crop residues as feed in the developing tropics and sub-tropics has been enormous. This is understandable as inadequate nutrition of man and animal is a major limiting factor in these regions. Large numbers of multi-purpose ruminants and large quantities of low-quality roughages (crop residues and dry-season standing hay) are dominating features. In India, Bangladesh and other Asian countries there is a long tradition of having to rely on crop residues for ruminant feeding (Verma and Jackson 1984). The fact that crop residues can be upgraded by low-technology treatments such as ammonia generated from fertiliser urea (Sundstol *et al.* 1978: Ahmed and Dolberg 1980) has had a major influence in accelerating research and development on the subject in the tropics. A further stimulator of interest has been the realisation that supplementation of crop residues (Preston and Leng 1980) has a vital role to play in maximising their utilisation. Several of the early reviews listed in Table 2 (e.g. Balch 1977; Jackson 1977; Jackson 1978) also stressed the relevance of crop residues and their treatment for improving the feeding of ruminants in developing countries where periods of acute fodder-shortage due to drought etc. are common-place.

Since 1980 a large number of papers on the subject have been published in scientific journals (see reviews by Sundstol and Owen 1984 and Doyle *et al.* 1986a). Research networks were established for Asia (Australian-Asian Fibrous Agricultural Residues Research Network, Melbourne University) and Africa (African Research Network for Agricultural By-products, International Livestock Centre for Africa, Addis Ababa). The number of institutions researching by-product utilisation is now large (FAO 1982a).

An indication of the size of the 'Residue Revolution' can be seen by the many workshops that have been held to consider the subject (Table 3). Several of the workshops have been the outcome of research networks. Table 3 also shows the many organisations that have been sponsoring the activities. Development of the subject has also been encouraged by FAO (FAO 1982b; FAO 1982c).

Production of crop residues in developing countries

The most recent global estimates of annual production of crop residues are those of Kossila (1984: 1985). Earlier estimates were made by Owen (1976) and Balch (1977). A common feature is that by-product is estimated from FAO statistics for the primary product such as grain, using multipliers which assume given grain: straw ratios. The uncertainty of these ratios can be judged by the different multipliers used by Owen (1976) (e.g. 2:1 straw: grain for maize) and Kossila (1984) (e.g. 3:1 straw: grain for maize). This stems from the remarkable lack of reliable information on yields of by-products, for example straw in relation to grain. This in turn reflects the past preoccupation with the primary product and lack of interest in by-products shown by cereal breeders and agronomists. Hopefully this will change in the future. The FAO (1982b) and others (e.g. ARNAB 1984) are engaged in collecting more reliable information on the production of crop residues.

Notwithstanding the case for more reliable data, Table 4 shows the enormous quantity of crop residue produced annually in different regions. Quantities produced in individual countries have also been estimated (Kossila 1985).

Cereal by-products represent about two thirds of the crop residues produced, particularly in Asia, Africa and the

Table 3 Recent international workshops on feeding crop-residues and by-products in developing countries

Date	Venue	Sponsor	Reference
01.80	Bangladesh	DANIDA	
10.80	Cameroon	ILCA	
01.81	Tanzania	NORAD	Kategile *et al.* 1981
02.81	Bangladesh	DANIDA.IDRC ODA.ADAB	Jackson *et al.* 1981
05.81	Philippines	ADAB*	Pearce 1983
09.81	Senegal	FAO.ILCA†	
02.82	Bangladesh	DANIDA.ADAB ODA.USAID	Preston *et al.* 1982
05.82	Malaysia	ADAB*	Doyle 1982
09.82	Kenya	IDRC	Kiflewahid *et al.* 1983
03.83	Egypt	NORAD.IDRC ODA. IUNS	
04.83	Sri Lanka	ADAB* Netherlands	Doyle 1984
05.83	Bangladesh	DANIDA.ADAB	Preston *et al.* 1983
03.84	Ethiopia	FAO.ILCA	Preston *et al.* 1985
04.84	Thailand	ADAB*	Doyle 1985
11.84	Thailand	IFS	Wanapat & Devendra 1985
04.85	Indonesia	ADAB*	Dixon 1986
10.85	Egypt	IDRC. ILCA†	Preston and Nuwanyakpa 1986
03.86	Austria	FAO.IAEA	IAEA 1987
03.86	Sri Lanka	Netherlands	Ibrahim and Schiere 1986
04.86	Philippines	ADAB*	Dixon 1987
09.86	Malawi	IDRC.ILCA†	Little and Said 1987
01.87	India	India and Netherlands	Sing *et al.* 1987
10.87	Cameroon	IDRC.ILCA†	Said and Little 1988
12.87	Ethiopia	ILCA	Reed *et al.* 1988

ADAB Australian Development Assistance Bureau.
DANIDA Danish International Development Agency.
FAO Food and Agriculture Organisation of the United Nations.
IDRC International Development Research Centre (Canada).
ILCA International Livestock Centre for Africa.
IUNS International Union of Nutritional Science.
NORAD Norwegian Agency for International Development.
ODA Overseas Development Administration (UK).
SAREC Swedish Agency for Research Cooperation with Developing Countries.
USAID United Stated Agency for International Development.

*Austrailian-Asian Fibrous Agricultural Residues Research Network.
†African Research Network for Agricultural By-products.

Table 4 Estimated production of fibrous by-products from cereals and other crops in relation to livestock units (Kossila 1984)

		Total dry matter (DM) produced Millions of tonnes of DM (*)		Total livestock units † Millions (‡)		By-product per livestock unit of 500kg Tonnes DM
Africa	1970	278.3	(66.5)	145.7	(4.4)	1.9
	1981	343.6	(68.8)	165.8	(5.5)	2.1
North and Central America	1970	717.4	(65.0)	202.6	(16.9)	3.5
	1981	1193.4	(68.6)	217.8	(17.9)	5.5
South America	1970	221.9	(56.3)	185.8	(7.1)	1.2
	1981	380.3	(48.2)	222.7	(8.6)	1.7
Asia	1970	1245.0	(66.9)	476.8	(12.6)	2.6
	1981	1628.9	(68.4)	551.7	(17.1)	3.0
Europe	1970	403.0	(63.7)	193.1	(29.4)	2.1
	1981	504.3	(67.4)	215.2	(33.7)	2.3
Oceania	1970	32.1	(61.1)	53.5	(2.4)	0.6
	1981	53.2	(67.7)	52.2	(3.3)	1.0
USSR	1970	358.1	(65.9)	120.9	(21.5)	3.0
	1981	320.4	(66.7)	148.5	(26.1)	2.2
Developed§	1970	972.9	(67.3)	361.6	(20.1)	2.7
	1981	1515.2	(69.8)	380.5	(22.4)	4.0
Developing‖	1970	1249.9	(59,6)	707.6	(5.6)	1.8
	1981	1679.8	(59.5)	812.0	(6.8)	2.1
Centrally¶ planned	1970	1033.0	(69.8)	309.2	(27.8)	3.3
	1981	1228.9	(72.0)	381.3	(35.0)	3.2
World	1970	3255.8	(65.2)	1378.4	(14.4)	2.4
	1981	4423.9	(66.5)	1573.8	(17.4)	2.8

*Percentage from cereals.
†One unit corresponds to 500 kg live weight and includes grass eaters (horses, mules, asses, cattle, buffaloes, camels, sheep, goats) and grain eaters (pigs, poultry).
‡Grain eaters, percentage of total.
§As defined by FAO, i.e. North America, Western Europe, Australia, New Zealand, Israel, Japan, South Africa and Centrally Planned Eastern Europe and USSR.
‖As defined by FAO, i.e. Africa (excluding South Africa), Latin America, Near East, Far East and Centrally Planned Asia.
¶As defined by FAO, i.e. Asia (China, Kampuchea, North Korea, Mongolia, Vietnam) Eastern Europe and USSR.

Developed regions. Quantities produced have increased substantially from 1970 to 1981 by 23 and 31 per cent in Africa and Asia, and by over 50 per cent in Developed regions. Quantities of crop residue in relation to livestock units are also shown in Table 4; these show less of an increase from 1970 to 1981. It is notable that annual production amounts to about 2000 kg DM/500 kg live-weight livestock unit in developing countries as a whole, with the figure being 3000 kg DM/unit in Asia. Also evident is the fact that ruminants make up about 90 per cent of the livestock units in Africa and Asia. The 2000 kg DM/livestock unit of crop residue generated each year in developing countries would provide maintenance requirements for 6 months if the animals could be persuaded to consume 22 g DM/kg live weight of crop residue daily. Of course this rate of intake would not be achieved with untreated crop residue fed alone, but the figure serves to demonstrate the enormous magnitude of the feed resource represented by crop residues. Following the FAO technical consultation in 1976 on new feed resources (FAO 1977), Devendra (1981) also undertook an assessment of non-conventional feed resources in Asia and the Far East. His report considers non-conventional sources of protein as well as fibrous crop residues, and further illustrates the large quantity and diversity of by-products generated in the region.

Potential use as feed

Cereal straws and other crop residues are characterised by low digestibility (<50 per cent), hence low metabolisable energy content (< 7.5 MJ/kg DM), low crude protein content (< 60 g/kg DM), low intake (10–20 g/kg live weight daily) and low content of available minerals and vitamins (Nicholson 1984; Doyle *et al* 1986a). As sole feeds they are therefore considered too poor, even, to maintain adult ruminants (Figure 1).

Experiments demonstrating the possible improvements in production due to treating and/or supplementing crop residues are shown in Tables 5 to 9. In general the production improvements are large, and are associated with increased digestibility and intake of the crop residue. A common feature is the low level of productivity of animals on control treatments. This typifies the problems with such feeds and indeed that of production levels in general. These experiments were chosen because they demonstrate production responses. In view of the large gut-fill of *Bos indicus* cattle fed high-roughage diets

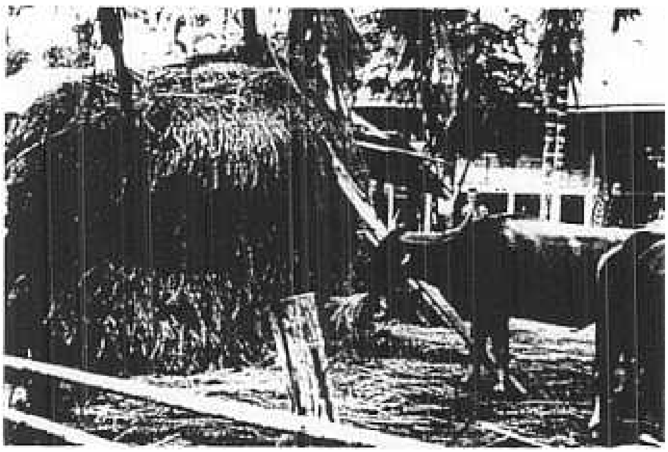

Figure 1 Traditional feeding of rice straw to water buffaloes in Thailand. (Photo: Dr M Wanapat).

(Saadullah 1986), the results would be more convincing if they also reported carcass gains in the case of growing animals. The experiments by Wanapat *et al.* (1984) (Table 7) and Leng (1984) (Table 9) involved too few replicates. This criticism also applies to many of the experiments reported in the workshops cited in Table 3, and is symptomatic of the constraints researchers are often working under in developing countries.

Criticisms notwithstanding, the data in Tables 5 to 9 are impressive, and illustrate the potential of treated and supplemented crop residues as feeds for ruminants in developing countries.

Factors limiting greater use as feed

The issuing of recommendations concerning research and development needs is a feature of the numerous workshops (Table 3) that have been held. The similarity of the recommendations from each workshop suggests general agreement on what further action is needed. However, the fact that each successive workshop feels obliged to make the same

Table 5 The effect on growth of Sahiwal heifers of ammonia treating rice straw by urea-ensiling* (Perdok *et al* 1982)

	Untreated straw	Treated straw
Number of heifers	17	17
Intake†		
Straw (kg DM/d)	2.09	2.84
Total (kg DM/d)	3.84	4.59
Total (kg DM/100 kg live weight.d)	2.31	2.58
Live weight		
Initial (kg)	165	167
Final (kg)	170	191
Daily gain over 70 d (g/d)	73	346
Feed conversion rate		
(kg food DM/kg live-weight gain	53	13

*Paddy straw (900 g DM/kg) sprayed with 1.0 litres/kg of 40 g/kg urea solution and ensiled in polythene bags for at least 28 d.
†Straw fed *ad libitum* with daily supplements of 6.0 kg grass silage, 0.5 kg concentrate, 20 g minerals and 20 g sodium sulphate.

Table 6 The effect of supplementing untreated or ammonia-treated* rice straw with gliricidia (*Gliricidia maculata*) forage for lactating water buffaloes in Sri Lanka (Perdok *et al* 1982)

Rice straw	Untreated		Treated	
Gliricidia supplement	No	Yes	No	Yes
Cow data†				
DM intake (g/kg live weight d)	28	28	37	40
Live-weight change (g/d)	−93	+59	+59	+126
Milk yield‡ (kg/d)	2.17	2.56	2.97	3.35
Milk fat (%)	6.71	6.94	7.54	7.62
Milking after 84 d (%)	60	90	100	90
Calf data				
Daily gain over 70 d (g/d)	165	265	295	344
Milk intake (kg/d)	0.95	1.03	1.03	1.15

*Treatment as in Table 5.
†All cows also received 1.0 kg/d concentrate and minerals.
‡Effects due to straw treatment and to gliricidia were significant at $P < 0.01$

Table 7 The effect of ammonia-treating (urea-ensiling) rice straw and supplementing with water hyacinth (*Eichhornia crassipes*) for buffaloes and cattle in Thailand (Wanapat *et al.* 1984)

	Untreated straw	Treated* straw	Treated straw plus water hyacinth†
Buffalo‡			
DM intake (g/kg WO.75.d)	78.8	88.2	111.1
Live-weight change (g/d) over 110 d	−182	+79	+232
Native cattle§			
DM intake (g/kg WO.75.d)	86.6	88.6	86.8
Live-weight change (g/d) over 110 d	−34	+7	+133

*Chopped paddy straw (927 g DM/kg) sprayed with 1.0 litres/kg of 50 g/kg urea and 3 g/kg salt solution and ensiled under polythene sheets for 21 d.
†Chopped paddy straw mixed with chopped water hyacinth (sun-dried to 400 g DM/kg) (3:1 DM basis) and sprayed with 1.0 litres/kg mix of 50 g/kg urea and 3 g/kg salt solution and ensiled under polythene sheet for 21 d.
‡Two-year old animals of initial weight 200 kg; 3/treatment.
§Steers of initial weight 125 kg; 3/treatment.

Table 8 The effect of ammonia treatment of maize cobs and maize stover for growing sheep in Kenya (Tubei and Said 1981)

Treatment*	Digestibility of diet DM (%)	Crop residue intake (g DM/d)	Live-weight gain over over 91 d (g/d)
Maize cobs†			
Untreated	55.0	359	79
Treated	61.2	634	130
Maize stover‡			
Untreated	56.1	338	62
Treated	58.9	434	89

*Dorper intact males of initial age 6–8 months and initial weight 28.5 kg were used. The growth trial involved 10/treatment and the digestibility trial 3/treatment. Crop residues were fed *ad libitum*. Concentrate supplement was fed at 40 g/d.
†Cobs were ground through 6 mm screen. Treatment involved adding water to cobs (to achieve 200 g DM/kg), adding 35 g/kg cob DM of anhydrous ammonia and storing in sealed plastic bags for 42 d.
‡Treatment was by injecting 40 g/kg stover DM of anhydrous ammonia into a stack of baled stover enclosed in plastic. The stack was kept sealed for 42 d.

Table 9 The effect of supplementing chopped rice straw using molasses/urea block and concentrate for growing water buffalo in the Philippines (Leng 1984).

Treatment*	Straw intake (kg/d)	Concentrate intake (kg/d)	Molasses block intake (g/d)	Live-weight change (g/d)
Nil			0	0
Molasses/urea block			380	69
Molasses/urea block† plus concentrate‡	4.0		280	161

*The Carabao calves were of initial weight 100 kg; 3/treatment; all animals had access to mineral blocks.
†Containing (g/kg): molasses, 480; urea, 150; rice bran, 240; bentonite, 60; minerals, 70.
‡Containing (g/kg): copra meal, 500; rice bran, 500.

pleas also demonstrates that little progress is being made. The recommendations are therefore pointers to factors hindering farmer-uptake of the technology. Various of the workshops have identified the need to:

1 Undertake comprehensive inventories of available crop residues; define (and develop methods of defining) their characteristics.
2 Develop village-level application commensurate with the overall strategy of integrated farming systems.
3 Develop treatment methods for crop residues which combine appropriate technology and economics.
4 Identify methods of supplementing low quality roughages, with emphasis on local resources and economics.
5 Use satisfactory experimental techniques, including appropriate statistical designs.
6 Undertake basic research to improve the feeding value of by-products *per se*, e.g. study of cell-wall chemistry, plant breeding.
7 Promote faster and effective interchange of information, both within and between countries.

1 Crop residue inventories

The global assessment of production made earlier (Table 4) illustrates the magnitude of the crop residue resource, but it lacks the detail needed concerning production patterns within countries. Absence of such detail on the production and feeding of crop residues was noted earlier by Owen (1976, 1980) and Devendra (1981), and this was evident in the results of the survey undertaken by FAO (FAO 1982b). Clearly questions such as when and where residues are produced need answering, as do questions relating to when, where and for what animals the residues are needed as food. Such information is needed for each farming system/ecological zone in each country. The process of gathering such information is now underway in many developing countries, as evidenced by reports to the workshops cited in Table 3.

Two factors emerging as contributors to the low utilisation of crop residues as feed are the large year to year variation in production and the seasonality of production. Experience in Sri Lanka and Bangladesh shows that the years when crop residues are particularly needed as feed during the dry season because of lack of standing hays, are also generally the years when crop residues are particularly scarce due to crop failure. In these situations crop residues are likely to be expensive, and the application of a technology whose success depends on increasing intake and therefore the amount of crop residue used will have little appeal.

Crop residues are seasonally produced. The time of production is usually such that they need to be conserved for when required as feed. In general, countries of the developing tropics have no history of conserving fodders for ruminants, except in the form of standing hays. Conserving crop residues is therefore a new concept in many situations. The difficulties of storing and handling them have been largely overlooked by researchers (Hilmersen *et al.* 1984; Owen and Aboud 1988). Difficulties include lack of space (on small farms), weather-proofing, pest infestation and fire risk. Nevertheless there are examples of well-developed systems of storing straws, e.g. Ethiopian Highlands, Bangladesh and Thailand.

Site of producing crop residues has a major bearing on usage, particularly regarding whether they are field-produced (e.g. cereal straws) or centrally-produced as a by-product of an industrial process (e.g. sugar-cane bagasse).

Field-produced crop residues are used as crop mulches and animal bedding as well as animal feed. The conventional method of feeding crop residues in many situations is to graze them *in situ* (stubble grazing), but this is associated with low utilisation rates due to trampling and spoilage (Chandler 1983). Crop residues are frequently burnt as a means of disposal, because it is impractical and uneconomic to transport them to where they could be used by ruminants. The bulky nature of residues such as straw makes them particularly expensive to transport, even over short-distances. In many Asian countries farmers and their animals live in villages which are some distance from the crop fields. Futhermore, in rice growing areas, e.g. Sri Lanka, the paddy fields are often only linked to the homesteads by narrow footpaths along the paddyfield bunds (dykes), so that the only means of transport is by foot. The limited use of crop residues as feeds in such situations is understandable.

Animal agriculture and crop cultivation are often completely divorced, e.g. sugar-cane plantations with no associated animal enterprises. Centrally-produced crop residues, as pointed out by Devendra (1981), have the potential advantage of not suffering transport costs, providing they can be utilised at the processing plant. Currently they are often burnt to fuel the factory, e.g. bagasse and rice hulls. Their use for feeding animals adjacent to the plants is hampered by the peri-urban location of many of the plants. FAO (1982b) also point to agro-industrial by-products being more likely to attract investment to develop their utilisation because of the large quantities available at one point and the existence of an infrastructure in which to apply 'industrial' processes. Nevertheless respondents to surveys (FAO 1982b; Devendra 1981) talked of the difficulties of attracting investment capital for processing plants. These were thought to be due to: (a) lack of technical and economic feasibility studies; (b) absence of economic incentives; (c) lack of assured markets for 'processed' by-products; (d) shortage of funds to undertake research and development; (e) lack of skilled manpower and scientists and (f) community predjudices.

A result of preparing crop residue inventories is the realisation that there is considerable range in nutritive value, both within and between crop residues. This is particularly so for cereal straws, as evidenced by research in Syria (Capper *et al.* 1985), Australia (Pearce 1984) and Sri Lanka (Sannasgala and Jayasuriya 1984). Large variation in the quality of temperate cereal straws has also been reported (Hartley *et al.* 1984; Jewell and Campling 1986; Kernan *et al.* 1984; Reid *et al.* 1988). A consequence of the variation in nutritive value of crop residues is that production responses to treatment and/or supplementation of the kind shown in Tables 5–9 are inconsistent, though in general, response is inversely related to quality (Doyle *et al.* 1986b). Variation in nutritive value and the difficulty of accurately predicting animal production response to treatment and/or supplementation of crop residues (MAFF 1984a; Preston *et al.* 1985; Devendra 1981) have doubtless contributed to the low farmer-uptake of research and development findings in developing countries.

Another issue to emerge from characterising crop residues is appreciation of the anti-nutritional influence of phenolic pigmentation in some varieties of sorghum and millet stovers (Reed *et al.* 1987). It is ironic that breeding grain for bird resistance has seemingly created crop residues of lower nutritive value (Reed *et al.* 1987). Large differences in the nutritive value of African fodder trees when used as supplements to straw have also been reported (Reed and Soller 1987). Much of the difference can be explained by the presence of high levels of polyphenolic compounds, but sheep are known to adapt to consuming species such as *Acacia albida*. Thus predicting nutritive value from chemical composition is difficult.

2 Village-level application

The importance of demonstrating the benefits of greater utilisation of crop residues on farms and in villages has been stressed in nearly all the workshops (Table 3), yet the number of papers reporting on-farm research and development are very few. It seems that the 'Residue Revolution' alluded to earlier has been confined largely to universities and experiment stations in developing countries. Why is this so? One reason is the weakness and frequent absence of agricultural extension services in developing countries. On the other hand persuading university researchers to undertake on-farm/village-level experiments is unlikely to succeed because such trials are difficult to design. They usually represent a compromise between what the researcher wishes and what the farmer will permit. Furthermore they are difficult to execute and control. Thus the researcher eventually produces results which are unsuitable for publication in a scientific journal. This is a major disincentive, because producing publishable data is likely to be the main goal of the researcher with career development in mind.

Some village-level research and development has been undertaken e.g. in Sri Lanka (Figure 2) and Bangladesh. Experience in Sri Lanka has shown that milk production is the most effective system for demonstrating the benefit of urea-ammonia treating and supplementing rice straw. This is because an obvious increase in milk production occurs within days of introducing treated straw. A point not anticipated in Sri Lanka was the reaction of some farmers who saw little point in producing more milk as they had sufficient for their family needs and had no means of selling the surplus. Having a marketing infrastructure and working within the farming system is therefore clearly important in getting the technology applied.

Several contributors to workshops have spoken of the difficulty of persuading uneducated farmers to improve the feeding of their non-lactating ruminants during droughts, unless the animals are clearly in danger of dying. Farmers point to the fact that the animals will recover condition when the rains come, therefore why resort to the trouble and expense of treating and supplementing crop residues? Doubtless this is an attitude contributing to the low farmer-uptake of research and development on crop residues.

3 Treatment methods

Treatments involving sodium hydroxide and ammonia gas are acknowledged as being inappropriate for most developing-country situations. The urea-ammonia method of treating crop residues has been hailed as suitable technology, but this is questionable, at least for the traditional small farmer. The method involves mixing the residue with its own weight of urea solution. This would be seen as an onerous task by a farmer, or more likely his wife, as water for treatment could be a scarce resource having to be carried by hand to the treatment point. In Sri Lanka, development officers stressed to farmers the importance of using the correct amount of urea, as using too much could result in urea poisoning of the animals. Farmers were consequently reluctant to apply the technology, particularly as the manual task of treatment was likely to be undertaken by wives or labourers.

Another point frequently made is that small farmers have shown willingness to try urea treatment only so long as the urea was freely provided. Greater effort should have been made to research methods of treatment involving the farmers' own resources e.g. use of wood ash and urine. Promotion of urea for treating crop residues has also been criticised on the grounds that it would be more beneficial to persuade farmers to use more fertiliser urea to improve crop yields in the first place.

4 Supplementation

Reports to the workshops cited earlier (Table 3) show an increasing trend to investigate supplementation of crop residues rather than treatment methods. This reflects the growing concensus that supplementation is more likely to be applied in practice than treatment. Nevertheless farmer-uptake of supplementation to date, is low. As pointed out earlier, the large variation in response to supplementation is likely to have had a dissuading influence on application. Also contributing has been the lack of convincing evidence showing production responses to using cheap, locally-available supplements. Much research on this aspect is now in progress.

5 Appropriate experimentation

Aspects of this have already been alluded to. Undoubtedly the general lack of production-type experiments has not helped in getting the technology applied. Much of the experimentation has been confined to chemical analysis and measurement of digestibility and intake of crop residues, before and after treatment and/or supplementation. As mentioned previously, this reflects the university/institute based nature of the researchers. It also reflects the difficulty of undertaking on-farm, production-type experiments and the lack of prestige attached to such development research. It is also the case that many of the experiments reported in workshops (Table 3) involve inadequately replicated treatments, indicating shortage of resources and lack of statistical advice.

6 Basic research to improve residues *per se*

There is increasing awareness of the variation which exists in the nutritive value of crop residues, as discussed earlier. Basic research is now underway to understand why this is so (e.g. Van Soest 1988; Mueller-Harvey 1988) and to find ways of producing improved residues through plant breeding (Khush and Kumar 1987; Reed *et al.* 1988). In cereal straws, differing proportions of leaf and stem play a large part in affecting nutritive value (Sannasgala and Jayasuriya. 1984). Owen *et al.* (1988) have shown that goats and sheep will selectively feed for more leaf and less stem in barley straw, provided they are allowed to refuse about half of the total amount of straw offered instead of the more conventional 10 to 15 per cent. In this study refused straw was treated with ammonia and refed to goats to achieve intakes which were similar to those of untreated straw

Figure 2 Upgrading rice straw in Sri Lanka by ensiling with urea (Photo: Dr M C N Jayasuriya).

fed generously. An alternative strategy would be to offer the straw refused by small ruminants to larger, less selective ruminants. Selective feeding by sheep fed straw has also been shown by Bhargava *et al.* (1988). These studies suggest the need for similar research on the practical aspects of feeding crop residues in developing countries.

7 Dissemination of information

Workshops and research networks (Table 3) have certainly played a useful role in disseminating crop residue information between researchers in developing countries. However, information appearing in international journals is often not seen by researchers in these countries because university and institute libraries do not have the foreign exchange to purchase the journals. Imparting information to farmers is particularly difficult in most developing countries because of ineffective agricultural extension services. The latter has undoubtedly contributed to the low farmer-uptake of crop residue technology, as mentioned previously.

Conclusions

The above discusses the many and varied issues considered to have contributed to the failure of the 'Residue Revolution' being applied at farmer-level in developing countries. The discussion also points to research and development currently in progress, and yet to be undertaken, to help bring about greater utilisation of crop residues as feed for ruminants.

There is no doubting the large potential role that crop residues have as a feed resource. This role will have to be realised increasingly in the future because world population is predicted to double in the next 40 years and 80 per cent of the population will be living in developing countries. Some consolation can be gained by remembering that crop residues are inevitably produced when cereals and other crops are grown for man. Production of crop residues will therefore increase in the future, particularly in developing countries. Hopefully their utilisation as feed for ruminants will also increase.

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