RICE STRAW AS A FEED FOR RUMINANTS

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RICE STRAW AS A FEED FOR RUMINANTS

by

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Foreword

In view of the amount of rice straw produced in Asia and its widespread use in diets for cattle and buffalo, it is surprising that so few attempts have been made to bring together the large amount of information on the utilization of this valuable feed resource. Much of the information is available in short articles or papers in a diverse range of journals, in proceedings of seminars, workshops and conferences and in institute or project reports and there has not previously been an attempt to discuss the broad range of issues associated with the use of rice straw as an animal feed.

This book is intended to provide students, teachers, researchers, agricultural advisers and policy-makers with basic and, in many instances, quite detailed information that will assist in understanding the characteristics of rice straw as a feed either by itself or as a component of a mixed diet. It draws attention to the fact that supplementation of rice straw with small amounts of feed which provide limiting nutrients is the most practical way of improving the efficiency of rice straw utilization at this time. Further, it describes the attempts being made to improve the feeding value of straw by pretreatments. Importantly, it places in perspective the role that chemical pretreatments, which have been the subject of intensive investigation throughout the world, might play in Asian agriculture. Many of the principles are equally applicable to crop residues other than rice straw. Finally, the information gaps that exist are defined and areas for profitable research are identified.

The authors of this book are admirably suited, both in qualifications and experience, to examine, assess and interpret the information that has become available from a wide number of sources over a long period of time. Dr P. T. Doyle, B.Sc. (Agr.) (W.A.), Ph.D. (W.A.) has established himself as a highly-respected ruminant nutritionist who has conducted research into a range of aspects of digestive physiology. For a period of about five years from 1980 he was Scientific Secretary of the Australian-Asian Fibrous Agricultural Residues Research Network which provided him with the opportunity to gain first-hand knowledge of animal feeding systems in Asia and of the research activities in the region. Dr C. Devendra, B.Agr.Sci. (N.Z.), M.Agr.Sci. (Malaya), Ph.D. (Nott.), D.Sc. (Nott.) is known internationally for his deep knowledge of animal feeding and management in the tropics. Until recently he was Principal Research Officer in the Animal Research Division of the Malaysian Agricultural Research and Development Institute (MARDI) in Serdang, Malaysia. He is at present Program Officer, Animal Production Systems (South and South East Asia) in the Division of Agriculture, Food and Nutrition Sciences, International Development Research Centre (IDRC) and is based in Singapore. He is a member of the Committee on Crop Residues Utilization, International Union of Nutrition Sciences, and of the NRC (USA) sub-committee that produced "Nutrient Requirements of Goats". In addition, he has been a consultant for FAO and USAID. He is a prolific writer of scientific papers and books. Dr G. R. Pearce, B.Sc. (Agr.) (W.A.), Ph.D. (W.A.) is an experienced researcher in the field of ruminant nutrition. He has spent much of his career studying aspects of the utilization of low quality roughages and has had international experience in South East Asia and Africa. Dr Pearce has worked with FAO and is currently consultant to the International Development Program of Australian Universities and Colleges for the Australian-Asian Fibrous Agricultural Residues Research Network. He is also involved in a program of research being carried out in Australia, the Philippines and Thailand into the utilization of fibrous agricultural residues which is supported by the Australian Centre for International Agricultural Research.

The International Development Program of Australian Universities and Colleges (IDP) is pleased to have been associated with this project and to have enabled this book to be published and distributed to students, scientists and libraries in South-East Asia and other developing countries. One of its activities has been the Australian-Asian Fibrous Agricultural Residues Research Network which is sponsored by the Australian Development Assistance Bureau. This Network provided the incentive for the authors to produce "Rice Straw as a Feed for

Ruminants". Its realization is a credit to the enthusiasm and commitment of the authors and there is no doubt that it forms a valuable contribution to the teaching and research effort in the Asian region and elsewhere.

D. E. Tribe
Executive Director,
IDP, Canberra.

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Some of the photographs used were kindly provided by Dr Boonlom Cheva-Isarakul, Department of Animal Husbandry, Chiang Mai University, Thailand, Mr D. P. Handunge, Straw Utilization Project, Sri Lanka, and Ir. M. Winugroho, Balai Penelitian Ternak, Bogor, Indonesia.

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ABBREVIATIONS

1. Nutritional terms

DM	dry matter
DMD	dry matter digestibility
DMI	dry matter intake
DOM	digestible organic matter
IVDMD	*in vitro* dry matter digestibility
IVOMD	*in vitro* organic matter digestibility
LW	liveweight
$LW^{0.75}$	metabolic liveweight
ME	metabolizable energy
NDF	neutral detergent fibre
NDS	neutral detergent solubles
OM	organic matter
OMD	organic matter digestibility
OMI	organic matter intake
RDN	rumen degradable nitrogen
SR	substitution rate
TDN	total digestible nutrients
UDP	undegraded dietary protein

2. Organizations or institutions

ARC	Agricultural Research Council
FAO	Food and Agriculture Organization of the United Nations
IRRI	International Rice Research Institute
NRC	National Research Council

1. INTRODUCTION

The ruminant populations of the rice-producing areas of Asia are dependent upon rice straw to meet part of their nutrient requirements during the cropping seasons, and in dry or drought periods. Consequently, research programs have been carried out in many parts of Asia over a great number of years to examine the feeding value of rice straw. However, no attempt has been made to collect and evaluate the information generated in these programs. Rice Straw as a Feed for Ruminants is a much needed comprehensive review of this resource for livestock production in Asia.

Several important considerations motivated this review of rice straw feeding in the context of the farming systems in which the residue is produced. Firstly, rice is the staple crop of the majority of people in Asia contributing approximately 60-80% of the total daily energy intake. Consequently, a great deal of emphasis has been placed on the development of this crop. However, the emphasis on crop production to meet the energy requirements of the Asian people has done little to relieve protein shortages. This points to the need for increased food production from livestock through more efficient use of the available feeds, including rice straw.

Secondly, the relationship between available grazing land and animal populations in Asia, when compared to the rest of the world, shows a marked imbalance indicating the need for better use of crop residues if animal populations are to increase. Incomplete utilization of the feed resources from the land, rather than limitations in the availability of land *per se*, represents the principal constraint to productivity from livestock as well as the viability of small farm systems in Asia (Devendra, 1983).

Thirdly, the utilization of rice straw by ruminants is possibly the most efficient means of conversion of this residue to overcome problems of pollution through slow breakdown or burning. This means of disposal overcomes problems of collection and transportation as the straw is used on the farm and useful products such as draught power, meat, milk and manure are produced.

For these reasons it is pertinent to examine the information that is available on utilizing rice straw as animal feed in small farm systems in Asia. In this region approximately 93% of the total world output of rice straw is produced (FAO, 1983). FAO has estimated that there exist 3.0 tonnes dry matter of crop residues, mainly straws, for each 500 kg livestock unit. Most of these residues occur in the preponderance of small farms which are characteristic of Asian agriculture, and where over 90% of the buffalo and cattle populations are found.

In this book *rice straw is defined as the vegetative parts of the rice plant cut for feeding to animals at grain harvest or subsequently.* Straw varies enormously in its morphological composition with variable proportions of leaf blades, leaf sheaths and stems. Its chemical and physical characteristics are affected by the management practices used in production, and by the harvesting and threshing methods used. *Rice stubble comprises the vegetative parts of the rice plant remaining in paddy fields after harvesting of the grain and straw.* Like straw, it can vary enormously in composition and may or may not be grazed by ruminants. The feeding value of stubble is not discussed in the same detail as that of straw due to a lack of information.

There are several important points that need to be made about the use of rice straw in Asia. Firstly, its importance as a feed for ruminants needs to be considered in the context of the amounts and quality of other feed resources available throughout the year. This varies enormously between regions and even between small farms in the same village. Since it is not possible in the context of this book to consider the complete range of situations, some generalisations are made regarding the availability of other feeds and it is acknowledged that exceptions to these do occur.

In addition, farmers in Asia often have different priorities for keeping livestock than do farmers in developed countries. This is important in considering what type of rice straw-based diet is appropriate for particular situations. Where large ruminants are kept primarily for draught power, as suppliers of fertilizer and as insurance against crop failure,with meat production being a secondary consideration, then the maintenance feeding systems already used in practice might be the best option for the farmer. However, if the number of rice crops per year were to be increased due to the introduction of improved varieties and irrigated farming systems, the need for draught power would be increased which might require an increase in livestock numbers. This, in turn, would lead to changes in the feeding systems used. In the future, ruminants may become more important as a source of food in this region leading to greater use of multipurpose animals and this would necessitate appropriate alterations to current feeding systems. However, at present, cash income from livestock is only a small part of total farm income and this needs to be considered when recommending improvements and alternatives to current feeding systems.

Rice straw has many uses other than animal feed and while these are only dealt with briefly in this book, attention is drawn to the fact that these alternative uses can, in some instances, limit the availability of straw for feeding.

One common feature of the currently practised feeding systems on small farms where rice straw is used is that the straw is not processed outside the harvesting and threshing processes. However, a large research effort has been directed at pretreatment processes for improving the feeding value of straw. Even without the introduction of pretreatment, the different systems currently in use vary enormously: the straw may be fed *ad libitum* or in restricted amounts; supplements of green forage may be available daily or on a less frequent basis; supplements of concentrates are not often used but are fed in certain circumstances; mineral supplements, usually salt, may or may not be given. Reliable documentation of what comprises the diet, how much is fed and the type of feeding system is lacking for these small farms. It has been necessary, therefore, to make generalisations, but in the process, it is intended that attention is drawn to the more promising ways of encouraging rice straw utilization in efficient feeding systems.

It is important to remember that rice straw is also produced outside the Asian region. However, it is not generally considered important as an animal feed in these other areas although it is sometimes used as a filler in mixed diets in some countries and as a feed during droughts in others. However, while this book concentrates on rice straw feeding in Asia, research findings from other regions are included. Additionally, information available from other cereal straws or feeds is used to emphasize particular points, particularly where comparable information for rice straw is not available.

Many of the findings from research that has been conducted in the utilization of rice straw have been reported only in institute publications or in the various proceedings of workshops and conferences. Much of the available information is piecemeal, fragmented, not always readily accessible and its relevance to application in small farm systems may be questionable if not inappropriate. This book attempts to integrate the information currently available to establish what is precisely known of rice straw as a feed, the opportunities for practical application, the gap that exists in our present knowledge and areas for profitable continuing research.

At the farm-level the use of rice straw for feeding to animals can no longer be considered in isolation to other farm activities. This is perhaps best emphasized by Dr M. S. Swaminathan, Director General, IRRI who said "The past 25 years have seen marked increases in the quantity and quality of rice production. From our early work to develop high yielding modern varieties we have moved to develop varieties with genetic resistance to many insects and diseases that attack rice. While we first considered rice as a crop in isolation to achieve a breakthrough in raising the yield ceiling, we now emphasize rice as part of the whole farm system, and also the whole plant rather than just grain utilization, to increase farmers' income."

In "Rice Straw as a Feed for Ruminants" attention is drawn to the importance of considering straw utilization and animal production as part of the whole farm system.

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2. AVAILABILITY OF RICE STRAW AND USES OTHER THAN ANIMAL FEEDING

2.1 Introduction

Associated with rice cultivation is the generation of five important by-products, namely rice straw, rice stubble, rice husk, broken rice and rice bran. The more nutritious by-products, broken rice and rice bran are commonly used in the diets of pigs and poultry and are seldom fed to ruminants, except to dairy animals. In contrast, rice straw and stubble are commonly fed to ruminants, particularly buffalo and cattle, but the straw also has other uses within small farm systems.

The eventual fate of the millions of tonnes of rice straw produced each year is dependent upon the type of farming system in which it is grown and the value that individual farmers perceive for the range of possible uses. Consequently, it is important to consider the various systems in which straw is produced, the amounts produced and their quality, as these factors are important determinants of eventual usage.

2.2 Types of rice grown

The types of rice grown inevitably affect the amount and quality of straw produced. In the most simple categorization, varieties are divided into three types according to the height of the crop:

i) Semi-dwarf and dwarf: <100 cm in height at maturity
ii) Medium: 100-125 cm in height
iii) Tall: >125 cm in height.

This classification is useful, but it should be remembered that rice is produced under an enormous range of conditions. Greenland (1984) has listed and discussed a recently accepted classification for rice growing environments (see Table 2.1). These environments and their

Table 2.1 Terminology for rice growing environments

Irrigated
Irrigated, with favourable temperature
Irrigated, low-temperature, tropical zone
Irrigated, low-temperature, temperate zone
Rainfed lowland
Rainfed shallow, favourable
Rainfed shallow, drought-prone
Rainfed shallow, drought- and submergence-prone
Rainfed shallow, submergence-prone
Rainfed medium deep, waterlogged
Deep water
Deep water
Very Deep water
Upland
Favourable upland with long growing season
Favourable upland with short growing season
Unfavourable upland with long growing season
Unfavourable upland with short growing season
Tidal wetlands
Tidal wetlands with perennially fresh water
Tidal wetlands with seasonally or perennially saline water
Tidal wetlands with acid sulphate soils
Tidal wetlands with peat soils

Source: Greenland (1984)

relation to other classifications have been described by IRRI (1984). The important aspects are that under irrigation the soil can be kept flooded relatively easily, whereas in rain-fed systems rice can be grown in lowlands which are naturally flooded or which are occasionally flooded, in areas where the water table is within the root zone of the crop and in true dryland or upland areas where rice is grown on well-drained soils without surface water accumulation. Substantial differences occur in the varietal characteristics of rice adapted to these different environments and to rices grown within any of the broad classifications (Greenland, 1984). For example, within upland rice environments it has been necessary to further classify the conditions according to the length of growing season and the fertility of the soil. Despite this, rice breeders have found local adaptation characteristics to be most important indicating a wide diversity in the types of upland rice.

Information on the amounts of the different types of rice grown is difficult to collect and collate. However, IRRI (1982) has provided estimates of the areas of rice grown in irrigated and rainfed systems of production based on the dominant water regime (see Table 2.2). In these different systems, the amounts of rice produced, its quality and nutrient content are known to vary, and it is also likely that characteristics of the straw will be quite different.

Table 2.2 Estimated areas of rice harvested (1000 ha) classified in terms of the dominant water regime

Country/ Region	Total rice area 1978-80	Rice area by type of water control					
		Irrigated		Rainfed			
		Dry season	Wet season	Shallow[1]	Deep water[2]	Floating[3]	Dryland
Bangladesh	10,100	1,000	200	4,300	2,600	1,100	900
Burma	4,800	100	700	2,000	1,000	200	700
China	35,300	-	33,600	1,800	0	0	0
India	39,500	2,700	12,700	11,100	4,500	2,500	6,000
Indonesia	9,000	2,700	4,600	600	300	200	700
Kampuchea DM	600	0	50	200	50	100	100
Korea REP	1,200	-	1,200	0	0	0	0
Laos	700	0	50	300	0	0	300
Malaysia	700	200	200	200	0	0	100
Nepal	1,300	0	300	700	200	50	50
Pakistan	2,000	0	2,000	0	0	0	0
Philippines	3,400	600	900	1,200	400	0	400
Sri Lanka	700	200	300	200	0	0	50
Thailand	9,300	500	1,300	4,900	1,100	400	1,000
Vietnam	5,200	800	1,200	1,400	900	400	400
Developing Asia	126,000	8,800	61,400	29,000	11,200	4,950	10,700
Latin American	8,200	0	1,200	0	900	0	6,100
Africa	4,600	0	800	700	700	0	2,300
Other	4,800	-	4,800	0	0	0	0
World	143,500	8,800	68,200	29,700	12,800	4,950	19,100

Source: IRRI (1982)
[1]0-30 cm; [2]30-100 cm; [3]More than 100 cm

The aim of the rice breeding programs has been to increase grain yields and one of the consequences of this has been a shift towards a greater use of dwarf and medium types of rice. Whereas the growth duration of tall, traditional rice types is around 140 to 150 days, many of the newer varieties have a shorter growth duration, some as low as 90 to 100 days. The changes in growth conditions, as well as in the genetic makeup of rice plants, has had important implications as regards grain quality. It is not known whether there have been significant alterations in straw quality, but it can be expected that the patterns of mobilization of nutrients from the vegetative parts of the plant to the grain would vary for these different rices. Some farmers consider the straw from high yielding varieties to be less acceptable to animals (Hilmersen *et al.*, 1984) although there is no clear experimental evidence for this.

In addition to the above factors, the variety of rice, the conditions of growth, and other factors, such as disease, may affect the characteristics of rice straw. They may be expressed in terms of variation in the proportions of different morphological components (leaf blades, leaf sheaths, stem internodes and nodes) that are present and in the physical and chemical characteristics of these components. These factors are important in determining the value of straw, whether it is used for feeding animals or for other purposes.

2.3 Estimated rice straw production

The amount of straw produced is usually calculated from grain production data and seldom measured directly. Such calculations are based on grain: straw ratios and with rice a ratio of 1:1 is generally assumed. Importantly, it is not possible to come up with one value that will apply under all conditions, as considerable variation can occur. In the west coast rice bowl area of Peninsular Malaysia between 1973 and 1978, data on the yields of rice and straw were

Table 2.3. Area of rice harvested, grain yield and estimated rice straw production in different regions of the world.

	Area harvested (1000 ha)		Grain yield (kg/ha)		Straw production* (1000 metric tons)	
	1973	1983	1973	1983	1973	1983
World	134,163	144,473	2,390	3,114	320,714	449,827
Africa	3,903	4,925	1,780	1,736	6,945	8,551
Madagascar	920	1,219	1,902	1,761	1,750	2,147
Nigeria	370	600	1,486	1,667	550	1,000
North-Central America	1,548	1,648	3,663	4,238	5,672	6,983
USA	878	878	4,794	5,153	4,210	4,523
South America	5,833	6,349	1,763	1,953	10,286	12,396
Brazil	4,900	5,112	1,520	1,518	7,448	7,760
Asia	121,953	130,469	2,409	3,197	293,793	417,135
Bangladesh	9,955	10,600	1,837	2,047	18,291	21,700
Burma	4,911	4,700	1,743	3,085	8,559	14,500
China	34,755	33,980	3,209	5,067	111,520	172,184
India	37,000	41,000	1,827	2,195	67,600	90,000
Indonesia	8,568	9,100	2,372	3,769	20,321	34,300
Japan	2,620	2,273	6,018	5,701	15,766	12,958
Kampuchea DM	737	1,755	1,293	969	953	1,700
Korea DPR	370	820	3,919	6,341	1,450	5,200
Korea REP	1,220	1,228	4,794	6,193	5,849	7,608
Laos	665	670	1,328	1,494	883	1,002
Malaysia	805	700	1,996	2,857	1,957	2,000
Nepal	1,300	1,290	1,962	2,127	2,550	2,744
Pakistan	1,512	3,020	2,411	2,579	3,646	5,210
Philippines	3,589	3,300	1,542	2,470	5,532	8,150
Sri Lanka	671	926	1,956	2,376	1,312	2,200
Thailand	7,392	9,400	1,982	1,972	14,650	18,535
Vietnam	4,900	5,900	2,136	2,458	10,600	14,500
Europe	404	336	4,758	5,079	1,920	1,709
Oceania	60	96	5,562	5,769	336	554
USSR	462	649	3,812	3,852	1,761	2,500
Developed Countries	-	4,220	-	5,264	-	22,215
Developing Countries	-	140,252	-	3,049	-	427,613

Source: FAO (1973, 1983)

*Estimated using a grain:straw ratio of 1:1.

collected for several improved varieties grown at different locations and under various management conditions. The mean grain: straw ratio for the different varieties varied from 1:0.90 to 1:1.34, but when all the data were pooled the value was 1:1 (Cheong, W.A., personal communication).

This ratio can be used as a guide to the amount of straw produced. It is important to bear in mind that such a ratio does not partition the vegetative material into straw and stubble. Little information is available on this topic and Schiere and Ibrahim (1985) have assumed for convenience that 50% of the plant material is harvested as straw and the remainder left in the paddies as stubble.

Data on the areas sown to rice, the grain yield and the estimated straw production in countries of the world are summarized in Table 2.3. These indicate the changes that have occurred over the period 1973 to 1983 in the rice-producing countries and regions.

During this period the Asian region produced, and still continues to produce, most of the world's rice. While the area of rice harvested has increased by only 8%, the estimated amount of straw produced has increased by 40%. This is attributed to the use of improved varieties, better management practices, the practice of double cropping where irrigation is available, and the introduction of cropping systems involving legume crops in the dry season with consequence increases in soil fertility.

In a review of non-conventional feed resources available in Asia and the Far East, Devendra (1985) drew attention to the fact that rice straw accounts for approximately 40% of the total availability of residues from field crops. This underlines the importance of straw as a resource not only for feeding, but also for alternative uses that will be discussed later.

2.4 Harvesting practices

Rice is harvested by manual or machine methods depending upon the scale of farming and the costs of machinery and fuel. Within these two broad categories, there are further variations in harvesting practices.

2.4.1 *Manual harvesting*

In parts of Indonesia, Malaysia, the Philippines and southern Thailand, it is traditional to harvest grain by removing the panicles only. This is usually done using a small knife or a special tool fitted into a short wooden block. The harvested panicles are tied into small bundles for transport and then sun-dried in the home compound or along roadsides. It has been estimated that a skilled person can harvest about 15 kg paddy per hour by this method (Khan, 1976). An important consequence of this practice is that any conservation by storage of rice straw requires a separate harvest. It is more likely that the standing stubble would be grazed, allowed to decay or burnt, although in Bangaldesh, Hilmersen *et al* (1984) have observed that farmers are prepared to harvest straw at a later date when the straw has dried out. Some of the more recent improved rice varieties are not suitable for harvesting by this method as they tend to be more susceptible to grain loss when only the panicle is cut. For this and other reasons, rice harvested in this way no longer comprises a large proportion of the total production in Asia.

The second manual harvesting method involves cutting the plants at a height between ground level and the panicle with a smooth or serrated sickle (Plate 2.1). Harvesting involves gathering and holding the plants and severing them with the sickle. Cutting height of plants varies widely between regions and with the variety of rice. In Bangladesh, where the rice is transported to the home compound prior to threshing, cutting height is often determined by the distance the grain and straw have to be transported (Hilmersen *et al.*, 1984). Thus, the longer the distance home, the higher is the height of cutting. However, it would seem that, in many countries, the height is determined by what is a suitable straw length for manual threshing. Khan (1976) reported that cutting heights ranged between 3 and 20 cm. In Thailand and Malaysia the cutting height may be up to 40 cm, particularly with traditional rice varieties.

An important advantage of this method of harvesting is reduced grain loss compared to removal of the panicle only. It has been reported (Ezaki, 1963, 1969) that a skilled man can harvest 0.01 ha/h with a sickle and a woman 0.006 ha/h. Using an average yield of 2350 kg/ha, these are equivalent to 23 and 14 kg rice/h.

Plate 2.1 Manual rice harvesting in Thailand.

After harvesting, the plants are tied into bundles weighing 5-10 kg and are sometimes allowed to dry prior to threshing (Plate 2.2). The amount of vegetative material harvested as straw or left as stubble is obviously dependent upon the height of cutting and, as discussed previously, the type of rice grown.

Plate 2.2 Harvested rice and straw left for drying in Thailand.

2.4.2 *Machine harvesting*

Machine harvesting methods have been developed for small and large farm situations. On small farms in Asia machine harvesting is limited to some irrigation areas and these machines generally employ a scissor-type cutting action. In developed countries, such as the United States and Australia, larger power-operated machines similar to those used in wheat and barley harvesting are used. These machines combine both harvesting and threshing operations. The straw is chopped during the process and expelled from the machine as "header trash".

The cutting height used in machine harvesting depends on the uniformity of the crop. Generally, the plants are cut close to the panicle so that a minimum of straw passes through the machine. However, in Asia the cutting height may be lowered to 10-15 cm above ground when the straw is required. In contrast to this, when straw is required in Australia, it is harvested in a separate operation using different machinery. In this case the cut straw is allowed to cure and is then baled along with the "header trash". The straw may be cut immediately after the grain harvest or after a period of some weeks.

2.5 Threshing practices

Threshing involves detaching the rice kernels from the panicle and is the final step in separating paddy from straw. It can be achieved by a rubbing action, by impact or by stripping. As with harvesting procedures, threshing can be conveniently classed into manual or power methods.

2.5.1 *Manual threshing*

Two main methods of manual threshing are practised in the developing countries of Asia, namely treading or beating on threshing boards, tubs or baskets. Treading is done either with human feet (Plate 2.3), with cattle or buffaloes (Plate 2.4) or with tractors. During the process, paddy is dislodged from the panicles after which the straw can be stored for use or burnt. The duration of treading is variable and is dependent upon the weight that is brought to bear on the cut plants. At times, two buffalos or bullocks tied to a bar and slowly driven in a circle may be used to speed up the process.

In the second method (Plates 2.5 and 2.6), bundles of cut plants are beaten on tubs, threshing boards or racks in order to separate the paddy from the straw. With traditional rice varieties the harvested plants are often left in the field to dry for 6 to 8 days before threshing. This may result in continued losses of cell solubles from the vegetative material. However, with some improved varieties threshing takes place immediately after harvesting to avoid grain loss due to shattering. In this case the straw may be quite green, and losses during drying will occur through continued cell metabolism, but not through continued movement of nutrients into the grain. The straw is then left in small heaps for subsequent use. Many farmers consciously shift the threshing site in order to spread the straw nutrients over their farms. This reduces the amount of labour required to spread straw over paddy fields, allowing it to decompose and return organic matter and minerals to the soil.

2.5.2 *Machine threshing*

The simplest form of mechanical equipment used is the pedal thresher commonly found in Japan and Taiwan (see Khan, 1976). In this process, one or two men thresh the rice on rotating cylinders kept moving by men taking turns to pedal, while others collect and carry new bundles of the cut material. The rice straw is generally discarded in these areas.

In power threshing using flow-through combines, either a tractor-trailer, tractor-mounted or self-propelled machine is used. Machines may be used to thresh manually-harvested straw or threshing can be carried out by machine harvesters. As part of these operations, the straw is blown in the form of chaff through a shute out of the back of the machine and left to lie in the field. This process reduces the straw to short lengths. Hilmersen *et al.* (1984) have suggested that machine-threshed straw may be a better feed than manually-threshed material as the straw surface may be fractured and this may render it softer for animals to eat. However, in a preliminary study using a small number of animals, Wanapat (1985) found no difference in the intake and digestibility of machine and hand-threshed straws.

Plate 2.3 Threshing by human treading in the Philippines.

2.6 Storage

Unbaled straw collected for storage in developing countries is stored using two systems. One involves stacking straw in a large clump using a central pole about 4 to 6 metres high (Plate 2.7). These stacks are not protected by a roof, and consequently at the top of the heap the straw is stacked at an angle to facilitate the run-off of rain. More enterprising farmers build

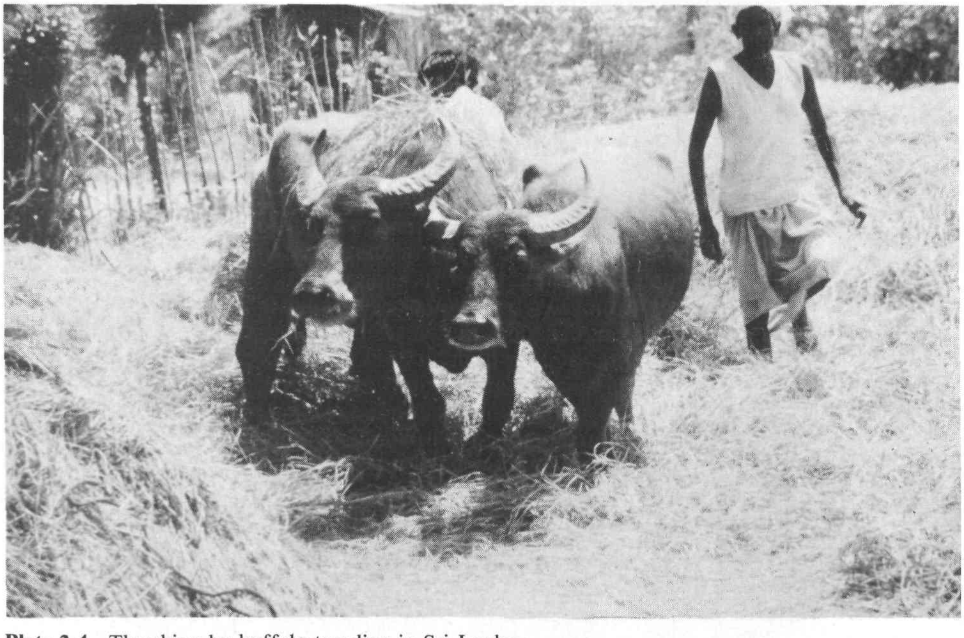

Plate 2.4 Threshing by buffalo treading in Sri Lanka.

Plate 2.5 Threshing by beating in Thailand.

these stacks under trees and in a few instances they may even be on raised wooden platforms or covered with polythene, corrugated iron or fronds from coconut trees. These practices assist in maintenance of straw quality by reducing the leaching effects of rainfall and microbial invasion that occurs when the straw is wet.

The second method is to place straw in stacks under a roof to reduce the effects of rainfall

Plate 2.6 Threshing by beating in the Philippines.

Plate 2.7 Storage of straw in an open stack in Sri Lanka.

(Plate 2.8). In the rural areas of Asia, this method is not common simply because of the capital cost of erecting a building and the fact that rice straw, being bulky, requires considerable storage space. Nevertheless, the method is used by dairy farmers in northern Thailand and in the wet zone of Sri Lanka.

The choice between these two methods depends on the resources available, the economic

Plate 2.8 Storage of straw in a shed in Thailand.

standing of the farmer and the prevailing environmental conditions of which rainfall is the most important. A survey in the Kurunegala and Matara districts of Sri Lanka, which are in the dry and wet zones, respectively, revealed that the percentage of farmers storing straw without shelter was 95 and 43% (Ibrahim *et al.*, 1984).

In developed countries, where the amounts of rice straw kept for animal feeding are relatively small, the problem of bulkiness is overcome by baling the rice straw. These bales can be neatly stacked, reducing the space required for storage, and the stacks may be in the open or under cover.

Devendra (1982) reported a preliminary investigation of the effects of storage conditions on the chemical composition of straw. The three conditions investigated were: fully exposed straw, partially exposed straw and straw kept under shade. Exposure to the weather decreased crude protein content from 5.6 to 3.4%, Ca from 0.31 to 0.21%, P from 0.11 to 0.02%, but did not affect total ash or Mg content. These data indicate that post-harvest handling and storage of straw can have important effects on its quality.

Another practical consideration for the collection and storage of rice straw relates to the season in which it is harvested. Crops from the wet season are generally harvested at the onset of a dry season. It is more practical to dry straw from these crops than from irrigated crops grown during the dry season, but harvested at the onset of the following wet period. These factors that contribute to the amount and quality of rice straw available, namely the harvesting, threshing and storage practices, also have important implications concerning the eventual use of the straw.

2.7 Alternative uses for rice straw

Several recent reviews (e.g. Han, 1978; Devendra, 1982; Castillo, 1983) have considered the alternative uses of rice straw. Consequently, these will only be dealt with briefly here. The more important uses of rice straw can be listed as:

i) burning
ii) fertilizer for paddy fields
iii) mulch for vegetable production
iv) substrate for mushroom growth
v) fibre subjected to acid hydrolysis and the resulting sugars used for single cell protein production
vi) bedding for livestock and poultry
vii) fibre for paper manufacture or use in construction materials
viii) fuel to produce heat, and
ix) feed for livestock.

Burning of rice straw and stubble is a traditional practice throughout the Asian region. There are several reasons for this and their importance varies between areas within the region. It reduces the incidence of pests and diseases, facilitates soil preparation for a second rice crop or for other off-season crops, and it returns minerals to the soil. Although burning leads to organic matter loss, it is quick and overcomes the many problems associated with slow decomposition of straw. In some developed countries, such as the United States, burning of straw is restricted by laws introduced to control environmental pollution, while in others, such as Australia, most of it is still burnt.

In some systems rice straw is allowed to decompose and hence to recycle nutrients for crop production. It is used in combination with animal wastes or chemical fertilizer to produce compost which is applied to rice fields. In Taiwan, compost has been compared to ammonium sulphate fertilizer; at an equal rate of nitrogen application, compost produced 90-95% as much rice as the chemical fertilizer (Lin, 1982). Consequently, it has been argued that when there is a lack of chemical fertilizer, composting is a suitable alternative for sustaining rice yields. In addition, long term beneficial effects of compost have been found due to increased humus content of the soil (Lin, 1982). The main obstacle to compost utilization is the labour requirements involved in its production, but it is inevitable that some of the straw used as bedding on small farms will end up in compost and be used to fertilize paddy fields or vegetable gardens.

The use of rice straw alone as a fertilizer has also been studied in Indonesia (Ismunadji *et al.*, 1973), Japan (Dei, 1975) and Taiwan (Chou and Lin, 1976; Houng and Liu, 1977). In general, the fertilizer effect of ploughed-in rice straw is not sufficiently marked to encourage farmers to adopt this practice (Lin, 1982). Much apparently depends on whether the straw is ploughed-in in the long form or in short lengths and whether it is spread evenly over the field. If straw is not chopped during mechanical threshing, the farmers are unlikely to include this as an extra step due to the increased cost of cultivation. In addition, the time between crops is important, as, in the short term, straw decomposition might lead to reduced availability of nitrogen and, in double and triple cropping systems, it is likely that straw breakdown will not have progressed sufficiently prior to sowing of the next crop. As regards energy recycling, Lin (1982) has suggested that it is better to use rice straw first as an animal feed and then use the animal wastes as fertilizer or in alternative processes that produce energy, such as methane. The best option is dependent on the cropping systems used, the cost of labour and whether technologies such as methane production are suited to the location and farming system.

Mulching involves covering the soil with materials that reduce moisture loss, soil erosion and the growth of weeds. Rice straw is traditionally used as a mulch in vegetable gardens on small farms. In addition, it has been used for this purposes in pineapple (Su, 1968) and tea (Lin, 1955) plantations and in soyabean production (Lin, 1982). While there are benefits in terms of keeping down weeds and in increased yields, these need to be evaluated against the costs of transportation and storage of the straw.

Mushroom production supplements the protein intake of small farm families or increases their monetary income. Rice straw is often used as the entire substrate or mixed with other ingredients as the growth medium for these edible fungi. Alicbusan (1983) drew attention to the fact that the amount of straw used in growing *Volvariella* and *Agaricus* mushrooms was very small in relation to the total amount produced. Nevertheless, this industry is growing in importance and investigations into the disposal of spent mushroom straws as organic fertilizers or as animal feeds (see Chapter 6) have occurred.

Considerable research effort has been directed towards the use of fibrous crop residues for single cell protein production after their hydrolysis with acid. Much of this work has been reviewed by Han (1978). Although these processes are technologically possible, their use in practice has been extremely limited. They are certainly inappropriate in the small farm systems of Asia, because to approach economic viability they would need to be carried out on an industrial scale.

The use of rice straw as bedding for livestock and poultry is common in Asia, particularly when the animals are kept on a floor of earth or rammed clay. During the wet season, when the floors are damp, straw is added in layers every day or two to form a deep litter, which is removed every four or five days. This use indicates that there may be a surplus of rice straw over and above the amount small farms channel into other uses or that farmers prefer to mix straw with animal manure before placing it in compost heaps or spreading it on gardens.

Rice straw is also used in construction materials, such as boards or panels, and in making paper. Of these uses the former is more common possibly because rice paper is often of poor quality.

Hilmersen *et al.* (1984) have also described situations in Bangladesh where rice straw is harvested and used as a fuel to produce heat. This occurs because of limited supplies of wood for burning. Rice straw is also used as fuel in the farm house in South Korea (Shin, 1978).

Few estimates have been made of the amounts of rice straw utilized for these various purposes. In South Korea, Sul (1978) and Im and Park (1983) found that over 70% of the straw produced was used in feeding ruminants, as a soil fertilizer and as fuel in the farm house (Table 2.4). Considerable quantities were also used for roofing. These data clearly illustrate that large amounts of rice straw 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 by ruminants.

Kossila (1984) has estimated that, on a world-wide basis, the quantity of crop by-products has risen faster than animal numbers (in livestock units) between 1970 and 1981. This is also the case in Asia, where rice straw contributes significantly to the increase in by-product feeds available. Thus, there is potentially more energy available from these feeds for livestock. However, the questions remains as to why fibrous crop residues are not being utilized more fully for livestock production in Asia. Rice straw as a feed for ruminants is considered in detail in subsequent chapters of this book.

Table 2.4 Utilization of rice straw in South Korea

Usage	1978[a] Quantity ($X10^6$ tonnes)	1978[a] Percent of total (%)	1982[b] Quantity ($X10^6$ tonnes)	1982[b] Percent of total (%)
Feed	1.4	20	1.6	15
Fertilizer	2.0	28	3.5	46
Fuel	1.9	26	1.5	20
Roofing	0.8	11	0.9	12
Straw by-products	0.2	3		
Straw pulp	0.2	2		
Others	0.7	10	0.5	7
Total	7.2	100	7.7	100

Source: [a]Sul (1978); [b]Im and Park (1983)

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3. CURRENT FEEDING SYSTEMS

3.1 Introduction

There exists a wide range of feeding systems to utilize rice straw. However, only general descriptions of current feeding practices are given in this chapter. Such descriptions are appropriate in a book focussing on rice straw, and are relevant in considering the opportunities that exist for implementing strategies to improve the use of this feed resource. An understanding of these practices is vital if the objectives of promoting efficient and more complete use of rice straw are to be achieved.

3.2 Types of ruminants fed straw

The population of large ruminants, buffaloes and cattle, in the Asian region is approximately 487 million compared to 612 million small ruminants, goats and sheep (FAO, 1983). Ownership of ruminants has several advantages: they are a capital investment which acts as a bank or insurance against crop failure, they are source of meat and milk, they provide fertilizer, they give the farmer prestige and they can earn supplementary income for the farmer. Large ruminants are especially valued in rice growing areas as a source of draught power during cultivation, threshing and in haulage. For this reason, large ruminants are found in relatively greater numbers in these areas.

The contribution of rice straw to the diets of large ruminants varies between countries and locations. For example, during the dry season, it can be the major component of the diet in parts of Thailand (Yano, 1984; Khajarern and Khajarern, 1985) and in India and Bangladesh (Verma and Jackson, 1984). However, Petheram *et al.* (1983) found that it comprised only 5 to 15% of the diet of hand-fed cattle at Peltong in West Java in either the wet or dry season. In other parts of Indonesia, such as East Java, more straw is used as feed.

During the last two decades, the value of draught animals in rice-growing areas has been diminishing due to the advent of tractors and the practice of multiple cropping where irrigation is available. The introduction of multiple cropping has favoured the use of tractors as they can prepare the land more quickly than animals. In addition, the time available to farmers for animal husbandry has been reduced. None-the-less, in integrated farming systems in Asia large ruminants are still important and, in the future, they are likely to become more dependent upon crop residues and by-products for their nutrients. This is especially so where draught power will continue to be required for crop production in rain-fed agricultural systems.

Goats and sheep are not found in large numbers in the rice-growing areas. These species are better adapted to drier climates and where they are found in wet areas they are kept in animal houses. Under stall-fed conditions, rice straw is generally not given in large amounts to sheep and goats (Chaniago *et al.*, 1982; van Eys *et al.*, 1984), but the amount fed varies between locations and season. Van Eys *et al.*, (1984) reported that, whereas rice straw comprised over 20% of the diet of small ruminants in both the wet and dry seasons at Garut in West Java, it comprised only 3 and 13% of the dry season diet at Ciburuy and Cirebon, respectively, locations where it was not fed at all in the wet season. Thus, when other feeds are readily available, straw is not fed to small ruminants.

3.3 Ruminant management and feeding systems

Where rice straw is important as a feedstuff, systems of management of ruminants have evolved to ensure that these animals contribute to efficient crop production, and at the same time do not compete with crops for land or cause damage to the crops. These systems vary in accordance with the type and frequency of crop production, the availability of uncultivated waste land and the number of animals in relation to these factors. They are commonly grouped into three categories:

(a) extensive systems,

(b) tethering systems, and
(c) stall-feeding systems.

These are not mutually exclusive in the context of Asian farming, as extensive grazing or tethering may be practised during the day with animals being kept in stalls at night.

The characteristsics of each of these management systems, as they relate to rice straw utilization, are described below. While some attention is given to the types of feed likely to be available, no attempt is made to look at the effects of other feeds to straw utilization. This is dealt with in detail in Chapter 7.

3.4 Extensive systems

Extensive grazing is practised on small farms, on plantation estates and on ranches. On estates and ranches, animals are generally allowed to graze throughout the day and night, and rice straw is only of importance as a feed when pasture is scarce.

On small farms, ruminants are allowed to graze on waste lands and in paddy fields and the grazing area may or may not be controlled by a herdsman. This practice may be restricted to the period immediately after harvest, when the feeds available can include rice straw that has not been collected for storage, rice stubble, weeds growing in the paddies, native pastures available on paddy bunds and roadsides, and browse from shrubs and trees. It is common to see animals ingesting shrub and tree leaves as they are herded back to villages in the evening. Thus, there is a wide range of feed types available, but the amounts of each which are ingested and their quality is generally unknown.

In some rice-producing areas farmers are not interested in storing straw. This is likely to be the situation where no prolonged periods of feed shortage occur, and also where multiple cropping is practised and farmers do not have the time or labour resources to transport straw for storage. In these situations, ruminants may have access to straw and stubble only for a short period before the crop residues are burnt. Burning is common in Indonesia, Malaysia and the Philippines, where, in some areas, livestock usually obtain their nutrients from roadside grasses, pasture on paddy bunds and tree materials.

In other circumstances farmers consciously collect and store straw. This occurs where prolonged dry periods occur, where the available feed resources do not meet the requirements of the livestock population and where it is necessary to confine animals during the cropping season. Examples of situations where straw comprises most of the diet can be found in Central, North and North-eastern Thailand, in the dry zone of Sri Lanka and in Bangladesh, India and Pakistan. No doubt localized areas are also found in other Asian countries. After harvest, ruminants are released each day to graze on stubble and other available feeds. When these supplies diminish, the animals rely largely on stored straw as their main source of nutrients. Again, the period of time over which rice straw-based diets are fed depends on the availability of other dietary ingredients.

When animals are grazing their nutrient intake is unknown, but it is likely that they consume better quality feeds from paddy bunds before consuming straw or stubble. In addition, they are likely to select more palatable and nutritious fractions from within the straw or stubble. Few data are available on the feeding value of rice stubble but it appears to vary greatly in quality. In some parts of Asia it is common to see animals grazing stubble containing a considerable proportion of green material, compared to other places where the stubble is dry and dead. Factors such as the ownership of the animals and/or the land may also influence what feeds ruminants have access to in different locations or countries. Given this lack of information on the diet eaten, the best measure of nutrient intake is the rate of weight change observed in the animals and this should determine what additional feeds are offered when animals are penned during the night.

3.5 Tethering systems

Tethering is a common method of animal management on small farms with only a few large ruminants. It restricts the area grazed, preventing animals from going into areas being cropped, it ensures that the available feed in particular areas, such as recently harvested paddies, is utilized and it prevents livestock from wandering. Often, large ruminants are tethered close to stacks of rice straw to enable self-feeding, particularly where the stacks are in the paddy fields, and to a lesser extent when the straw has been transported to the farm house or yards. However, while it is convenient way of feeding straw, there is sometimes considerable wastage because of the manner in which the animals select straw from the stack. Reducing such wastage would improve the utilization of stored feed.

3.6 Stall-feeding systems

At different times of the year, large ruminants may be kept in stalls continuously or only during the night. The reasons for confining animals vary throughout Asia and depend upon the type of animals, the availability of feeds and climatic conditions. For example, small ruminants are often kept in total confinement in wet areas, dairy animals may be kept continuously in stalls when available grazing land or feed supplies are short, and draught animals may be kept completely confined during cropping seasons.

The diet given to stall-fed animals is also variable and several broad categories are described.

3.6.1 *Feeding rice straw alone*

Rice straw is traditionally fed during periods of feed shortage, but it does not provide adequate nutrients for maintenance. Under experimental conditions it has been shown that buffaloes (Wanapat *et al.*, 1984; Wongsrikeao and Wanapat, 1985), cattle (McLennan *et al.*, 1981; Wanapat *et al.*, 1982, 1984; Suriyajantratong and Wilaipon, 1985) and sheep (Vijchulata and Sanpote, 1982) fed straw alone lose weight (see Chapter 4). Usually the straw is fed in the long form, but in some parts of Asia, notably India, it may be chopped to limit selection and wastage. At times the amount of straw collected and stored does not enable farmers to feed their animals *ad libitum*. In these feeding systems salt is sometimes provided, but other mineral supplements are uncommon.

3.6.2 *Feeding rice straw with forage supplements*

Many Asian farmers offer other forages with rice straw to stall-fed ruminants. There is little quantitative information as to how much of these forages are fed and how frequently they are given. The most common feeds provided with rice straw are roadside grasses, while other important forages are cassava (*Manihot esculenta* Crantz), gliricidia (*Gliricidia maculata*), leucaena (*Leucaena leucocephala*) and sesbania (*Sesbania grandiflora*). In specific areas forages from many other trees, crops and water weeds, including acacia (*Acacia arabica*), banana (*Musa* spp.), jackfruit (*Artocarpus heterophyllus*), pigeon pea (*Cajanus cajan*), neem (*Azadirachta indica*), sweet potato vines (*Ipomoea batatas*) and water hyacinth (*Eichornia crassipes*), are utilized.

It is known that small quantities of green forage can improve the utilization of straw diets through increases in intake and digestion. These beneficial effects are apparently due to influences on rumen function. Thus an important strategy, which has been under investigation in recent years, for improving the nutrient intake of ruminants in developing countries is the introduction of fodder shrubs and trees. The leaves of these plants remain green during dry periods when the availability of and quality of roadside grasses are low and hence they can be valuable supplements. Within small farm systems these plants can have other beneficial effects in that they often provide fuel and in the case of leguminous types they may help to improve soil fertility by fixing atmospheric nitrogen. However, care should be taken to ensure they are palatable and that they do not contain toxic constituents.

The value of forage supplements in feeding systems based on rice straw has recently been discussed by Devendra (1984). Advantages additional to their nutritional effects occur where they are available on the farm and, hence, are easily accessible and relatively cheap and in that they reduce requirements for other supplements.

3.6.3 *Feeding rice straw with concentrate supplements*

While concentrate supplements are generally fed to milk producing or dairy replacement animals, they are rarely given to growing or draught cattle and buffaloes. Concentrate supplements which are used may be home-grown or by-product feeds from mills, such as rice bran, coconut cake, cassava chips and palm kernel cake. Purchased concentrates from feed manufacturers have advantages in that they may be formulated feed mixtures designed to provide limiting nutrients in balanced amounts or they may be individual feeds required for specific purposes, like coconut cake, fish meal or molasses. Costs of the various formulated feeds have been increasing due to rising prices of ingredients and this has acted as a major deterrent to their use as the profit margin becomes small. A further problem is the variable feed quality in both formulated diets and individual feedstuffs. Hence, in recent years there has been a trend towards the use of on-farm self-mixed concentrates, the feeding values of which are largely unknown.

3.6.4 *Potential for other approaches*

A considerable amount of research interest has been directed towards pretreatment of straw with chemicals and to making silages from rice straw mixed with other forages or manures. These approaches are discussed in detail in Chapter 6 but there is only limited evidence that pretreatments are being adopted by farmers in Asia.

3.7 Use of rice straw for maintenance and production

At present, the main use of rice straw in animal feeding in most Asian countries is to see large ruminants through periods of feed or labour shortage. Principally, these periods are from the time of cultivation and planting through to harvesting, when animals have only limited or no access to grazing, and during dry periods or droughts. Under these circumstances rice straw is a valuable feed although it would be necessary to provide forage of concentrate supplements to maintain the animals. It may become profitable to feed draught animals to maintain their weights during periods of feed scarcity if it is desirable to improve reproductive performance and the size of the animal population, or to keep multipurpose, draught/meat or draught/milk, animals.

There are of course circumstances where rice straw is incorporated into production diets for draught or beef animals. This is the case around major cities where the demand for meat is sufficient to justify feeding for increased growth rates. In these circumstances, rice straw comprises a lower proportion of the total diet.

The situation with dairy animals is quite different as they may be fed rice straw-based diets supplemented with both forages and concentrates to achieve acceptable levels of milk production. The use of rice straw in such rations is increasing rapidly as developing countries strive to develop efficient dairy industries. It is also likely that replacement heifers will be fed on rice straw-based production diets in these industries.

The use of rice straw for production represents the main thrust of current efforts to increase its utilization. In recent years there has been an upsurge in efforts to investigate the most efficient and practical ways to achieve this objective. This is reflected in various reports in workshops and seminars held in Asia. Examples of these are the workshops of the Australian-Asian Fibrous Agricultural Residues Research Network (see Doyle, 1982, 1984, 1985; Pearce, 1983) and the annual meetings on Maximum Livestock Production from Minimum Land in Bangladesh (see Haque *et al.*, 1980; Jackson *et al.*, 1981; Preston *et al.*, 1982, Davis *et al.*, 1983). In general however, much of the investigative effort has been made at the laboratory and experiment station level. The challenge that remains is to extend the accumulated findings in terms of efficient feeding systems that are realistic in small farm situations.

In succeeding chapters attention is drawn to the considerable research effort that has been directed towards efficient utilization of rice straw in feeding systems. However, despite this effort only small changes in the traditional systems used in villages have occurred. It is apparent that the general descriptions of traditional feeding systems are not sufficient to bridge the gap between research scientists and farmers. An essential ingredient which would contribute to more applicable research is the acquisition of quantitative information from particular locations on the amounts and quality of the various feeds given in specific ruminant production systems including the times of the year when they are important. In addition to this, it should be remembered that the farmers' perception of what is an acceptable level of production is of the utmost importance in formulating systems to improve current practices.

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4. FEEDING VALUE

4.1 Introduction

In order to optimize the utilization of rice straw it is necessary to have some knowledge of its nutritive characteristics and the extent to which it will, alone or in interaction with nutrients from other feeds, meet the requirements of different types of animals. Rice straw is usually categorized as a poor quality roughage, but its feeding value can vary over quite a wide range. In this chapter, the nutritive characteristics of rice straw are examined and the factors contributing to variation in its feeding value are discussed. Where necessary, use is made of data obtained from other materials, particularly wheat straw.

4.2 Feeding value

Several components contribute to the feeding value or nutritive value of forages, namely
(a) chemical composition, representing the gross amounts of nutrients available;
(b) level of voluntary intake, indicating the amounts of nutrients consumed;
(c) digestibility, indicating the proportions of nutrients that are digested and absorbed and become available for metabolism; and
(d) efficiency of metabolism at the tissue or cell level.

It is not always possible to define feeds according to these criteria because, in many cases and particularly with cereal straws, there is a shortage of adequate information obtained in *in vivo* experiments. The low intake of cereal straws when fed alone is a deterrent to conducting digestibility and metabolism experiments without supplementary ingredients in the diet. Therefore, reliance has to be placed on chemical composition and measurements of digestibility made in the laboratory *in vitro* and the limitations of such assessments need to be appreciated.

The voluntary intake of low quality roughage, such as straw, is regulated by interactions between metabolic processes in the tissues and the transactions that occur in the reticulo-rumen (Weston, 1979, 1982, 1984). With straw, the level of intake is governed by the amount of material in the reticulo-rumen, its rate of digestion and the rate of passage of digesta out of the reticulo-rumen. Thus, mechanical processes associated with digestion, namely, particle size reduction during eating and rumination, and rates of microbial fermentation are important in relation to the level of intake. These aspects have received very little investigation with rice straw, although it is known that the rate of digestion is depressed by nutrient deficiencies, particularly of nitrogen, which restrict microbial activity in the reticulo-rumen. In many cases, rectifying such deficiencies results in a significantly increased intake.

Where rice straw constitutes 100% of the diet, then all its limitations, in terms of physical characteristics, chemical characteristics and low contents of essential nutrients, will manifest themselves and the animals will lose weight. However, sometimes even small contributions from other feeds in a mixed diet can produced markedly improved results through effects at the rumen and/or tissue level. Knowledge of the specific limiting nutrients in a particular batch of straw can enable the selection of the supplements that will make up those deficiencies effectively and there have been many examples in which this has been demonstrated (see Chapter 7).

4.3 Difficulties in sampling straw

Rice straw, and cereal straws in general, is difficult to sample representatively because the plants are large and bulky and because the different morphological fractions (leaf, stem etc.) differ markedly in their chemical composition and other characteristics, as is discussed later. In addition, the rice plant is unusual in its growth pattern. Whereas other cereals usually pass through uninterrupted and predictable phases of development, maturity and senescence, rice, at least when grown under flood irrigation conditions, may not mature and senesce evenly within the plant. Sometimes new, vegetative tillers may appear late in the development of the plant and it is not unusual for the bottom parts of the plant to be green when the grain is mature. In fact, the grain is often harvested at an earlier stage than is the case in other cereals so as to avoid losses by "shattering". As a result, the bottom parts of the plant are sometimes more digestible than the top parts; in other cereals the reverse is the case. Thus, samples of rice straw from cuts made at different heights may vary markedly in chemical composition and in digestibility. Unless sampling and description are thorough the value of detailed chemical analyses on straws may be questionable. It is necessary for researchers to be aware of variable influences associated with the growth of the plant, the management of the crop and the collection and handling of samples and, in published reports, an adequate description of the relevant features should be made.

4.4 Variability in chemical composition and *in vitro* digestibility of rice straw

Ruminant nutritionists use various chemical descriptions of forages as indices of their feeding value. For mature, senescent and dead plant material it is valuable, in the first instance, to measure the proportions of cell contents and cell wall constituents by the detergent analysis procedures of Goering and Van Soest (1970). This is because the cell contents represent the readily digestible nutrients, while the cell walls are more resistant to fermentation. The nitrogen content of feeds is also important as it is indicative of whether or not this nutrient is limiting for microbial digestion. While more sophisticated and greater numbers of analyses can yield information on the amounts of particular compounds present, such information is generally only useful in basic research or in other specifically defined situations. At present, these more detailed analyses have little application to practical feeding situations in Asia.

The chemical composition of rice straw has been determined in many countries and representative data are presented in Table 4.1. Pronounced variability occurs in the contents of some components, but usually the cell wall constituents, measured as neutral detergent fibre (NDF), are high (up to 86% of the dry matter). This indicates that the more readily digestible components of the cell contents are often only present in small amounts. While the crude protein content is usually low (mean 4.1%) there is a considerable range in the reported values (2.2 to 9.5%). In rice straw collected from farms, that is, not including those from research stations, the crude protein content is below that required to maintain ruminants and it is taken for granted that nitrogen supplementation would be needed to ensure reasonable levels of intake and digestion. Hence, rice straw is looked on primarily as a source of energy yielding substrates.

In vitro digestibility estimates are often used as an index of feeding value because of the difficulties associated with conducting feeding trials. Taken in context, this measurement is a useful description for comparisons between forages. It can be seen in Table 4.1 that, like chemical composition, the *in vitro* digestibility of rice straw varies widely from 30 to 55%.

Some minerals are essential to ruminants and mineral analyses that have been carried out on rice straw are presented in Table 4.2. As with crude protein the amounts of some minerals are lower than required to maintain ruminants, but there are also wide variations in the concentration of individual elements. In reviewing the limited information available on the mineral status of tropical fibrous agricultural residues in general, Little (1985) concluded that phosphorus, sodium and copper were likely to require most frequent attention. In the case of rice straw, there are generally insufficient data to establish clearly the status of specific minerals. For example, the few analyses performed indicate that sulphur (mean content 0.04%) would be limiting. It is generally accepted that the critical value for sulphur in forages is in the range 0.12 to 0.15% for sheep although it may be lower for large ruminants (Doyle and Djajanegara, 1983). This element is particularly important because, like nitrogen, it is required for microbial protein synthesis and this is discussed further in Chapter 7.

Obviously, responses to mineral supplementation can not be expected without rectifying primary deficiencies of energy and nitrogen. Again, in the context of present knowledge, rice straw is looked on as providing energy although undoubtedly it does make some contribution to the mineral nutrition of ruminants.

Table 4.1. The chemical composition (% dry matter) and *in vitro* organic matter digestibility (IVOMD, %) of rice straw*

Crude protein	Crude fibre	Ether extract	Nitrogen free extract	Total ash	Neutral detergent fibre	Acid detergent fibre	Hemi-cellulose	Cellulose	Lignin	IVOMD	Number of varieties	Country/ Region	Reference
2.2	34	2	49	13	-	-	-	-	-	-	1	Thailand	Vijchulata & Sanpote (1982)
2.3	38	2	40	17	86	63	23	-	5	-	-	Thailand	Cheva-Isarakul & Cheva-Isarakul (1984a)
2.4	-	-	-	-	85	57	28	-	7	-	-	Thailand	Tinnimit (1985)
2.5	-	-	-	10	-	-	-	-	-	40	-	Sri Lanka	Ibrahim *et al.* (1984)
2.6	-	-	-	15	77	52	24	-	5	-	-	Thailand	Wanapat (1985)
2.7	28	2	56	12	-	-	-	-	-	-	-	Bangladesh	Hossain & Rahman (1981)
2.8	38	2	32	15	-	-	-	-	-	-	-	Thailand	Promma *et al.* (1985)
2.9 (2.7-3.3)	22 (20-23)	-	-	12 (11-13)	-	-	-	-	-	-	5	Bangladesh	Haque *et al.* (1981)
3.0 (2.2-3.8)	32 (29-34)	3 (2-4)	48 (46-50)	15 (10-19)	-	-	-	-	-	-	5	India	Mohammed & Viswanatha Rai (1969)
3.2 (2.7-3.5)	-	-	-	19 (17-21)	77 (74-80)	55 (50-58)	22 (19-25)	50 (45-52)	5 (4-6)	-	7	Bangladesh	Saadullah (1982)
3.3	31	1	44	20	-	-	-	-	-	-	-	Bangladesh	Saadullah (1984)
3.4	-	-	-	17	-	44	-	-	6	-	-	Thailand	Sriwattanasombat & Wanapat (1985)
3.5 (3.3-3.7)	42 (39-45)	2 (1-2)	33 (30-36)	20 (20-21)	-	-	-	-	-	-	3	India	Narasa Reddy & Das (1980)
3.5	35	0	47	15	-	49	-	-	4	-	1	Thailand	Wanapat *et al.* (1982)
3.5	-	-	-	15	-	49	-	-	4	-	-	Thailand	Wanapat *et al.* (1984)
3.8 (3.4-4.8)	-	-	-	21 (17-24)	72 (69-74)	49 (47-53)	22	-	7 (6-10)	38 (34-42)	3	Sri Lanka	Sannasgala *et al.* (1985)
3.8	-	-	-	17	-	56	-	-	-	-	-	Thailand	Wongsrikeao & Wanapat (1985)
3.9 (3.3-4.5)	30 (26-34)	2 (1-2)	47 (35-55)	16 (11-19)	-	-	-	-	-	-	7	Malaysia	Devendra (1982)
3.9	30	-	-	17	-	-	-	-	-	-	-	Sri Lanka	Jayasuriya *et al.* (1981)
3.9	33	1	-	25	-	-	-	-	-	-	-	Indonesia	Moran *et al.* (1983)

4.0 (2.2-5.8)	-	-	-	18 (15-24)	74 (68-79)	53 (49-57)	21	-	5 (4-6)	48 (37-54)	7	Thailand	Cheva-Isarakul & Cheva-Isarakul (1985)
4.1	-	2	-	18	76	57	19	52	5	52	-	Thailand	Cheva-Isarakul & Potikanond (1985)
4.4 (3.8-5.7)	35 (34-37)	-	-	15 (12-17)	78 (78-79)	53 (51-54)	26 (24-27)	35 (34-36)	8 (7-10)	39** (30-34)	5	Korea DPR	Shin *et al.* (1981a)
4.6 (4.3-5.3)	31 (27-35)	2 (1-3)	45 (42-48)	18 (15-21)	67 (62-73)	41 (37-46)	25	36 (33-40)	10 (8-12)	-	-	Japan	Toyokawa *et al.* (1982)
4.6	-	-	-	-	73	50	23	-	-	-	-	India	Jaiswal *et al.* (1983)
4.9 (3.2-7.6)	32 (28-35)	3 (2-3)	46 (43-49)	15 (13-18)	-	-	-	-	-	-	11	India	Devasia *et al.* (1976)
4.9	30	2	37	26	-	-	-	-	-	-	-	Philippines	Dumlao & Perez (1976)
5.2 (4.9-5.4)	-	-	-	17	77 (76-78)	-	-	-	-	-	-	Australia	McManus & Choung (1976)
5.4 (3.8-6.6)	35 (30-45)	-	-	12 (7-16)	77 (72-81)	49 (45-52)	28	39 (36-43)	-	35 (30-45)	9	Sri Lanka	Sannasgala & Jayasuriya (1984)
5.5	35	1	49	11	75	46	29	34	6	-	-	Korea DPR	Yoon *et al.* (1983)
5.6	34	1	43	17	-	-	-	-	-	-	-	Ghana	Grieve (1976)
6.3	29	-	-	23	76	-	-	-	-	-	-	Philippines	Trung *et al.* (1984)
6.3	-	-	-	26	72	-	-	-	-	-	-	Indonesia	Winugroho & Chaniago (1984)
6.4 (3.7-9.5)	-	-	-	20 (16-23)	67 (61-70)	-	-	31 (24-38)	6 (4-8)	46 (36-55)	4	Philippines	Roxas *et al.* (1985)
6.9 (4.8-8.7)	30 (28-33)	-	-	26 (21-28)	61 (54-71)	55 (41-61)	6 (1-9)	30 (24-35)	8 (5-12)	38 (30-46)	15	Philippines	Roxas *et al.* (1984)
7.5	33	1	38	20	-	-	-	-	-	-	-	Bangladesh	Saadullah (1984)
MEANS													
4.2	33	2	44	18	75	52	23	38	6	42			
FEED COMPOSITION TABLES													
3.2	-	-	-	19	-	-	-	-	-	-		Australia	Leche *et al.* (1982)
3.7	31	1	35	21	-	-	-	-	-	-		Philippines	Gerpacio & Castillo (1979)
3.8	33	2	44	18	-	-	-	-	-	-		Asia	Kearl (1982)
5.4	36	2	39	18	-	-	-	-	-	-		Latin America	Kearl (1982)

*Values in parenthesis are the range of values reported.
**Nylon bag digestibility values.

Table 4.2. The macro-mineral (% dry matter) and trace mineral (mg/kg dry matter) contents of rice straw*

A. MACRO-MINERALS

Total ash (%)	Calcium (%)	Magnesium (%)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulphur (%)	Silica (%)	Number of varieties	Country/ Region	Reference
12 (7-16)	-	-	-	-	-	-	7 (5-8)	9	Sri Lanka	Sannasgala & Jayasuriya (1984)
15	0.62	-	0.10	-	-	-	-	-	Thailand	Wanapat *et al.* (1982)
15 (10-19)	0.33 (0.27-0.46)	-	0.09 (0.02-0.14)	-	-	-	-	5	India	Mohammed & Viswanatha Rai (1969)
15 (13-18)	0.53 (0.25-0.67)	-	0.31 (0.15-0.54)	0.41 (0.25-0.81)	0.20 (0.14-0.30)	-	-	11	India	Devasia *et al.* (1976)
15 (11-19)	0.42 (0.11-0.58)	0.32 (0.17-0.48)	0.21 (0.13-0.41)	2.05 (1.61-2.40)	-	-	-	6	Malaysia	Devendra (1982)
17	-	-	-	0.30	0.12	0.01	16	-	Australia	McManus & Choung (1976)
17	0.21	-	0.08	-	-	-	-	-	Korea DPR	Shin *et al.* (1981b)
20 (16-23)	-	-	-	-	-	-	16 (14-19)	4	Philippines	Roxas *et al.* (1985)
21 (17-24)	-	-	-	-	-	-	9 (6-12)	3	Sri Lanka	Sannasgala *et al.* (1985)
25	0.09	-	0.12	-	-	-	-	-	Indonesia	Moran *et al.* (1983)
26 (21-29)	-	-	-	-	-	-	18 (14-23)	15	Philippines	Roxas *et al.* (1984)
-	-	-	0.06	-	0.15 (0.09-0.22)	0.07	-	-	Australia	Ernst *et al.* (1976)
-	-	-	0.19 (0.08-0.32)	2.1 (1.5-2.6)	-	-	-	11	Bangladesh	Biwas & Choudhury (1981)
-	-	-	0.27 (0.23-0.32)	1.80 (0.29-2.29)	-	-	-	6	Bangladesh	Biwas & Choudhury (1981)
-	-	-	0.11 (0.09-0.13)	2.6 (2.0-2.9)	-	-	-	2	Bangladesh	Biwas & Choudhury (1981)
-	-	-	0.10 (0.04-0.18)	1.9 (1.7-2.2)	-	-	-	4	Bangladesh	Biwas & Choudhury (1981)
-	-	-	0.08 (0.06-0.10)	1.7 (1.5-1.7)	-	-	-	1	Bangladesh	Biwas & Choudhury (1981)
-	0.55	-	0.23	-	-	-	-	-	Indonesia	Soedomo (1982)
-	0.40	0.12	0.10	0.80	0.27	0.05	-	-	Korea DPR	Lee *et al.* (1983)
-	0.36	0.17	0.07	1.65	0.09	-	-	-	Thailand	Vijchulata *et al.* (1984)

-	0.22 (0.13-0.55)	0.19 (0.10-0.33)	0.12 (0.04-0.27)	-	0.10 (0.01-0.25)	-	-	-	Indonesia	Little (1985)
-	0.38 (0.33-0.45)	0.15 (0.11-0.21)	0.08 (0.03-0.15)	-	0.06 (0.00-0.13)	-	-	-	Indonesia	Little (1985)
MEANS										
18	0.37	0.19	0.14	1.53	0.14	0.04	13			
FEED COMPOSITION TABLES										
18	0.29	0.11	0.36	1.32	0.31	-	-		Latin America	Kearl (1982)
18	0.32	0.11	0.10	1.95	0.02	-	-		Asia	Kearl (1982)
19	-	-	-	-	0.05	-	-		Australia	Leche *et al.* (1982)

B. TRACE MINERALS

Total ash (%)	Copper (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Zinc (mg/kg)	Number of varieties	Country/ Region	Reference
15 (11-19)	1 (1-2)	-	-	75 (68-81)	6	Malaysia	Devendra (1982)
-	21 (17-24)	-	399 (307-365)	221 (168-290)	1	Bangladesh	Biwas & Choudhury (1981)
-	4	644	-	20	-	Korea DPR	Lee *et al.* (1983)
-	1	467	444	13	-	Thailand	Vijchulata *et al.* (1984)
-	3 (2-3)	392 (96-690)	241 (53-510)	31 (18-43)	-	Indonesia	Little (1985)
-	2 (2-3)	74 (18-160)	440 (190-270)	22 (2-59)	-	Indonesia	Little (1985)
MEANS							
15	5	394	381	64			
FEED COMPOSITION TABLES							
18	-	-	346	-	-	Latin America	Kearl (1982)
18	3	449	276	58	-	Asia	Kearl (1982)

*Values in parenthesis are the range of values reported

Table 4.3. Intake, digestibility and liveweight change in ruminants fed rice straw*

Liveweight (kg)	Straw dry matter intake (kg/day)	(kg/100kg LW)	(g/kg $LW^{0.75}$)	Dry matter digestibility (%)	Liveweight change (g/day)	Country	Reference
A. BUFFALOES							
98	2.56	2.6	82			India	Ramachandra Reddy & Das (1982)
100	1.89	1.9	60			India	"
109	2.19	2.0	65			India	"
195	3.6	1.9	70	49		Thailand	Cheva-Isarakul & Cheva-Isarakul (1984a)
200	4.21	2.1	79	50	−182	Thailand	Wanapat et al. (1984)
260	4.68	1.8	73	37		Indonesia	Moran *et al.* (1983)
279	4.60	1.7	67	55		Thailand	Wanapat (1985)
289	5.87	2.0	84	43	−103	Thailand	Wongsrikeao & Wanapat (1985)
309	7.62	2.5	105			Philippines	Castillo *et al.* (1982)
MEANS		2.1	76	47			
B. CATTLE							
114	3.03	2.7	87	44	−34	Thailand	Wanapat *et al.* (1984)
133	2.95	2.2	75			India	Ramachandra Reddy & Das (1982)
140	3.37	2.4	83			India	"
141	3.05	2.2	75			India	"
142	3.02	2.1	73		−165	Thailand	Suriyajantratong & Wilaipon (1985)
180	3.47	1.9	71	41		Sri Lanka	Ibrahim (1985)
199	3.36	1.7	63		−149	Australia	McLennan *et al.* (1981)
233	2.8	1.2	46	51		Thailand	Cheva-Isarakul & Cheva-Isarakul (1984a)
276	5.13	1.9	75	38		Indonesia	Moran *et al.* (1983)
286	4.97	1.7	65		−134	Thailand	Wanapat *et al.* (1982)
MEANS		2.0	71	44			

C. SHEEP							
20	0.40	2.0	43	37		Malaysia	Devendra (1978)
20	0.27	1.4	29	35		Korea DPR	Yoon *et al.* (1983)
20	0.33	1.7	35	43		Malaysia	Sharif & Fadzil (1985)
22	0.57	2.6	51	46		Malaysia	Devendra (1983)
22-24	0.45	2.0	43	40		Malaysia	Devendra (1976)
24	0.54	2.3	50	41		Malaysia	Devendra (1983)
25	0.64	2.5	55	45		Malaysia	"
25	0.68	2.7	60	42		Malaysia	"
25	0.48	1.9	43	36		Malaysia	"
25	0.68	2.7	60	43		Malaysia	"
26	0.47	1.8	41	45		Malaysia	"
26	0.56	2.2	50	48		Thailand	Cheva-Isarakul & Cheva-Isarakul (1984b)
25-28	0.36	1.5-1.0	33-24	40		Australia	McManus *et al.* (1972a)
27	0.64	2.3	53	50		Thailand	Cheva-Isarakul & Cheva-Isarakul (1984b)
27	0.58	2.1	48	47		Thailand	"
29	0.54	1.9	43	43		Thailand	Cheva-Isarakul & Cheva-Isarakul (1984a)
31	0.67	2.2	51	55		Thailand	Cheva-Isarakul & Cheva-Isarakul (1984b)
36	0.85	2.4	58	47		Thailand	"
37	0.38	1.0	25	35	−92	Thailand	Vijchulata & Sanpote (1982)
41-52	0.56	1.4-1.1	35-29	47		Australia	McManus *et al.* (1972b)
MEANS		2.0	45	43			
D. GOATS							
26	0.48	1.8	40	44		Malaysia	Devendra (1983)
28	0.56	2.0	46	52		Malaysia	"
MEANS		1.9	43	48			

*Some of the data presented in this table have been calculated from information given in the reports cited.

4.5. Variability in intake and in *in vivo* digestibility of rice straw

Rice straw has been fed alone in a number of experiments and the intake and digestibility results are presented in Table 4.3. *In vivo* dry matter digestibility values range from 37 to 55% for buffaloes and cattle, and from 35 to 55% for sheep and goats. In one experiment (Sharif, 1984) where sheep were allowed to select the more nutritious parts and some grain from fresh and stored straw, digestibilities of over 60% were recorded. From Table 4.3 it can be seen that, for buffaloes and cattle, intakes up to 7.6 kg dry matter per day have occurred and for sheep and goats up to 0.85 kg dry matter per day. On the basis of liveweight, intakes of buffaloes and cattle have ranged from 1.2 to 2.7 kg/100 kg liveweight and intakes of sheep and goats have ranged from 1.0 to 2.7 kg/100 kg liveweight. However, when compared on the basis of metabolic liveweight, which assumes that $LW^{0.75}$ is the appropriate scaler for comparison between species, then large ruminants consumed between 46 and 105 g/kg $LW^{0.75}$ (mean 74) compared to only 25 to 60 g/kg $LW^{0.75}$ (mean 46) by small ruminants. This may indicate that large ruminants, the animals which are traditionally fed rice straw, are better able to consume this type of feed. In all cases where liveweights were measured animals fed rice straw alone lost weight.

The reasons for these wide ranges in intake and digestibility are not clear and many factors could be contributing. In the first instance, variation in the straws, themselves, would undoubtedly have contributed. The low voluntary intake of rice straw has often been attributed to the high content of slowly fermentable cell wall materials. Recently, Terashima and Itoh (1984) have implicated low palatability as another contributing factor. While there are indications from preference tests that the acceptability or palatability of rice straw can be improved by adding sweeteners (Toyokawa and Tsubomatsu, 1977), there have been no experiments comparing preferences for different straws or showing that there is a palatability effect *per se* superimposed on nutrient limitations. Secondly, animal factors, such as age and body condition, genotype and species, nutrition prior to experiments and health would also contribute to the ranges in intake and digestibility reported. Finally, variations in the data presented could be due to differences in experimental procedures used and in management of experimental animals, and, importantly, due to errors associated with poor experimentation.

4.6 The potential significance of wide variability in the feeding value of rice straw

The wide variability in the chemical composition, digestibility and intake of rice straw that has been reported has prompted researchers to attempt to define the factors that might be responsible. The practical importance of this lies in the fact that rice straw of "high quality" might be expected to meet nearly all of the energy requirements for maintenance of ruminants, while straw of average and low quality falls far short of meeting those needs and, in any case, is likely to be consumed at low levels. A knowledge of the factors affecting straw quality might be valuable from three points of view: (a) it might permit a farmer to predict, some time before grain harvest, whether the crop residue will be of high or low quality so that he can adjust his alternative feed resources (if any) accordingly; (b) it might suggest modifications to the procedures associated with growing the crop (obviously, of course, without jeopardy to the amount and quality of grain) and with the handling and storage of the straw after grain harvest; (c) it might provide critical information to rice breeders to assist them to select varieties having improved straw characteristics as well as the desirable grain attributes. While a knowledge of the factors affecting the feeding value of rice straw might have these beneficial effects, it is stressed from the outset that sophisticated and time-consuming measurements of chemical composition of straws should be left largely to those involved in basic research. A proliferation of such measurements can only be justified when their benefits to practical feeding situations have been demonstrated. Having made this qualification, much of the ensuing discussion is by necessity based on such measurements of chemical composition in conjunction with laboratory assessments of digestibility.

4.7 Plant factors contributing to variability in feeding value

The nature and extent of variation in the plant itself have attracted some detailed attention, but most of the studies in this field have been commenced comparatively recently. Results to date have not been sufficiently comprehensive to have any practical impact, but some clarification has been achieved as to the most important features in relation to nutritive value that require attention. The two major aspects that have been shown to be significant are (a) the relative proportions of the different plant parts that constitute a given batch of straw and that an animal actually eats, and (b) the extent of variation in nutritive value that occurs within particular plant parts. Within plant parts, the respective roles of cell contents and cell walls are critical, particularly in senescent and dead tissues where they behave as separate nutrient pools with distinct characteristics. It is important to appreciate that, when a whole plant or a mixture of plant parts is fed to animals, or even subjected to *in vitro* digestibility procedures, the pattern of digestion that occurs is the resultant of two or more separate and distinct patterns.

4.7.1 *The proportions of different plant parts*

The major plant parts in straw are the leaf blades, the leaf sheaths and the stem. The stem may be divided into internodes and nodes but the nodes are relatively unimportant because of their small proportionate mass. Winugroho (1981) found that internodes constituted 31% of the total rice straw, and leaf sheaths 36% and blades 28%, but large variability occurred in the proportions of each of these fractions. The *in vitro* organic matter digestibility (IVOMD) values were: internodes 54% (ranging from 42 to 77%); sheaths 45% (from 38 to 56%); blades 52% (from 45 to 60%). In a similar study in Sri Lanka, Sannasgala and Jayasuriya (1984) found that, for straw from four rice varieties, stem internodes comprised 31% (range 18 to 50%) of dry matter, leaf sheaths 33% (24 to 37%) and leaf blades 31% (21 to 43%). They also reported wide ranges in the IVOMD of plant parts for a greater number, nine varieties: internodes 44% (ranging from 35 to 50%); sheaths 31% (24 to 45%); blades 32% (20 to 52%).

In studying 24 varieties of rice straw collected in Malaysia, C. Devendra, S. Kent and G. R. Pearce (unpublished data) obtained compositional data and IVOMD values for internodes, sheaths and blades as shown in Table 4.4. In these rice straws, some heterogeneous combinations occurred in individual samples. For example, one sample yielded IVOMD values for internodes, sheaths and blades of 46, 54 and 59%, respectively, while another yielded values of 51, 51 and 42%, respectively. Thus, the digestibility of the leaf blades may be appreciably higher or appreciably lower than that of the internodes in material from different sources.

The differences in chemical composition and mean IVOMD between the plant parts of rice straws in these studies do not appear to be as pronounced as those reported for some other cereal straws. For example, Winugroho (1981) found that the IVOMD values of wheat straw internodes, sheaths and blades were 27, 53 and 68%, respectively. However, it is apparent

Table 4.4 Chemical composition (% of dry matter) and *in vitro* organic matter digestibility (IVOMD, %) of internodes, sheaths and blades of rice straw. (C. Devendra, S. Kent and G. R. Pearce, unpublished data)

	Internodes		Sheaths		Blades	
	mean	range	mean	range	mean	range
Crude protein	2.7	1.7-6.4	3.5	2.0-6.9	4.6	3.2-8.6
Total ash	15	11-20	20	14-25	18	12-25
Residual ash	8	6-13	14	6-20	14	8-20
Neutral detergent fibre	81	77-85	82	77-86	76	71-81
Acid detergent fibre	60	55-64	57	54-62	51	47-56
Hemicellulose	21	13-28	25	21-31	25	20-29
Cellulose	47	38-51	39	33-49	31	27-35
Lignin	5	4-6	4	4-6	6	4-8
IVOMD	42	34-54	45	39-55	44	31-59

that the chemical composition and digestibility of rice straws can be influenced by the inclusion of different plant fractions.

4.7.2 *The cell contents*

The cell contents, which can be measured as neutral detergent solubles (NDS = 100 – NDF), include soluble proteins, non-protein nitrogen compounds, sugars, starches, lipids and minerals (Van Soest, 1982). The data in Table 4.1 indicate values in rice straw ranging from 14 to 46%. Generally, the digestibility of cell contents is high, being reported as 98% (Van Soest, 1976) and 86 to 92% (Moir, 1974, 1982) for a wide range of grasses; 92% for *Panicum* spp. (Minson, 1971); and 92% for rice straw internodes (Pearce, 1984). While it is possible that the digestibility of this fraction can be lower than these values this is only likely to occur in materials with less than 20% cell contents.

Because of the generally high digestibility of cell contents, this fraction can potentially influence the organic matter digestibility of straws to a great extent and it is, therefore, pertinent to focus attention on the extent to which different proportions of cell contents, particularly storage proteins and carbohydrates, might remain in senescent and dead plant material. It has been shown in wheat (Blacklow and Incoll, 1981; L. Incoll, personal communication) that the upper stem segments and leaves act as storage tissues for fructans and soluble nitrogen compounds. In rice, starch is also an important storage carbohydrate (Itoh *et al.*, 1981). The synthetic processes associated with such storage are most active shortly prior to anthesis and, in the case of the top-most segments, for several weeks afterwards. Following anthesis, grain development proceeds slowly at first, but then there is rapid movement of stored materials into the grain which increases greatly in volume and mass during a period of several weeks. The stem and leaves thus become depleted of solubles and their organic matter digestibility falls. In terms of straw quality, the critical features are, therefore, (a) the amount of storage of cell solubles, and (b) the extent of their subsequent removal during the grain-filling period. Presumably, the efficiency and effectiveness of both of these operations can be affected by environmental conditions interfering with the metabolic activity of the plant tissues. The conditions of plant growth that might be important in these respects are soil nutrient availability, water availability, light conditions, the ambient temperature range, and, superimposed on these, the incidence of plant diseases. The effects of these factors on the proportion of NDS in crop residues have not been investigated in any comprehensive manner. There might also be genotype X environment interactions that could be significant in the final outcome.

4.7.3 *The cell wall*

The main components of the cell wall are cellulose, hemicellulose, lignin and residual ash. The data in Table 4.1 show the mean cellulose content of rice straw ranging from 30 to 51% of the dry matter; hemicellulose content ranging from 6 to 28% and lignin content ranging from 4 to 10%.

S. Kent (University of Melbourne, unpublished data) has obtained cell wall digestibility values of rice straw internodes, measured *in vitro*, ranging from approximately 35 to 50%, but insufficient measurements have been made to permit the conclusion as to whether this represents the full range that might occur. In addition, the cell walls in different parts of plants may be widely different in their digestibilities.

Aspects of the chemical and physical structure of the plant cell wall that limit its digestibility continue to be studied intensively in many laboratories throughout the world. Although there is widespread agreement as to the limiting role of lignin on digestibility, the specific mode of action remains unclear. The traditional view that lignin forms an encrusting barrier against enzyme penetration and, hence, cellulose and hemicellulose digestion, has not been discounted in principle, but evidence of more specific means of protection or inhibition has been sought. For example, attention has been drawn to the complexity of the lignin molecule and its resistance to degradation (e.g. Hall, 1980), and emphasis has been placed upon its physical and chemical relationship to the other cell wall components and to the characteristics of the other components themselves. Lignin is known to be bonded strongly to hemicellulose (but probably not to cellulose) and the nature of this bonding has been regarded as a barrier to digestion (Wardrop, 1971). Hartley (1972) and Hartley and Jones (1976) proposed that phenolic acids associated with lignin were active inhibitors of microbial enzymes. Despite a great deal of follow-up work the specific mode of action of these compounds has not been determined and doubt exists as to their significant. However, Chesson (1982) suggested that the accumulation of inhibitors, such as polyphenolic material, resulting from the removal of digestible fractions, might be sufficient to block adhesion sites of bacteria or of their enzyme complexes. An inhibitory role of acetyl groups associated with hemicellulose has also been suggested by Morris and Bacon (1977) but the evidence of Chesson (1981) did not support these claims.

The nature of cellulose, in terms of the occurrence of refractory crystalline areas that constitute part of the fibrillar structure (Cowling, 1975), has also been incriminated as contributing to the slow digestion of cell walls. However, the significance of this feature in graminaceous species as against trees has been questioned (Puri, 1984). The degree of polymerization of cellulose molecules has also been implicated but the evidence is not sufficient, at least in the case of cereal straws, to draw firm conclusions.

Silica has long been regarded as contributing to poor digestibility in plants, including rice, that accumulate the compound but the nature of its possible involvement has not been established. Rice straws can contain between 5 and 23% silica (Table 4.2). In this regard, Van Soest and Jones (1968) found a strong negative relationship between silica content and digestibility of grasses in the eastern parts of the United States, but Minson (1971) found a poor relationship when he examined varieties of the tropical grass, *Panicum*, in Australia. McManus *et al.* (1977) suggested that the cell wall includes a framework of insoluble mineral complexes of calcium, phosphorus, magnesium and silicon which prevent the penetration of enzymes. However, the exact nature of this framework has not been established and the evidence for it has been questioned by Harper *et al.* (1982).

Other approaches to cell wall digestion have been directed towards examining the interface between plant tissue and cellulolytic organisms. The micro-organisms that digest the cell contents are not necessarily the same as those that digest the cell wall but it is thought that there is a strong symbiosis between them and that such a symbiotic relationship is essential for digestion to initiate and proceed (Demeyer, 1981; Cheng *et al.*, 1983). The evidence for this is that the organisms which digest the cell wall need to adhere to the straw particles before digestion can take place. This adherence or colonization apparently takes place very quickly, perhaps within minutes, but there is a pronounced lapse of many hours before measurable amounts of cell wall disappear suggesting the need for a build-up in concentration and types of bacteria and their enzymes before digestion takes place. In general, once digestion is initiated, the pattern follows a sigmoid curve in which the steady rate of digestion may extend over a considerable period until it flattens out to reach the potential digestibility determined by the nature of the substrate and of the microbial population (Hungate, 1966).

Electron microscope studies have emphasised the differences in the degradability of walls of different cell types and Akin and Burdick (1975) have ranked rates of cell wall digestion (fastest to slowest), as follows: mesophyll, phloem > epidermis, parenchyma sheath > sclerenchyma > lignified vascular tissue. Such studies have raised the question as to what extent the differences in cell wall digestion within a plant part is due merely to the proportions of different cell types and of the characteristics of their cell walls. Such a question is difficult to answer because it requires the quantitative isolation of the different cell walls and examinations of their specific characteristics. Separation of cell walls has been achieved with fresh, vegetative material (e.g. McCluskey *et al.*, 1984) and the digestibility of the whole plant was attributable largely to the proportions of different cell types, particularly to the amount of vascular cell walls in the stems. Similar techniques have not been successful with straw.

The rate of colonization and the rate of initial digestion is probably affected by the extent to which rice straw is reduced in particle size during eating and rumination. The greater the extent of particle size reduction, the greater the release of cell contents and the greater the accessibility of the inner cell wall to bacterial colonization. The external plant surfaces are protected by cutin and waxes which are relatively indigestible and so form a barrier to bacteria. These factors are important in determining intake and digestion, but studies in this aspect of rice straw digestion are scarce. Particle size of digesta in the rumen is also important because only small particles pass readily out of the reticulo-rumen into the lower digestive tract. Therefore, particle size reduction is an important feature of the retention time or rate of passage of digesta. It is not, however, the only criterion because many small particles are held in the main body of digesta in the rumen before they are separated out and conveyed via the reticulum to the lower digestive tract.

Taking into account all of these considerations, characteristics such as the rate of colonization by bacteria and the rate of digestion would be expected to be important in terms of the amount of digestion attained. However, in straw, and particularly with straws of different qualities, these aspects have not been examined comprehensively. Certainly, under normal conditions, the digestion of the cell wall in the reticulo-rumen is critical because little further digestion takes place in the lower digestive tract.

In spite of all of the investigations that have been conducted into the many aspects of cell wall composition and structure the essential features that determine its digestibility by rumen micro-organisms have not been resolved. The questions as to the effects of changes in cell wall composition on its digestibility is still an important one and the extent to which environmental conditions in the growth of plants can affect cell wall composition is an area of research that is attracting a great deal of attention.

4.8 Environmental factors affecting the chemical composition and digestibility of plants

Many of the studies conducted to determine the effects of environmental conditions on chemical composition and digestibility have been with pasture species and have not always been carried through to the senescent stages of plant growth. Wilson (1982) has reviewed many of the investigations of effects of light, temperature, soil moisture and fertilizers.

4.8.1 *Light*

The effect of growing grasses under low light intensities has been shown to decrease their digestibility. Usually the decreases have been small (1-5 percentage units) but Wong (1978) reduced digestibility by 10-12 units by growing *Panicum maximum* under conditions of 60 or 40 percent shade for 2 to 4 months. Such decreases are apparently caused by a reduction in the proportion of soluble carbohydrates in the plant (Smith, 1973), increases in cell wall components (e.g. Burton *et al.*, 1959) and a decrease in the proportion of mesophyll in relation to epidermis (e.g. Evans, 1964). The extent to which such changes may occur in rice grown under normal conditions in different regions is not known.

4.8.2 *Temperature*

In general, the effect of increasing temperatures, in the case of both tropical and temperate grasses, is to reduce their digestibility. Dirven and Deinum (1977) attributed the decrease in digestibility to more rapid growth of the plants, particularly of the stem, resulting in a lower proportion of soluble carbohydrates and a corresponding increase in the cell wall content at different stages of growth. Decreases in cell wall digestibility have been reported (Deinum and Dirven, 1976; Moir *et al.*, 1977) attributable to apparently greater lignification (e.g. Ford *et al.*, 1979).

4.8.3 *Soil moisture*

In surveying the literature on the effects of moisture stress, Wilson (1982) concluded that relatively moderate stress has either no effect on digestibility or that it resulted in increases. Increases are caused by slower growth, and more leafiness because of delayed stem development; maturity is delayed and the decline in digestibility associated with normal ageing is retarded. In water-stressed plants the contents of soluble carbohydrates may be increased (Ford and Wilson, 1981) and cell wall and lignin contents may be reduced (Wilson *et al.*, 1980). The effects of moisture stress on the chemical composition and nutritive value of cereal straws has not been examined in detail.

4.8.4 *Fertilizers*

4.8.4.1 *Nitrogen.* Wilson (1982) has pointed out the variable responses that have been obtained

Table 4.5. Chemical composition (% dry matter) and *in vitro* organic matter digestibility (IVOMD, %) of rice straw following varying levels of nitrogen fertilizer application

Fertilizer level (N kg/ha)	Composition of straw								
	Crude protein	Total ash	Neutral detergent fibre	Acid detergent fibre	Hemi-cellulose	Cellulose	Lignin	Silica	IVOMD
A. Sannasgala *et al.* (1985)—Sri Lanka[1]									
50	3.4	21	72	50	22	31	7	11	39
100	4.4	22	71	49	22	31	7	8	36
150	3.7	19	72	49	23	32	8	8	40
[1]Means of three varieties of rice; for varietal differences see Table 4.6									
B. Roxas *et al.* (1985)[2]									
0 Wet season	5.6	20	67	-	-	31	6	16	48
30	6.2	21	67	-	-	28	6	17	48
60	6.2	22	66	-	-	29	6	17	48
120	6.9	21	65	-	-	29	6	17	48
0 Dry season	6.1	18	68	-	-	33	5	15	44
30	6.0	18	67	-	-	32	5	15	44
60	6.6	18	68	-	-	32	6	15	42
120	6.9	19	66	-	-	31	6	16	46

[2]Means of four varieties of rice; for varietal differences see Table 4.6

to nitrogen fertilizer application on the digestibility of grasses. Increased digestibility may be obtained from the stimulation of new growth with a high protein content and a low cell wall content. However, decreased digestibility may result from a more rapid rate of maturation, an increased number of flowering culms and greater stem development. The rate of leaf senescence may also be increased. Hence, the overall effect of nitrogen fertilizer application to a pasture is likely to depend upon the time interval from application to sampling or measurement and upon the stage of growth of the pasture. It is not clear how these interactions affect the quality of senescent and dead material such as straw.

Recently, several measurements have been made on rice straw fertilized with varying levels of nitrogen. The results are summarized in Table 4.5. In these data the only pronounced effect was that nitrogen fertilizer application increased markedly the nitrogen content of the straw analysed by Roxas *et al.* (1985). There were no changes in the proportions of cell contents and cell walls and consequently no marked or consistent effects on IVOMD occurred in either experiment.

4.8.4.2 *Phosphorus.* The applicationof phosphatic fertilizer to grasses has not been shown to have any marked effect on digestibility (Wilson, 1982).

In general, the results of experiments in which environmental effects on pasture species have been studied are difficult to extrapolate to cereal straws for two main reasons: (a) measurements made on grasses have usually been made in immature, vegetative material without continuing through to measure effects on senescent and dead plants, (b) any effects on cell wall composition have often been distorted by expressing cell wall components as a proportion of dry matter rather than as a proportion of cell wall. Sometimes changes in cell wall composition have been implied when, in fact, increases in lignin, cellulose and hemicellulose contents, as percentage of dry matter, have arisen merely as a result of a decrease in the proportion of cell contents.

4.9 Genotypic contributions to variability in rice straw quality

It is generally believed that differences occur between cultivars in their nutritive value, but the nature and magnitude of such differences have not been defined clearly enough for them to be taken into account in the practical situation. Some of the comparisons that have been made are shown in Table 4.6. In some cases the differences in chemical composition and digestibility revealed by these data are apparently great enough to constitute strong evidence of differences due to the genotype, but it is necessary to exercise caution in drawing conclusions because of the difficulties in relation to sampling outlined previously. In addition, genotype X environment interaction might favour one cultivar over another if they are both grown in one location, but perhaps not if they were grown under other conditions.

The data of Devendra, Kent and Pearce (previously unpublished), included in Table 4.6, show some differences in the chemical composition and IVOMD of the main parts of the straw lending support to the contention that real differences occur between varieties. In fact, however, it is quite difficult to show conclusively that one cultivar produces a higher quality straw than another. Experimentally, approaches to overcoming the problems may be followed at two levels. In the first case, where the straw used for feeding to animals is derived from set and invariable practices in relation to the time of grain harvest (in terms of development and stage of maturity of the plant), height of cutting, rate of drying, method of threshing, and subsequent handling, storing and feeding of the straw, then it is valid to compare samples of straw of different cultivars in the form in whch they are fed. Repeated comparisons in different locations may then show one straw to be superior to another. However, usually there is no guarantee that the series of operations leading up to the feeding of straw is consistent, in which case a second approach of evaluating straws might be adopted. This involves sampling whole plants at the time of grain harvest, separating the main morphological fractions (at least, the stems, leaf blades and leaf sheaths), and performing analyses separately on each fraction. From such data, the composition and digestibility of different combinations of fractions can be calculated to apply to a range of different conditions. If fractionation is made from the top of the plant to the bottom, then effects of different heights of cutting can be calculated. Again, in comparing cultivars, such examinations need to be conducted over a range of locations to determine whether genotype X environment interactions occur. To date, comparisons of cultivars of rice have

Table 4.6. Chemical composition (% dry matter) and *in vitro* organic matter digestibility (IVOMD, %) of rice straw of different varieties

Variety	Crude protein	Crude fibre	Ether extract	Nitrogen free extract	Total ash	Neutral detergent fibre	Acid detergent fibre	Hemi-cellulose	Cellulose	Lignin	Residual ash	Silica	IVOMD
A. McManus and Choung (1976) – Australia													
Calrose	4.9	-	-	-	17	78	-	-	-	-	-	17	34*
Kulu	5.4	-	-	-	17	76	-	-	-	-	-	16	34
**In vitro* dry matter digestibility													
B. Devendra (1979) – Malaysia													
Bahagia	4.2	30	1	46	18	-	-	-	-	-	-	-	-
Mahsuri	3.6	32	1	45	18	-	-	-	-	-	-	-	-
Mat Candu	3.3	29	2	35	11	-	-	-	-	-	-	-	-
Malinja	3.7	34	1	43	19	-	-	-	-	-	-	-	-
Murni	4.5	30	2	55	15	-	-	-	-	-	-	-	-
Ria	3.3	29	2	55	11	-	-	-	-	-	-	-	-
Sri Malaysia I	4.5	26	2	51	17	-	-	-	-	-	-	-	-
C. Haque *et al.* (1981) – Bangladesh													
BR3	3.0	23	-	-	12	-	-	-	-	-	-	-	30*
BR4	2.7	21	-	-	13	-	-	-	-	-	-	-	31
BR5	2.7	21	-	-	12	-	-	-	-	-	-	-	33
IR20	3.3	20	-	-	13	-	-	-	-	-	-	-	34
Nizershail	2.7	23	-	-	11	-	-	-	-	-	-	-	35
*Dacron bag dry matter digestibility values													
D. Winugroho (1981) – Australia													
Kulu	-	-	-	-	-	-	-	-	-	-	-	-	52
YR-73	-	-	-	-	-	-	-	-	-	-	-	-	50
Inga	-	-	-	-	-	-	-	-	-	-	-	-	51
Calrose	-	-	-	-	-	-	-	-	-	-	-	-	52
71001	-	-	-	-	-	-	-	-	-	-	-	-	49
71003	-	-	-	-	-	-	-	-	-	-	-	-	51
Bungala	-	-	-	-	-	-	-	-	-	-	-	-	57
Shioji	-	-	-	-	-	-	-	-	-	-	-	-	51
Chow Sung	-	-	-	-	-	-	-	-	-	-	-	-	44
Ali Combo	-	-	-	-	-	-	-	-	-	-	-	-	50
Honenwari	-	-	-	-	-	-	-	-	-	-	-	-	57
M9	-	-	-	-	-	-	-	-	-	-	-	-	55
HD45	-	-	-	-	-	-	-	-	-	-	-	-	53
Tainan 3	-	-	-	-	-	-	-	-	-	-	-	-	46
Balila Solana	-	-	-	-	-	-	-	-	-	-	-	-	49
SML 1010-1	-	-	-	-	-	-	-	-	-	-	-	-	62
Rykito-Norin 20	-	-	-	-	-	-	-	-	-	-	-	-	51
Itape	-	-	-	-	-	-	-	-	-	-	-	-	46
Calrose 76	-	-	-	-	-	-	-	-	-	-	-	-	50
IR 1105	-	-	-	-	-	-	-		-	-	-	-	56

Table 4.6 cont.

Variety	Crude protein	Crude fibre	Ether extract	Nitrogen free extract	Total ash	Neutral detergent fibre	Acid detergent fibre	Hemi-cellulose	Cellulose	Lignin	Residual ash	Silica	IVOMD
Criollo	-	-	-	-	-	-	-	-	-	-	-	-	53
E. Shin *et al.* (1981a) – Korea DPR													
Akibare	5.7	37	-	-	13	79	54	26	34	10	-	-	30*
Tongil	4.4	36	-	-	12	79	51	27	36	9	-	-	38
Milyang 23	3.8	35	-	-	17	78	53	25	35	8	-	-	40
Yooshin	3.9	34	-	-	17	78	53	24	36	7	-	-	44
Suwon 264	4.2	34	-	-	15	78	52	26	34	7	-	-	41
*Nylon bag organic matter digestibility values													
F. Roxas *et al.* (1984)* – Philippines													
IR5	6.9	31	-	-	26	67	55	12	31	7	-	17	38
IR20	6.9	32	-	-	27	59	56	4	33	7	-	16	33
IR24	7.8	30	-	-	28	58	54	4	29	7	-	18	35
IR28	7.8	29	-	-	26	57	53	4	29	7	-	18	39
IR30	7.5	30	-	-	26	58	54	4	30	6	-	18	-
IR32	6.3	29	-	-	26	56	53	3	29	6	-	19	42
IR36	7.5	31	-	-	22	61	56	5	31	10	-	14	36
IR38	7.6	30	-	-	25	67	58	10	31	10	-	17	31
IR40	8.0	29	-	-	26	63	57	7	29	11	-	17	31
IR42	6.2	30	-	-	26	57	54	2	29	6	-	19	42
IR44	5.7	31	-	-	25	65	56	9	31	6	-	19	42
IR46	4.9	31	-	-	25	58	50	8	28	7	-	20	44
IR48	5.6	30	-	-	25	55	49	7	28	6	-	20	43
IR50	6.8	31	-	-	25	64	56	8	30	10	-	16	36
IR52	7.4	31	-	-	26	64	60	3	32	11	-	17	33
*Means of values from plots sprayed or not sprayed with insecticide													
G. Sannasgala and Jayasuriya (1984) – Sri Lanka													
Bg 380-2	-	-	-	-	-	-	-	-	-	-	-	-	45
Bg 3-5	-	-	-	-	-	-	-	-	-	-	-	-	41
Bg 276-5	-	-	-	-	-	-	-	-	-	-	-	-	34
Bw 266-7	-	-	-	-	-	-	-	-	-	-	-	-	30
Bw 100	-	-	-	-	-	-	-	-	-	-	-	-	34
Bw 78	-	-	-	-	-	-	-	-	-	-	-	-	33
Bw 267-3	-	-	-	-	-	-	-	-	-	-	-	-	34
Bw 293-1	-	-	-	-	-	-	-	-	-	-	-	-	31
Bw 293-2	-	-	-	-	-	-	-	-	-	-	-	-	37
H. Cheva-Isarakul and Cheva-Isarakul (1985)* – Thailand													
Sanpatong	3.6	-	-	-	18	75	54	-	-	5	-	-	45
Mali	3.4	-	-	-	17	73	53	-	-	5	-	-	47
RD 1	4.2	-	-	-	19	74	54	-	-	5	-	-	48
RD 6	3.4	-	-	-	17	73	53	-	-	5	-	-	47
RD 7	4.6	-	-	-	19	74	53	-	-	4	-	-	51

RD 8		3.8	-	-	-	19	74	53	-	-	5	-	-	47
RD 10		5.1	-	-	-	19	75	56	-	-	5	-	-	49
*Data for individual varieties was provided by the authors														
I. Roxas *et al*. (1985)* – Philippines														
Wet season														
H4		4.8	-	-	-	22	68	-	-	33	6	-	16	45
IR8		7.1	-	-	-	22	65	-	-	27	6	-	18	48
IR36		7.3	-	-	-	20	63	-	-	28	6	-	16	53
IR42		5.6	-	-	-	20	68	-	-	31	5	-	17	47
Dry season														
H4		6.2	-	-	-	17	69	-	-	37	5	-	15	39
IR8		7.6	-	-	-	19	64	-	-	27	7	-	17	45
IR36		6.0	-	-	-	19	67	-	-	32	5	-	14	51
IR42		6.1	-	-	-	18	68	-	-	32	6	-	15	41
*Means of four levels of nitrogen fertilizer; for fertilizer effects see Table 4.5														
J. Sannasgala *et al.** – Sri Lanka														
BG 34-6		3.8	-	-	-	20	73	48	25	30	7	-	8	39
BG 276-5		4.2	-	-	-	21	72	50	22	32	8	-	8	37
Heenati		3.7	-	-	-	21	70	50	20	32	7	-	11	38
*Means of three levels of nitrogen fertilizer; for fertilizer effects see Table 4.5														
K. Hart and Wanapat (1985) – Thailand														
RD2		3.1	-	-	-	16	78	56	-	-	5	-	10	41*
RD6		3.6	-	-	-	18	76	56	-	-	4	-	11	41
RD8		3.1	-	-	-	18	76	56	-	-	4	-	11	42
RD10		3.7	-	-	-	17	78	53	-	-	4	-	9	42
Kham Phai		2.1	-	-	-	15	82	57	-	-	5	-	8	41
Sun Patong		3.5	-	-	-	16	77	53	-	-	4	-	9	43
Neeo Ubon		2.7	-	-	-	14	74	51	-	-	5	-	8	45
RD7		2.7	-	-	-	15	79	55	-	-	4	-	7	40
RD9		3.3	-	-	-	13	79	54	-	-	4	-	6	41
RD11		4.4	-	-	-	16	76	52	-	-	5	-	9	43
RD15		3.1	-	-	-	15	78	54	-	-	5	-	8	41
RD21		1.9	-	-	-	15	80	57	-	-	5	-	8	41
RD23		2.4	-	-	-	16	80	58	-	-	5	-	9	46
RD25		6.9	-	-	-	18	72	46	-	-	4	-	10	45
RD27		2.8	-	-	-	16	78	55	-	-	6	-	8	40
Kauw Dok Mali 105		3.0	-	-	-	14	81	55	-	-	4	-	7	42
Naang Mon-S-4		3.1	-	-	-	13	80	48	-	-	6	-	7	40
**In vitro* dry matter digestibility														
L. Devendra, Kent and Pearce (unpublished data) – Malaysia														
Kadaria (a)	In*	2.8	-	-	-	16	82	64	17	48	6	10	10	40
	Sh	3.9	-	-	-	25	82	62	21	37	5	20	20	48
	Bl	4.8	-	-	-	22	80	56	24	31	6	19	19	47
Kadaria (b)	In	1.5	-	-	-	13	83	55	28	38	4	13	-	34
	Sh	2.1	-	-	-	18	83	61	22	49	6	6	-	38
	Bl	3.9	-	-	-	18	78	50	28	30	6	14	-	31

Table 4.6 cont.

Variety		Crude protein	Crude fibre	Ether extract	Nitrogen free extract	Total ash	Neutral detergent fibre	Acid detergent fibre	Hemi-cellulose	Cellulose	Lignin	Residual ash	Silica	IVOMD
Sri Malaysia (a)	In	3.4	-	-	-	14	83	59	25	47	4	8	-	45
	Sh	3.6	-	-	-	18	85	56	29	40	4	12	-	44
	Bl	3.8	-	-	-	16	81	52	29	34	4	14	-	41
Sri Malaysia (b)	In	2.2	-	-	-	19	77	64	13	49	5	10	10	51
	Sh	3.5	-	-	-	23	83	58	24	39	4	16	15	52
	Bl	4.6	-	-	-	19	76	50	25	31	6	14	14	52
Sri Malaysia II	In	2.4	-	-	-	16	85	62	22	48	5	9	-	42
	Sh	3.3	-	-	-	22	84	58	27	34	4	19	-	50
	Bl	3.4	-	-	-	21	79	54	25	31	5	18	-	53
Sekencang (a)	In	2.3	-	-	-	17	78	63	15	49	5	9	9	42
	Sh	2.8	-	-	-	22	80	58	21	39	4	16	16	46
	Bl	3.3	-	-	-	22	73	51	22	28	6	17	17	46
Sekencang (b)	In	2.2	-	-	-	14	80	60	20	48	5	7	7	46
	Sh	3.1	-	-	-	19	81	56	25	37	4	14	14	54
	Bl	3.9	-	-	-	20	74	50	25	28	8	15	14	59
Setanjung (a)	In	2.7	-	-	-	14	81	63	18	50	5	8	8	42
	Sh	3.8	-	-	-	18	80	56	24	40	4	12	12	41
	Bl	5.6	-	-	-	15	76	50	26	32	7	11	10	46
Setanjung (b)	In	1.9	-	-	-	14	81	56	25	45	4	7	6	40
	Sh	3.1	-	-	-	16	84	56	29	41	4	10	10	39
	Bl	4.2	-	-	-	14	76	47	29	33	5	9	9	39
Sri Setanjung	In	2.1	-	-	-	14	81	56	25	44	5	6	6	41
	Sh	4.0	-	-	-	14	85	54	31	39	5	10	10	43
	Bl	5.4	-	-	-	14	76	48	29	31	7	10	9	49
MR1 (a)	In	2.1	-	-	-	13	83	61	23	48	6	7	7	39
	Sh	2.4	-	-	-	16	86	57	29	42	4	10	10	44
	Bl	3.5	-	-	-	13	79	50	30	35	6	8	8	47
MR1 (b)	In	2.6	-	-	-	12	81	59	23	47	5	6	6	41
	Sh	4.2	-	-	-	14	84	55	28	41	5	9	9	41
	Bl	5.3	-	-	-	12	74	48	27	32	8	8	7	37
MR71 (a)	In	2.6	-	-	-	12	81	61	20	50	5	6	5	45
	Sh	3.0	-	-	-	15	82	58	24	44	4	10	10	46
	Bl	4.6	-	-	-	14	76	51	25	35	6	10	10	49
MR71 (b)	In	2.3	-	-	-	13	83	62	21	50	6	6	5	40
	Sh	2.6	-	-	-	16	85	58	27	42	5	11	10	44
	Bl	3.6	-	-	-	15	77	50	27	34	6	10	10	39
Mahsuri (a)	In	1.7	-	-	-	11	83	63	20	51	6	6	6	35
	Sh	2.0	-	-	-	15	85	55	30	39	4	12	11	44
	Bl	3.8	-	-	-	14	76	49	27	32	7	10	10	34
Mahsuri (b)	In	2.3	-	-	-	15	79	61	18	48	6	7	7	41
	Sh	2.7	-	-	-	18	83	57	26	38	5	14	14	48
	Bl	3.7	-	-	-	21	77	53	23	30	7	17	16	46

Jaya	In	2.2	-	-	-	19	76	60	16	46	5	9	9	42
	Sh	3.3	-	-	-	22	78	56	22	35	4	17	17	40
	Bl	4.5	-	-	-	21	73	50	23	27	7	16	16	36
Masria	In	3.3	-	-	-	20	79	60	19	45	5	11	11	51
	Sh	4.4	-	-	-	26	79	58	21	33	5	20	20	51
	Bl	4.5	-	-	-	25	75	54	21	27	7	20	20	43
Pulut Malaysia	In	3.2	-	-	-	16	77	58	19	47	4	8	-	54
I	Sh	3.8	-	-	-	22	82	57	24	38	4	15	-	53
	Bl	3.9	-	-	-	20	79	55	24	30	8	17	-	49
Murni	In	6.4	-	-	-	17	82	58	24	42	5	11	10	43
	Sh	6.9	-	-	-	24	81	57	24	33	5	20	20	36
	Bl	8.6	-	-	-	22	76	52	24	28	6	18	18	36
IR42	In	2.9	-	-	-	13	79	58	21	48	4	6	6	50
	Sh	3.3	-	-	-	17	84	55	28	40	4	12	12	56
	Bl	4.5	-	-	-	13	76	50	25	34	7	9	9	52
Ria	In	3.6	-	-	-	19	77	58	20	43	5	11	11	40
	Sh	4.4	-	-	-	25	77	55	22	35	5	16	16	44
	Bl	4.6	-	-	-	24	71	51	20	28	6	17	17	43
Malinja	In	2.6	-	-	-	16	80	60	21	47	5	7	7	36
	Sh	2.8	-	-	-	24	81	59	22	38	6	15	15	41
	Bl	4.1	-	-	-	23	77	55	22	32	5	18	17	37
Sekembang	In	4.1	-	-	-	16	79	61	18	46	7	8	8	37
	Sh	5.9	-	-	-	22	83	59	24	39	5	16	15	39
	Bl	7.7	-	-	-	20	79	54	25	30	6	17	17	34

(a) (b) The same variety grown under different conditions or in a different location.
*In = stem internode; Sh = leaf sheath; Bl = leaf blade

not been carried out sufficiently to permit conclusions to be drawn as to the superiority of particular cultivars in relation to straw quality.

One particular aspect in rice, and in some other cereals, that deserves attention in terms of straw quality is the influence of dwarf genes. Dwarfing has been introduced in order to reduce the height of the plant and prevent problems with lodging. At the same time, dwarf and semi-dwarf plants tend to have a greater proportion of leaf tissue than tall plants and this feature is thought to favour faster growth and higher production by means of a greater relative proportion of photosynthetic tissue. However, the significance of this in relation to straw quality has not been determined. The possibilities for breeding rice varieties with better quality straws is discussed in Chapter 5.

4.10 The effects of harvesting, threshing and storage methods on rice straw quality.

As outlined in Chapter 2, differing harvesting, threshing and storage procedures are used in different areas, between and perhaps within, countries. Usually, the straw that is available for feeding to animals comprises the stem and leaves removed with the panicle during harvest and remaining after threshing. One of the main variations in harvesting methods is in relation to the height of cutting. Recently, Hart and Wanapat (1985) have found that rice stubble is of higher digestibility (49 vs 42%) than rice straw. In general, however, it is more usual for the top of plants to be more digestible than the bottom. Therefore, different cutting heights may lead subsequently to straws of different qualities. The significance of this in the practical situation has not been investigated and it is not known to what extent it is a factor which might be taken into account when a farmer adopts a particular harvesting procedure.

The method of threshing may also influence straw quality in that different procedures may result in the removal of varying proportions of leaf and stem from the fraction which is retained for feeding to animals. Again, the practical significance of this has not been determined and different threshing methods have not been evaluated in terms of their effects on straw quality.

The extent of protection of straw during storage varies widely. Under good storage conditions the general experience is that little deterioration in nutritive value occurs. However, deleterious effects have been recorded when effective protection has not been provided. Where under temperate conditions, wheat and oat stubbles were left unharvested for several months the average daily decline in *in vitro* digestibility was 0.15% units (Round and Jacka, 1976). With rice straw, Devendra (1982) reported on the effects of partial and full exposure. Compared with storage under cover, there were apparent losses of nutrients due to exposure. Sharif (1984) obtained reduced digestibility and intake by sheep of stored rice straw compared with fresh material.

4.11 Influence of management practices on straw quality

In most practical situations, there are some options available for manipulation either in terms of the selection of dietary ingredients or in terms of the feeding regime of the animals that are being used. It is a useful exercise, therefore, to consider what factors in management might improve straw quality and its utilization. Firstly, the question arises as to whether different rice cultivars produce straw of different qualities. This is a question which can only be answered by rigorous studies of the growth and chemical composition and digestibility of different varieties as alluded to in Section 4.9. It is an exercise in basic research which might have some practical application in the future. As such it should be left to those laboratories with the capabilities and terms of reference to investigate such aspects.

Secondly, more information is required on the extent to which different conditions of growth of the plant affect straw quality. As far as the farmer is concerned, the practices that may be manipulated are time of sowing, timing and rate of fertilizer application, and timing and rate of water application and removal. Given that the prime consideration is grain yield and quality, insufficient is known of the effects of these management practices on straw yield and quality. This type of investigation is also unlikely to produce practical results in the short term and research should be limited to where it can be supported and carried out properly.

Thirdly, the harvesting, handling and storage procedures may affect the quality of the straw which is available eventually for feeding to animals. Again, little is known of the effect of these procedures on straw quality and this information needs to be collected. Such information could be collected rather easily from farms in different areas to indicate whether benefits can be gained from altering traditional practices.

Fourthly, the nature of the supplementation which is required for acceptable levels of production needs to be established more clearly for particular classes of livestock fed rice straw-based diets. This is considered in some detail in Chapter 7.

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5. IMPROVING FEEDING VALUE THROUGH BREEDING

5.1 Introduction

The components of feeding value and variations in regard to rice straw have been discussed in Chapter 4. Improvement in feeding value may be achieved by a range of pretreatments, as outlined in Chapter 6, or by appropriate supplementation to alleviate limitations in the supply of essential nutrients, as discussed in Chapter 7. A third possibility is to undertake breeding and selection programs which will lead to improved straw quality. Information in this area is scarce but well worthy of examination. Because more attention has been given to improving pasture grasses by these means, it is relevant to assess the usefulness of this approach and its possible extrapolation to rice and other cereal straws.

As was pointed out in Chapter 4, there are a number of components of feeding value and it is not possible to consider all of them in a breeding and selection program. In mature and senescent forages attention is most often given to energy relationships on the grounds that additional nitrogen and minerals can be provided more easily than energy, at least up to maintenance levels of requirement. However, even in terms of energy relationships alone, the situation is difficult and complex because neither the animal factors nor the plant factors governing optimum nutrient supply and utilization are completely understood. At least in the early stages of investigation emphasis has been placed upon *in vitro* digestibility with follow-up to measure *in vivo* digestibility and voluntary intake.

5.2 Breeding and selection of forage grasses

Improvement in the digestibility and palatability of forage grasses through breeding programs has received some attention. Significant improvements in the *in vitro* or nylon bag digestibility of bermudagrass (*Cynodon dactylon* (L.) Pers) (Burton *et al.*, 1967); tall fescue (*Festuca arundinacea* Schreb.) (Buckner and Burrus, 1968) and smooth bromegrass (*Bromus inermis* Leyss.) (Collins and Drolsom, 1982) have been reported. The *in vitro* dry matter disappearance of 35 clones of smooth bromegrass, all harvested at early heading to remove influences of maturity, was found to range from 55 to 67% (Collins and Drolsom, 1982) with nine clones of high digestibility averaging 6% higher digestibility than the same number of low digestibility clones. The lower cell wall content (57 vs 61%) of these high digestibility clones, and the consequent increase in the amount of readily digestible cell contents, largely explained their higher feeding value. In addition, the high digestibility clones had a lower lignin content in cell walls (4.1 vs 5.4%), which led to a wide range in the *in vitro* digestion of cell walls at 12 h (22 to 42%) and indicated that selection for cell wall characteristics may lead to improved feeding value through increased digestion rates. These studies did not investigate the effects of these breeding programs on feed intake, although a reduction in neutral detergent fibre content might be expected to result in an increase in forage consumption.

More recently, Minson (1984) measured the intake and digestibility of five species of *Digitaria*, selected after an earlier study involving twenty *Digitaria* accessions (Strickland and Haydock, 1978), grown in swards. *Digitaria setivalva*, which was superior in the earlier study based on *in vitro* digestibility, was also superior to the other four species on the basis of *in vivo* digestibility and voluntary intake. This superiority was associated with a higher content of digestible neutral detergent solubles and of cellulose. The findings indicate that it may be possible to select for plants of higher feeding value from studies of chemical composition and *in vitro* digestibility, although it is desirable for the final appraisal to feed selected materials to animals.

5.3 Breeding and selection of cereal straws

In contrast to the situation with forage grasses, no deliberate attempts have been made to include straw quality in cereal breeding and selection programs. The major objective of such programs with rice has been to increase grain yield. Hence, there has been a great deal of work oriented towards selection for high yielding varieties. Of course these programs by necessity have also needed to take into account grain quality (protein content), resistance to disease, resistance to insect infestation, responsiveness to fertilizer applications, and ability to grow in adverse environments (e.g. saline conditions). The wealth of information of these aspects underlines the success of work at the International Rice Research Institute and in National Breeding Programs in different countries.

If breeding is to be considered seriously as a means of improving the feeding value of straw several important conditions would need to be satisfied. In the first instance, increasing the number of traits in a selection program could conceivably lower the intensity of selection possible for components of grain yield and quality or could even lead to detrimental effects on these characteristics. If such effects were to occur then the benefits of higher quality straw would need to outweigh any detrimental influences. This aspect has not been addressed in rice, but there have been some encouraging results with other cereals. For example, White *et al.* (1981) found that differences in straw digestibility among cultivars of winter and spring wheats, barley and oats were greater than the differences between crops and, in addition, cultivars with higher straw digestibility did not have lower grain yields and were not more susceptible to lodging.

Secondly, it would need to be clearly established whether significant differences do occur between straws from different varieties, and whether or not the magnitude of such differences would enable worthwhile advances to be made in nutritive value from an expensive and time-consuming breeding program. Differences in the *in vitro* digestibility of rice straws grown at particular sites within countries have been shown to differ by as little as 2 percentage units and as much as 18 percentage units (Table 5.1). Most of the studies cited report substantial variation and the possible reasons for this have been discussed in detail in Chapter 4.

Table 5.1. Variation in the *in vitro* organic matter digestibility of different varieties of rice straw

Source	Country	Number of varieties	*In vitro* organic matter digestibility (%)		
			Mean	Standard error	Range
Haque *et al.* (1981)	Bangladesh	5	33	0.9	30-35*
Winugroho (1981)	Australia	21	52	0.9	44-62
Shin *et al.* (1981)	Korea DPR	5	39	2.4	30-44**
Roxas *et al.* (1984)	Philippines	14	38	1.2	31-44
Sannasgala & Jayasuriya (1984)	Sri Lanka	9	35	1.6	30-45
Cheva-Isarakul & Cheva-Isarakul (1985)	Thailand	7	48	0.7	45-51
Roxas *et al.* (1985)	Philippines				
Wet season		4	48	1.7	45-53
Dry season		4	44	2.6	39-51
Sannasgala *et al.* (1985)	Sri Lanka	3	38	0.6	37-39
Hart & Wanapat (1985)	Thailand	17	42	0.4	40-46***

*Dacron bag dry matter digestibility values
**Nylon bag organic matter digestibility
****In vitro* dry matter digestibility

Studies such as these indicate that it may be possible to select for straw-quality within a cereal species. However, a great deal more needs to be known about the magnitude of the environmental contribution, as against the genotypic contribution, to straw quality so that proper assessments can be made in specific situations where interactions may occur. In particular, the extent to which improvement can be manipulated by increased cell wall digestibility or by increasing the proportion of storage carbohydrates, or by both means, needs to be defined. In some species, improvement can be effected by selecting for leafiness, since leaves have both a higher cell wall digestibility and a higher proportion of cell contents than stems. But, as shown in Chapter 4, the leaf and stem in rice straw do not necessarily differ greatly in chemical composition and digestibility.

It can only be concluded that a clear demonstration of differences in the quality of straw from different varieties of rice is not yet available despite suggestions that straw from high yielding varieties is less acceptable to ruminants than that from traditional rices. Such clear demonstrations, a knowledge of whether or not variety X environment interactions occur and an understanding of why particular straws are of higher feeding value is essential if breeding and selection programs in this area are to be undertaken.

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6. IMPROVING THE FEEDING VALUE THROUGH PRETREATMENTS

6.1 Introduction

The low biodegradability and poor voluntary intake of rice straw by ruminants have been discussed in Chapter 4. Many processing methods or pretreatments have been tested as a means of improving the feeding value of fibrous feeds. These can be conveniently classified into physical, chemical, physico-chemical and biological methods. This chapter reviews much of the available information on pretreatments that have been applied to rice straw.

Pretreatment processes can improve the feeding value of straw by increasing its digestible energy content, by increasing feed intake or by a combination of these effects. Maximal increases in digestibility are only achieved with an adequate balance of energy and other essential nutrients, such as nitrogen and minerals. Further, limitations in the supply of these essential nutrients can limit the intake of straw independently of their effects on digestion and, consequently, they are also necessary to allow expression of potential intake responses. These principles are discussed in detail in Chapter 7, but they need to be considered in relation to the ensuing discussions of the effects of various pretreatments on the feeding value of rice straw as they influence the magnitude of responses obtained in different experiments.

In addition to the effects on feeding value, other factors are also important. Pretreatments can range from simple chopping and soaking procedures to elaborate chemical pulping operations or carefully controlled fermentation processes. Many of these processes are technologically feasible, but economic constraints limit their use to particular situations or, in fact, rule out their use under practical conditions. Pollutional effects of some of the pretreatments need to be considered and evaluated before promoting their use. For completeness, all of the pretreatments that have been tested are discussed here, but attention is given to the relevance of each pretreatment to Asian village situations where rice straw is commonly fed to ruminants.

6.2 Physical pretreatments

Some physical processing methods such as chopping or grinding are unlikely to affect the chemical composition of straw. However, others such as soaking, steaming under pressure and gamma irradiation do have effects on the chemical composition of fibrous residues ranging from losses of cell solubles to alterations in the structural carbohydrates of the plant cell wall. These effects as well as the physical alterations are discussed in relation to feeding value.

6.2.1 *Soaking and wetting*

Dumlao and Perez (1976) reported dry matter losses of 8-14% when rice straw was soaked for 3 days indicating removal of soluble cell contents and reduced feeding value. In this regard, the *in vitro* and nylon bag digestibilities of rice straw were reduced from 33 to 28% after soaking (McManus and Choung, 1976). Soaking of barley straw, pea straw, sugarcane bagasse or sunflower hulls in boiling water for 30 to 90 min decreased both cell soluble material and *in vitro* digestibility (Ibrahim and Pearce, 1982). In addition, Castillo *et al.* (1982) found that soaking chopped straw for 2 h in a drum followed by 3 h drainage did not improve intake of buffaloes offered rice straw *ad libitum* and a concentrate mix.

When chopped wheat straw was wetted, as distinct from soaked, at the rate of 1 l/kg and let stand for 2 h prior to feeding, the total feed intake of calves given straw-based diets containing a fixed amount of concentrate was increased (Chaturvedi *et al.*, 1973), but there were no effects of wetting on organic matter digestibility. In contrast, Devendra (1983) reported that sheep consumed and digested less organic matter from wetted than from dry rice straw. More recently, in a comprehensive trial with large numbers of cattle on each treatment A. L. Badurdeen, M. N. M. Ibrahim and J. B. Schiere (personal communication) have been unable to demonstrate any effects of wetting on the intake and digestibility of rice straw. The main effect of wetting fibrous feeds, where increased intake has been reported, is likely to be improved palatability due to reduced dustiness of the feed although this should be confirmed in experiments where nutrient limitations are removed.

The evidence presented indicates that soaking or wetting alone is unlikely to result in significant improvements in straw intake and, hence, it is difficult to justify this type of pretreatment in practical situations. However, in parts of India it is traditional to soak straw prior to feeding and this is believed to have beneficial effects through removal of oxalates.

6.2.2 *Chopping*

Straws are sometimes chopped to reduce wastage and to facilitate feeding, but this does not alter the cell wall structure in such feeds. Castillo *et al.* (1982) found that buffaloes fed concentrates at 0.5% of liveweight consumed slightly more chopped than long rice straw (67 vs 63 g/kg $W^{0.75}$), while Devendra (1983) found no differences between long and chopped straw in dry matter intake (51 vs 50 g/kg $W^{0.75}$) and digestibility (46 vs 41%) by sheep.

In work with other cereal straws, weight gains of animals fed long and chopped straw-based diets have been found to be similar (Mathison, 1976; Drennan, 1980). This indicates that chopping is unlikely to improve the feeding value of rice straw. Machine threshing incorporates chopping of straw and in some countries, notably India, hand-operated chaff cutters are common. However, where these are not found farmers do not cut straw with a sickle before feeding it.

6.2.3 *Grinding and pelleting*

In the rumen, degradation of cellulose requires direct association of microbial cellulases with the substrate and, hence, the rate of hydrolysis would be expected to be affected by the cellulosic surface area accessible to the enzyme. The extent of any increase in cellulosic surface area is likely to be determined by the fineness of grinding. A process such as ball-milling results in extreme reduction in particle size to the point of the physical separation of cell wall components (Stone *et al.*, 1969; Millett *et al.*, 1970) and this results in marked increases in *in vitro* digestibility (see Moore *et al.*, 1972). The high cost of the process, however, means that it has no practical significance for animal production.

Grinding by the usual methods employed with animal feeds apparently results in only moderate increases in the exposed cellulosic surface area because of the length-width relationships of fibres (see Walker, 1984). Nevertheless, it results in increased dry matter losses from nylon bags containing ground straws (e.g. Coombe *et al.*, 1979b). At the same time, there may be a depression in *in vivo* digestibility due to increased voluntary intake and rate of passage (Minson, 1963; Donefer, 1972). Despite this, digestible dry matter intake is usually increased and this occurs more so with lower quality roughages than with good quality feeds (Minson, 1982). There is no clear evidence that pelleting, *per se*, affects feeding value.

In the case of rice straw, there are few reports of the effects of grinding and pelleting. With rice straw-cassava leaf diets, Winugroho and Chaniago (1984) found that goats weighing 17-28 kg consumed 1.5 kg DM/day of a ground and pelleted 75% rice straw, 25% cassava leaf diet and grew at 50 g/day. This is a great deal more than could be expected from a similar unprocessed diet. However, economic constraints imposed by the cost of collection, transportation, redistribution and processing of straw restrict or prevent the use of grinding and pelleting in most of Asia.

6.2.4 *Steaming under pressure*

Steaming exerts physical effects through the separation of cell wall structures and chemical effects including the cleavage of bonds between cell wall constituents, the degradation of hemicellulose, and a hydrolytic action of the acids resulting from these processes. Varying degrees of destruction of hemicellulose have been reported for rice sraws (Rangnekar *et al.*, 1982) and for other fibrous residues (Ibrahim and Pearce, 1982) and the process results in the production of acetic and other acids, furfurals and phenolic derivatives (see Walker, 1984). All of these factors affect the digestibility of the treated material and the net yield of digestible dry matter available. It is clear that the optimum conditions of treatment vary between different residues and that overtreatment and significant dry matter losses can occur.

Hart *et al.* (1981) studied the effects of steam treatment of rice straw, which had been ground through a 2.5 cm screen in a hammer mill, at pressures ranging from 1 to 42 kg/cm^2. An enzymatic *in vitro* assay indicated that the digestibility of the straw was increased from 26 to 47% after 1.5 min at a pressure of 21 kg/cm^2. It was found that the time needed to achieve a particular *in vitro* enzymatic digestibility fell rapidly as the treatment pressure was increased. However, as the treatment time at a particular pressure was extended, digestibility increased to a maximum and then declined due to overtreatment. Steaming at 21 to 28 kg/cm^2 increased the moisture content of the rice straw to 40 to 50% and there were losses (5 to 16%) of dry matter due to volatilization.

In a subsequent study involving pretreatment pressures of 5 to 9 kg/cm^2 for relatively long periods (30 and 60 min), Rangnekar *et al.* (1982) reported increases in *in vitro* dry matter digestibility, but again the digestibility was depressed at the higher pressure and longer treatment times. Importantly, the most severe of these treatments (9 kg/cm^2 for 60 min) resulted in dry matter losses of 40% and this meant there was a net loss of digestible dry matter.

When rice straw comprised 65% of the diet, lambs fed straw treated for 20 sec at 28 kg/cm^2 pressure consumed similar amounts of feed (2.04 vs 1.88 kg/day) and gained similar amounts of weight (130 g/day) to those fed an untreated straw-based diet (Garrett *et al.*, 1981). However, treatment at the same pressure for 90 sec depressed feed intake to 1.30 kg/day and the lambs lost weight. Diets containing treated straw had lower digestibilities of organic matter and cellulose than did those based on untreated straw. These *in vivo* results indicate that steam treatment did not improve the feeding value of rice straw and suggest that such a costly and energy intensive treatment is unlikely to be used.

6.2.5 *Gamma irradiation*

Ionizing radiation has been investigated as a means of increasing the availability of nutrients in plant cell walls for microbial digestion as this pretreatment may reduce the resistance of fibrous feeds to physical degradation without the necessity for fine grinding.

Arthur (1971) has listed the major effects of ionizing radiation on cellulose as molecular depolymerization, acid group formation, reducing group formation, gas production and radical production. The nature of the effects of this treatment on the cell wall constituents of fibrous residues has been discussed by Walker (1984) and it appears that the percentages of cellulose, hemicellulose and lignin all decrease due to solubilization. At high levels of irradiation, greater than 100 Mrad (Yu *et al.*, 1975) or 250 Mrad (Pritchard *et al.*, 1962) degradation products harmful to rumen microorganisms are produced which can result in decreases in digestibility.

When chopped dry rice straw was subjected to gamma irradiation at 0, 5, 10, 25, 100 and 200 Mrad the higher levels substantially increased dry matter disappearance from terylene bags from about 45 to 90% (McManus *et al.*, 1972a). Increases at the lower levels of irradiation were much smaller. At the effective levels of treatment, dry matter disappearance from the nylon bags was greater than increases in solubility indicating that the treatment had real effects on the rate of fermentation of the straw.

McManus *et al.*, (1972b) found no differences in the intake by sheep of chopped rice straw which had been subjected to different dose levels of gamma irradiation (0, 25, 50, 75 Mrad). However, irradiation depressed apparent dry matter digestibility from 47 to 27, 38 and 20% as the level of irradiation was increased. Non-irradiated feed particles had a longer mean retention time in the digestive tract than irradiated particles indicating that irradiation rendered the straw more susceptible to and/or caused some physical breakdown. However any advantage obtained by an enhanced rate of passage was not manifest in an increase in feed consumed and the consequent depression in digestibility meant that the animals' energy supply was reduced. Supplementation of the irradiated rice straw diets tended to increase voluntary feed consumption, but diet digestibility remained depressed.

Evidence available to this time indicates that irradiation of low-quality rice straw could severely depress the digestible energy value of an already poor quality feed. In addition, the long exposure times required and consequent cost of treatment mean that the process has no practical application.

6.3 Chemical pretreatments

The objective of chemical pretreatments of fibrous feeds is to increase their digestibility and intake through solubilization of some of the cell wall components or disruption of complexes of lignin and cell wall carbohydrates. Some such treatments solubilize lignin, while others such as extreme pH conditions, whether acid (below pH 4) or alkaline (above pH 8) increase the solubility of hemicelluloses. The chemicals which have been most extensively studied for the purpose of increasing cell wall degradation can be broadly classified into three groups: alkalis, oxidative reagents and acids. Of these alkalis have been the most commonly investigated chemicals for improving the feeding value of fibrous residues.

In addition to these three groups of chemicals some attempts have been made to improve the biodegradation of fibrous feeds with salts and surfactants, but these have generally been unsuccessful with the exception of sodium carbonate (see Owen *et al.*, 1984).

Chemical pretreatment of crop residues has been extensively reviewed by many workers in various parts of the world (e.g. Jackson, 1977; Sundstøl *et al.*, 1978; Ibrahim, 1983; Sundstøl, 1984). In view of the amount of information available on chemical pretreatments, the following discussions only summarise the main features of the various processes again giving particular attention on their effects on the feeding value of rice straw.

6.3.1 *Pretreatment with alkalis*

Alkali pretreatments solubilize hemicellulose (Klopfenstein, 1978), saponify uronic acid, and acetic acid esters and neutralize free uronic acid groups and they may or may not also delignify some of the cell wall material (Feist *et al.*, 1970; Theander and Åman, 1984). Chesson and Ørskov (1984) point out that as well as hydrolysing hemicellulose-lignin linkages, severe alkali pretreatment probably breaks some bonds within the lignin molecule thus reducing its molecular weight. These actions which weaken bonds between lignin and hemicellulose, which solubilize hemicellulose and which increase the swelling capacity of the cell walls facilitate penetration of microbial enzymes and lead to greater digestion of structural carbohydrates.

Alkali pretreatments have been carried out by wet or soaking methods (see Homb, 1984) and dry or spray methods (see Rexen and Bach Knudsen, 1984; Wilkinson, 1984a, 1984b), although some processes that have evolved incorporate features of each of these methods. Soaking processes have several disadvantages in that vessels are required for soaking; there is a high requirement for water; there are significant organic matter losses if the soaking solution is frequently replaced or if washing steps are included; and the end-product has a high moisture content. In some instances this method has created pollution problems and this led to the development of closed treatment systems where the soaking solution is reused and also to the advent of spray treatment methods.

Spray treatment methods involve the use of only enough water to achieve uniform wetting of the fibrous material. As a consequence, stronger alkali solutions are used and, as the end-product is not washed, high concentrations of minerals may remain in the feed. This process eliminates organic matter losses and leads to an end-product of higher dry matter content than soaking methods, but the treated feed may be less palatable due to high alkalinity.

6.3.1.1 *Sodium hydroxide.* Pretreatment with this chemical has been in practical use in European countries since the early 1940s, but its use in other regions of the world has been limited and it has been discarded as a practical option in Asia. This is largely because of its cost and availability, but also because of the need to take care to avoid contact with the skin when handling concentrated solutions as required for spray treatment, and the risk of soil pollution from the treatment process or excretion of ingested sodium by animals. Nevertheless, sodium hydroxide is generally regarded as the most effective alkali for improving digestibility and some effects of pretreatment of rice straw are discussed.

Results from laboratory-scale experiments involving sodium hydroxide pretreatment of rice straw by either wet or dry processes are summarized in Table 6.1. Of the techniques used to assess digestibility, the nylon bag method indicates that the effects of pretreatment are greater than the *in vitro* rumen fluid technique (see McManus and Choung, 1976). Chandra and Jackson (1971) and Shin *et al.* (1981b, 1982) found that the nylon bag digestibility of rice straw increased by about 4% units/g NaOH added by spraying up to 9 or 10 g/100 g straw. Some *in vitro* assessments of digestibility indicate that levels above 8 g/100 g straw applied by spraying may

Table 6.1. Effects of sodium hydroxide pretreatment on the organic matter digestibility of rice straw in laboratory-scale studies

Wet or soaking treatment				Dry or spray treatment			
Level of NaOH (g/100g straw)	Organic matter digestibility (%)	Assessment method	Reference	Level of NaOH (g/100g straw)	Organic matter digestibility (%)	Assessment method	Reference
0	49	*in vitro*	Said *et al.* (1982)	0	57**	nylon bag	Chandra & Jackson (1971)
2.5	55			3.3	69		
5.0	65			6.7	82		
6.5	75			10.0	89		
8.0	76						
0	34**	nylon bag	McManus & Choung (1976)	0	30	*in vitro*	Thiruchittampalam & Jayasuriya (1978)
12.5	68			4	56		
50.0	74			8	79		
0	34**	*in vitro*	McManus & Choung (1976)	0	32	*in vitro*	Thiruchittampalam & Jayasuriya (1978)
12.5	50			4	63		
50.0	53			8	78		
0*	32	*in vitro*	Ibrahim & Pearce (1983b)	0	32	*in vitro*	Jayasuriya & Perera (1979)
6	52			2	50		
12	59			4	62		
18	65			6	70		
24	68			8	71		
				10	68		
0	32	*in vitro*	Ibrahim & Pearce (1983b)	12	68		
6	49			14	60		
12	61						
18	63			0	35	nylon bag	Shin *et al.* (1981b)
24	65			3	52		
				6	66		
				9	72		
				0	29	nylon bag	Shin *et al.* (1982)
				3	37		
				6	50		
				9	64		
				12	62		
				0	36	*in vitro*	Ibrahim & Pearce (1983b)
				6	52		
				12	59		
				18	63		
				24	35		

*Soaked and pressed without washing; the values are means of treatments involving different pressures during pressing
**Dry matter digestibility values

have detrimental effects on fermentation (Jayasuriya and Perera, 1979), while others found that depressions in digestibility did not occur until 18 g NaOH/100 g straw (Ibrahim and Pearce, 1983b). The data of Ibrahim and Pearce (1983b) indicated that wet treatment with sodium hydroxide increased digestibility to the same extent as dry treatment despite the removal of neutral detergent solubles by washing or pressing of the treated material. This effect is also apparent when the results of Said *et al.* (1982) are compared to other findings, and indicates that wet processing has a greater effect on cell wall degradation than spraying. In addition, there were no adverse effects of high concentrations of sodium hydroxide (24 g/100 g straw) when the wet process was used. While the laboratory techniques used in these experiments are useful for screening the effects of chemical pretreatments on the digestibility of fibrous feeds, it is usually necessary to establish the optimum levels and the best method of pretreatment in feeding trials. This is because of the complex interactions between many factors, such as palatability, rumen digesta load, retention time of digesta in the reticulo-rumen and rate of digestion in the reticulo-rumen, which ultimately determine how much of a particular feed ruminants eat and how much of that feed is digested. When high levels of sodium hydroxide are used to treat straw the digestibility *in vivo* is often low compared to that measured by *in vitro* techniques. This is related to the rate of passage of the feed as affected by the treatment *per se* and the high levels of sodium in the diet (see Doyle, 1983).

Table 6.2 contains the results of some feeding trials involving sodium hydroxide-treated rice straw. Where straw comprised the entire diet, pretreatment with this alkali depressed the voluntary intake of straw by sheep (Holm, 1972) and cattle and buffaloes (Moran *et al.*, 1983) despite increased digestibility. The overall effect in these experiments was a decrease in the digestible organic matter intake mediated through effects of the high alkalinity and sodium levels in the end-product on its palatability or on rumen pH. In contrast, El-Shazly and Naga (1981) found that such depressions in intake do not always occur and that the method of pretreatment is important. Wet treatment followed by washing of the straw resulted in higher intake and digestibility and, hence, a greater energy supply to the animals than dry treatment where high levels of alkali remain in the straw. As mentioned earlier, the washing step has some disadvantages in that soluble organic matter is removed. For example, the digestibility of wet-treated rice straw which was washed was found to be lower (65 vs 69%) than that of spray-treated straw when the straws were fed in restricted amounts (Mehrez *et al.*, 1981).

Attempts have been made to alleviate the effects of high alkalinity of sodium hydroxide-treated feeds by spraying with organic or mineral acids (Donefer, 1968; Fernandez Carmona and Greenhalgh, 1972; Jayasuriya and Owen, 1975). In addition, cubing of such straw is believed to overcome the palatability problems (Dobie and Walker, 1977). In the work reported by Moran *et al.* (1983), leucaena supplementation overcame the adverse effect of sodium hydroxide treatment on straw intake resulting in not only higher total dry matter consumption, but an increase of up to 30% in treated straw intake. In contrast, when leucaena was given with untreated straw, it had a substitution effect decreasing straw intake by 10 to 20%. Thus, dilution with other feeds or removal of nutrient limitations may be a more practical solution to overcoming acceptability problems with sodium hydroxide-treated straw.

Garrett *et al.* (1979) examined the effects of sodium hydroxide pretreatment of rice straw on the performance of lambs given diets containing 72% or 36% straw. At the high straw content, treatment increased the digestibility of organic matter and cellulose with consequent increases in the rate of liveweight gain, but at the low content there were no changes in digestibility or animal response. Similarly, Kang *et al.* (1985) recorded only small responses in growth rate when treated straw comprised 30% of the diet. Hence, alkali pretreatment is only likely to be beneficial or, in fact, economical when straw comprises a large proportion of the total diet.

Spraying roughages with 3-6 g NaOH/100 g straw has had beneficial effects for livestock fed submaintenance or maintenance diets (Coombe *et al.*, 1979a, 1979b), for growing animals (Thiago *et al.*, 1979), for finishing animals (Braman and Abe, 1976) and for lactating animals (Jayasuriya, 1980). It has also been tested experimentally in many Asian countries including Indonesia (e.g. Sutardi *et al.*, 1980; Moran *et al.*, 1983), Malaysia (Devendra, 1979), Thailand (Holm, 1972), India (Singh and Jackson, 1971) and Sri Lanka (Jayasuriya, 1979). Importantly, sodium hydroxide pretreatment has not been adopted for use in practical farming situations in Asian countries and is unlikely to be for the reasons outlined earlier.

Table 6.2 Effects of sodium hydroxide pretreatment on the organic matter intake (OMI), digestibility (OMD) and digestible organic matter intake (DOMI) of rice straw-based diets

Level of NaOH (g/100g straw)	Treatment method	Animal	Straw OMI (kg/day)	Straw OMD (%)	Total diet OMI (kg/day)	Total diet OMD (%)	DOMI (kg/day)	Liveweight change (g/day)	Reference
A. STRAW ONLY DIETS									
0		Sheep	0.31	52			0.16		Holm (1972)
12.5*	Wet		0.13	62			0.08		
0		Sheep	0.59	53			0.31		El-Shazly & Naga (1981)
12.5*	Wet		0.73	75			0.55		
5	Dry		0.69	60			0.42		
5	Dry		0.68	56			0.38		
0		Cattle	3.84	46			1.76		Moran *et al.* (1983)
4	Dry		2.56	57			1.45		
0		Buffaloes	3.51	44			1.53		Moran *et al.* (1983)
4	Dry		2.46	59			1.45		
B. DIETS CONTAINING 60-80% STRAW									
0		Lambs	1.11*		1.54	53	0.82	84	Garrett *et al.* (1979)[1]
4	Wet		1.16*		1.61	65	1.04	137	
4	Dry		1.22*		1.70	61	1.03	132	
0		Cattle	3.45*		5.29	49	2.59		Moran *et al.* (1983)[2]
4	Dry		3.00*		4.66	54	2.53		
0		Buffaloes	2.86*		4.38	45	1.97		Moran *et al.* (1983)[2]
4	Dry		3.24*		5.03	57	2.84		
0		Sheep	0.58		0.98				Shin *et al.* (1985)[3]
4	Dry		0.65		1.06				
4	Dry/ pelleted		0.85		1.30				
C. DIETS CONTAINING 20-40% STRAW									
0		Lambs	0.60*		1.67	72	1.21	184	Garrett *et al.* (1979)[1]
4	Wet		0.60*		1.68	75	1.27	196	
4	Dry		0.67*		1.86	73	1.36	217	
0		Cattle	2.53*		8.42			1040	Kang *et al.* (1985)[4]
5	Dry		2.22*		7.41			1120	
10	Dry		2.13*		7.12			960	

*Calculated from information presented in the reports

Supplements given: [1]Alfalfa hay, barley, cottonseed meal, sugarcane molasses, urea and minerals
[2]Leucaena
[3]Corn and barley
[4]Concentrates

6.3.1.2 *Ammonia or urea.* Interest in the use of anhydrous ammonia (gaseous ammonia) and aqeuous ammonia (ammonium hydroxide) for the treatment of cereal straws has increased considerably in Europe and North America. Appropriate methods of treatment as determined by the form of ammonia, type of material to be treated, feeding system and climatic conditions have been described in detail and discussed by Sundstøl *et al.* (1978) and Sundstøl and Coxworth (1984). However, the widespread use of these chemicals for treatment of fibrous roughages may not be feasible in Asia due to difficulties of transportation and handling and differences in the scale of farming. Consequently, Asian scientists have concentrated on the use of urea in pretreatment of straws. However, it is still pertinent to first briefly discuss the effects of ammonia pretreatment on feeding value.

Ammoniation of straws using anhydrous or aqueous ammonia has been carried out under a range of conditions. Ammonia levels of 3 to 4% of dry matter significantly improve digestibility and little benefit is obtained from increasing the levels further (Sundstøl *et al.*, 1978). In relation to sodium hydroxide, ammonium hydroxide is a slow-reacting chemical and Sundstøl *et al.* (1978) suggested that for temperatures above 30°C a reaction time of one week is suitable, but in cold conditions 4 to 6 weeks might be required. Obviously, the temperature in a stack of straw will increase as a result of chemical reactions, and will be dependent upon the size of the stack, but the ambient temperature is also important. As ammoniation is dependent upon ammonium hydroxide for effective treatment the moisture content of straw will also be important and optimum moisture levels of 30% (Waiss *et al.*, 1972) and 50% (Sundstøl *et al.*, 1979; Solaiman *et al.*, 1979) have been suggested. Some practical implications of treating straw at high moisture contents are the likelihood of spoilage if airtight conditions are not maintained and the difficulties of handling the heavier straw. In developed countries, an important aspect in the process has been the need to maintain airtight conditions for effective treatment.

As well as increasing the digestibility of straws, pretreatment with anhydrous or aqueous ammonia has benefits in that it increases the crude protein content by 5-6% units and thereby has a positive effect on roughage intake. The degree to which intake and digestibility of straw are improved by ammoniation will be dependent on the amount and nature of other dietary ingredients. Yoon *et al.* (1983) found that ammoniation of rice straw increased the digestible organic matter intake by sheep from 90 to 180 g/day. In Korea, this pretreatment has also been investigated as a means of improving the feeding value of straw for beef cattle (Shin *et al.*, 1985).

Urea is a more readily available source of ammonia to farmers in the developing countries and has been used to treat straw in Bangladesh (e.g. Saadullah *et al.*, 1981b), India (Jaiswal *et al.*, 1983), Indonesia (Djajanegara *et al.*, 1983), Sri Lanka (Perdok *et al.*, 1982; Schiere and Ibrahim, 1985) and Thailand (Wanapat *et al.*, 1982; Promma *et al.*, 1985). It would seem that, with adequate moisture content and suitable temperature conditions, microbes which produce urease are capable of degrading urea with the formation of ammonium compounds, such as ammonium carbonate, bicarbonate or hydroxide, which then permeate through the straw. Effects of pretreatment of rice straw with anhydrous ammonia, aqueous ammonia and urea on *in vitro* digestibility are summarized in Table 6.3. Increases in digestibility with urea pretreatment have at times been small, 2-6% (e.g. Wanapat *et al.*, 1982; Jayasuriya and Pearce, 1983; Ibrahim *et al.*, 1984b), while in other cases increases of 10% or more have been found (Ambar and Djajanegara, 1982). These responses are generally less than is achieved with aqueous or anhydrous ammonia treatment. It is of interest that in Europe, Ørskov *et al.* (1981) and Mira *et al.* (1983) have found that urea pretreatment did not improve the nutritive value of straw. This may have occurred because of low urease activity in the straw, low moisture content, low ambient temperatures and/or limited increases in pH. An important consequence of this is that the high levels of urea remaining in the straw may be toxic to animals. Similar findings to this have not been reported from tropical areas although in some feeding experiments urea supplementation has been nearly as effective as pretreatment in improving the feeding value of straw raising questions as to how much of the response is due to addition of nitrogen or pretreatment *per se*.

Thus, considerable controversy remains over the optimum conditions for urea pretreatment and the effects that it has on cell wall structure of straws. This has arisen for several reasons. Firstly much of the information on the level of urea required, time of treatment and moisture

Table 6.3 Effects of ammonia and urea pretreatments on the digestibility of rice straw in laboratory scale studies

Chemical	Level of treatment (g NH_3/ 100g straw)	Dry matter or organic matter digestibility (%)	Assessment method	Reference
		DMD		
-	0	30	Enzyme solubility	Waiss *et al.* (1972)
Aqueous NH_3	2.6	52		
Aqueous NH_3	5.2	62		
Aqueous NH_3	7.8	65		
		DMD		
-	0	39	*in vitro*	Tohrai *et al.* (1978)
Aqueous NH_3	1.0	41		
Aqueous NH_3	1.0	42		
Aqueous NH_3	2.5	46		
Aqueous NH_3	5.0	48		
		DMD		
-	0	35	*in vitro*	Itoh *et al.* (1979)
Aqueous NH_3	5.0	44		
		OMD		
-		45	*in vitro*	Kiangi *et al.* (1981)
Anhydrous NH_3	2.5 & 5.0	54		
Aqueous NH_3	2.5 & 5.0	54		
Urea	2.5 & 5.0	50		
		DMD		
-	0	38	Nylon bag	Ambar & Djajanegara (1982)
Urea	2.3	41		
Urea	9.0	58		
		DMD		
-	0	48	*in vitro*	Wanapat *et al.* (1982)
Urea	2.8	54		
		OMD		
-	0	46	*in vitro*	Jayasuriya & Pearce (1983)
Urea	1.1	50		
Urea	2.3	51		
Urea	3.4	52		
Urea	4.5	52		
		OMD		
–	0	40	*in vitro*	Ibrahim *et al.* (1984b)
Urea	2.3	42		

content has been derived from laboratory scale experiments and assessment has been on the basis of *in vitro* digestibility. More recently in the quest to reduce storage time, it has become apparent that the temperature and moisture conditions in stacks of straw are different from those encountered in laboratory experiments. Further, one of the important attributes of the treatment is that is increases straw intake. Consequently it would seem that optimum levels of urea for use, times for treatment and amounts of water used should be determined in large-scale feeding experiments. Again, it is likely that the rate of reaction will be variable at different sites in stacks of straw of different sizes. Secondly, it is important to consider the cost of materials involved in the treatment process. In Asia, the search for cheap local materials which can be used to cover stacks has meant that airtight conditions are not always achieved. This will again affect the choice of level of urea to be used and treatment time. It would seem that higher levels of urea and shorter treatment times would reduce the incidence of mould growth in relatively open stacks. The methods and materials used for this treatment in Bangladesh, Sir

Lanka and Thailand have been described by Saadullah *et al.* (1981d), Schiere and Ibrahim (1985) and Promma *et al.* (1985), respectively. Finally, there are no detailed reports of the chemical reactions which occur in stacks of straw during this pretreatment process. If the principal ammonium compounds present are ammonium carbonate and bicarbonate then the pH may only rise to between 8 and 9. This would mean that hemicellulose may be partly solubilized, but effects on lignin bonding may not be as great as would occur if ammonium hydroxide was formed and the pH rose to 10 or above.

The effects of urea-ammonia pretreatment of rice straw from experiments with growing or mature buffaloes and cattle are presented in Table 6.4 and with lactating animals are given in Table 6.5. It is difficult to interpret all of the results obtained from the information presented in these research reports and hence discussion is restricted to the main findings of these trials.

Urea-ammonia pretreatment has been found to improve rice straw from a submaintenance to a maintenance diet for cattle and buffaloes (Wanapat *et al.*, 1982, 1984; Wongsrikeao and Wanapat, 1985). The mechanisms involved have been an increase in straw intake, an increase in digestibility and in some experiments increases in both (e.g. Ibrahim *et al.*, 1984a; Wonsgrikeao and Wanapat, 1985). It is also possible that the increases in supply of energy and microbial amino acids to the animal's tissues which result from treatment with urea could improve the efficiency of use of nutrients at the tissue level. The work of Ibrahim *et al.* (1984a) clearly illustrates that airtight treatment conditions result in more effective treatment and less spoilage of the straw. As regards level of treatment, Wongsrikeao and Wanapat (1985) found 6% urea to be better than 3% and this would seem to be reasonable given that the optimum conditions for ammonia treatment in Europe are said to be between 3-4% (see Sundstøl *et al.*, 1978). It would also seem logical that higher levels of application would be more effective when short treatment times or incomplete sealing of the stacks are desirable. However, this needs to be counter-balanced against the likelihood of higher ammonia losses. It is generally considered that two-thirds of the ammonia applied during straw treatment is lost to the air (Sundstøl and Coxworth, 1984) and this is also the case with urea pretreatment.

The effects of replacing untreated rice straw with urea-treated straw in mixed feed diets fed to growing animals (Table 6.4) and lactating animals (Table 6.5) has been studied in many regions. These experiments indicate that urea treatment is only considered to increase the nutritive value of straw to maintenance level and that additional supplements are required for production. It is clear that as long as straw remains as a substantial part of the diet, then urea-treated straw has substantial advantages over untreated material. This is because the animals are still able to express their potential to consume and digest more of the straw. If straw were to be only a small component of the diet then the effects of treatment might well be lost.

Several trials (Hossain and Rahman, 1981; Saadullah *et al.*, 1981c 1982a, 1983; Jaiswal *et al.*, 1983; Karunaratne and Jayasuriya, 1984; Perdok *et al.*, 1984; Djajanegara and Doyle, unpublished data) have compared the effects of urea supplementation of straw to urea pretreatment. Supplementation has generally been found to increase the value of straw compared to untreated, unsupplemented controls, but not to be as effective as pretreatment. Thus, the pretreatment process has some effects in addition to supplying rumen degradable nitrogen. In a tightly controlled experiment in which urea-treated rice straw which was dried to remove excess ammonia was fed to sheep, Djajanegara and Doyle (unpublished data) have attempted to partition the effects of supplementation with rumen degradable nitrogen and pretreatment *per se*. Four treatments were used: untreated straw, untreated straw supplemented with urea and sulphate, urea-treated straw and urea-treated straw supplemented with urea and sulphate. All diets contained 5% molasses and 3% of a complete mineral and vitamin premix, and the urea and sulphate supplements were given under ideal conditions by infusing urea (1.2% of DM intake) into the rumen over 24 h. Urea supplementation increased the intake and digestibility of untreated straw so that digestible organic matter intake increased from 270 to 430 g/day (50%), while urea treatment resulted in an intake of 480 g/day (78%) and when supplemented 570 g/day (111%). The intakes of nitrogen on untreated-supplemented straw and treated-unsupplemented straw were about 12 g/day and the sheep had rumen ammonia levels of 100 and 60 mg N/1. This indicates that appropriate supplementation given under ideal conditions accounted for 75% of the increase in feeding value of rice straw obtained by treatment. The pretreatment solubilized some of the hemicellulose and resulted in increased cell wall digestibility (60 vs 50%) when compared to supplementation.

Table 6.4. Dry matter intake (DMI), digestibility (DMD) and liveweight change of non-lactating cattle and buffaloes fed untreated, urea-supplemented or urea-treated rice straw-based diets.*

Treatment	Storage time (day)	Liveweight (kg)	Total DMI (kg/day)	Total DMI (kg/100kg LW)	Total DMI (g/kg $LW^{0.75}$)	Straw DMI (kg/day)	Straw DMI (kg/100kg LW)	Straw DMI (g/kg $LW^{0.75}$)	DMD (%)	Liveweight change (g/day)	Supplement	Reference
A. BUFFALO												
U		200				4.21	2.1	79	50	−182	M	Wanapat et al. (1984)
5% Urea T	21	203				4.75	2.3	88	52	79	M	
5% Urea T	21	255				5.6	2.0	88	51		M	Sriwattanasombat
5% Urea T	21	282	6.2	2.2	90	5.9			55		F + M	& Wanapat (1985)
5% Urea T	21	282	6.2	2.2	90	5.9			58		F + M	
5% Urea T	21	276	5.8	2.1	86	5.5			58		F + M	
U		289				5.87	2.0	84	43	−130	M	Wongsrikeao & Wanapat
3% Urea T	21	296				6.42	2.2	90	53	−50	M	(1985)
6% Urea T	21	290				7.32	2.5	104	55	210	M	
B. CATTLE												
Urea S		100	2.6	2.6	82				49		F + C + M	Hossain & Rahman (1981)
5% Urea T	14	102	3.1	3.0	97				63		F + C + M	
5% Urea T	21	99	3.1	3.1	99				62		F + C + M	
U		56	1.8	3.2	87	1.7	3.0	83	40	35	F + M	Saadullah *et al.* (1981c)
5% Urea T	10	61	2.0	3.3	92	1.9	3.1	87	51	110	F + M	& Saadullah *et al.* (1982a)
Urea S		62	1.8	2.9	82	1.7	2.7	77	46	75	F + M	
U		127	3.45	2.7	91	2.93	2.3	77		125	F + C + S	Khan & Davis (1982)
5% Urea T	7	137	4.20	3.1	105	3.68	2.7	92		310	F + C + S	
Urea S		133	4.28	3.2	109	3.94			65		F + C + M	Mould *et al.* (1982)
4% Urea + 1% lime T	10	141	4.54	3.2	111	4.20			64		F + C + M	
U		166	3.84	2.3	83	2.09	1.3	45		73	F + C + M	Perdok *et al.* (1982)
4% Urea T	28	178	4.59	2.6	94	2.84	1.6	58		346	F + C + M	
U		118	3.9	3.3	109	3.4	2.9	95		224	F + C	Saadullah *et al.* (1982c)
U		113	3.8	3.4	110	3.3	2.9	95		193	F + C + M	
Urea T	-	116	4.0	3.4	113	3.3	2.8	93		306	F + C	
Urea T	-	125	4.2	3.4	112	3.4	2.7	91		295	F + C + M	
U		286				4.97	1.7	72	42	−134	M	Wanapat *et al.* (1982)
5% Urea T	21-28	282				6.82	2.4	99	52	430	M	
U		198	4.03	2.0	76	2.69	1.4	51	36	−312	C + M	
5% Urea T	21-28	230	6.59	2.9	112	4.82	2.1	82	48	75	C + M	
U		63	2.3	3.7	102	2.0				107	F + C + M	Hamid *et al.* (1983)
5% Urea T	10	68	2.5	3.7	106	2.2				226	F + C + M	
5% Urea T	10	71	2.5	3.5	102	2.2				295	F + C + M	
U		123	3.0			2.4				114	F + C	Haque & Saadullah (1983)
U		124	2.9			2.4				132	C	

5% Urea T	-	136	5.4			4.8				227	F + C	
5% Urea T	-	138	5.0			4.6				227	C	
U				3.2			1.9		49	473	C + M	Jaiswal *et al.* (1983)
Urea S				2.8			2.8		45	111	M	
5% Urea T	28			4.0			4.0		43	246	M	
5% Urea T	28			3.9			3.7		45	427	C + M	
5% Urea T	28			3.8			3.5		47	290	F + M	
5% Urea T	28			3.6			3.5		46	327	C + M	
Urea S		75	2.79	3.7	109	2.16	2.9	87		207	F + C + M	Saadullah *et al.* (1983)
4% Urea T	10	78	3.02	3.9	114	2.39	3.1	91		297	F + C + M	
4% Urea T	10	91	2.99	3.3	96	2.82	3.1	90		140	F + M	Saadullah *et al.* (1983)
4% Urea T	10	104	3.17	3.0	98	2.87	2.8	89		360	F + C + M	& Saadullah *et al.* (1982b)
4% Urea T	10	105	3.55	3.4	108	2.99	2.8	91		350	F + C + M	
4% Urea T	10	102	3.79	3.7	118	2.98	2.9	93		330	F + C + M	
4% Urea T	10	90	3.34	3.8	116	2.92	3.2	101		190	F + C + M	
4% Urea T	10	93	3.57	3.8	116	2.90	3.1	94		250	F + C + M	
4% Urea T	10	96	3.85	4.0	127	2.92	3.0	99		230	F + C + M	
4% Urea T	21	93				2.25	2.4	75	53			Ibrahim *et al.* (1984a)
4% Urea T	21	87				2.49	2.9	87	60			
4% Urea T	21	92				2.36	2.6	79	60			
4% Urea T	21	86				2.27	2.6	80	57			
4% Urea T	21	88				2.61	3.0	91	61			
4% Urea T	21	86				1.85	2.1	66	58			
Urea S		245	6.30	2.6	102	5.04	2.1	81	52		F + C	Karunaratne & Jayasuriya
4% Urea T	21	245	7.51	3.1	121	6.01	2.5	97	61		F + C	(1984)
U		166	4.30	2.6	93	3.39	2.0	73		141	C + M	Kumarasuntharam
4% Urea T	3	178	5.10	2.9	105	4.19	2.4	86		308	C + M	*et al.* (1984)
4% Urea T	3	177	4.86	2.8	100	3.94	2.2	81		336	C + M	
4% Urea T	9	165	5.66	3.4	123	4.75	2.9	103		207	C + M	
4% Urea T	9	175	5.56	3.2	116	4.65	2.7	97		307	C + M	
4% Urea T	27	172	5.46	3.2	115	4.55	2.7	96		213	C + M	
4% Urea T	25			2.9			2.8			318	F + M	Perdok *et al.* (1984)
4% Urea T	25			2.9			2.7			398	F + C + M	
4% Urea T	25			2.7			2.1			489	F + C + M	
4% Urea T	25			2.2			1.9			472	F + C + M	
4% Urea T	25			2.8			2.4			472	F + C + M	
4% Urea T	25			2.5			2.0			483	F + C + M	
U				3.2			2.1			103	F + C + M	Perdok *et al.* (1984)
Urea S				3.4			2.3			213	F + C + M	
4% Urea T	9			3.9			3.0			278	F + C + M	
4% Urea T	9			3.8			3.0			237	F + C + M	
4% Urea T	9			3.8			3.0			282	F + C + M	
4% Urea T	27			3.8			2.9			310	F + C + M	
U		113				3.03	2.7	87	44	− 34	M	Wanapat *et al.* (1984)
5% Urea T	21	120				3.24	2.7	89	52	7	M	
5% Urea T	7	52	1.43	2.8	74	1.35	2.6	70	50	57	F + M	Saadullah (1984)
5% Urea T	7	68	1.66	2.5	70	1.56	2.3	66	57	198	F + C + M	

Table 6.4 cont.

Treatment	Storage time (day)	Liveweight (kg)	Total DMI (kg/day)	Total DMI (kg/100kg LW)	Total DMI (g/kg $LW^{0.75}$)	Straw DMI (kg/day)	Straw DMI (kg/100kg LW)	Straw DMI (g/kg $LW^{0.75}$)	DMD (%)	Liveweight change (g/day)	Supplement	Reference
5% Urea T	7	67	1.76	2.6	75	1.61	2.4	69	59	197	F + C + M	
5% Urea T	7	66	1.72	2.6	73	1.52	2.3	66	60	205	F + C + M	
5% Urea T	7	65	1.80	2.8	79	1.56	2.4	68	62	192	F + C + M	
5% Urea T	7	68	1.91	2.8	81	1.63	2.4	69	59	215	F + C + M	
5% Urea T	7	59	2.09	3.5	98	1.98	3.4	93	58	80	F + M	Saadullah (1984)
5% Urea T	7	61	2.19	3.6	99	2.07	3.4	95	60	142	F + C + M	
5% Urea T	7	62	2.22	3.6	100	2.09	3.4	95	61	151	F + C + M	
5% Urea T	7	66	2.26	3.4	98	2.10	3.2	91	61	203	F + C + M	
5% Urea T	7	67	2.47	3.5	98	2.23	3.3	95	62	206	F + C + M	
5% Urea T	7	59	2.23	3.8	104	1.94	3.3	91	61	95	F + C + M	
U		139	3.51	2.5	87	2.07	1.5	51		480	F + C + M	Cheva-Isarakul & Potikanond
6% Urea T	21	121	2.91	2.4	80	1.95	1.6	53		420	C + M	(1985)
U		180				3.47	1.9	71	41		-	Ibrahim (1985)
4% Urea T	21	169				4.71	2.8	100	48		-	
4% Urea T	10	185				4.62	2.5	92	47		-	
4% Urea T	5	177				4.72	2.7	97	47		-	
4% Urea T	5	172				4.36	2.5	92	47		-	
U		177	5.65	3.2	116	4.33	2.5	89		304	C	Promma *et al.* (1985)
6% Urea T	21	196	4.91	2.5	94	3.59	1.8	67		598	C	

*Much of the data presented in this table have been calculated from information given in the reports cited.

Note: supplement definitions: C = concentrate, F = forage, M = minerals
pretreatment definitions: U = untreated, T = treated, S = supplemented with urea

Table 6.5. Dry matter intake (DMI), liveweight (LW) change and milk production of animals fed untreated or urea-treated rice straw-based diets

Treatment	Storage time (day)	Liveweight (kg)	Total dry matter intake (kg/day)	Total dry matter intake (kg/100kg LW)	Total dry matter intake (g/kg $LW^{0.75}$)	Straw dry matter intake (kg/day)	Straw dry matter intake (kg/100kg LW)	Straw dry matter intake (g/kg $LW^{0.75}$)	LW change (g/day)	Milk production (kg/day)	Supplement	Reference
A. BUFFALO												
U				2.8	119				−93	2.17	C + M	Perdock *et al.* (1982)
U				2.8	123				59	2.56	F + C + M	
4% Urea T	28			3.7	163				59	2.97	C + M	
4% Urea T	28			4.0	178				126	3.35	F + C + M	
4% Urea T	11-29			3.3			3.3		115	2.41	M	Perdok *et al.* (1984)
4% Urea T	11-29			3.3			3.1		113	2.60	F + M	
4% Urea T	11-29			3.3			3.1		229	2.73	F + M	
4% Urea T	11-29			3.5			3.3		236	3.09	C + M	
4% Urea T	11-29			3.1			2.7		286	3.18	F + C + M	
4% Urea T	11-29			3.3			2.9		324	3.36	F + C + M	
B. CATTLE												
U		235[L]	5.8			4.7	2.0	78	−87	0.6	F + C + M	Khan & Davis (1981)
5% Urea T	7	222[L]	10.6			9.5	4.3	165	49	2.1	F + C + M	& Davis (1983)
U		263[C]	6.8			5.7	2.2	87	−211	1.7	F + C + M	
5% Urea T	7	273[C]	12.0			10.9	4.0	162	168	2.6	F + C + M	
U		264	6.6	2.5	101	5.2	2.0	79	−266	2.42	C + M	Perdok *et al.* (1982)
4% Urea T	28	294	10.0	3.4	141	8.6	2.9	121	93	3.41	C + M	

Note: pretreatment definitions: U = untreated; T = treated
livestock definitions: L = local animals; C = crossbred animals

Attempts have been made to reduce the time necessary for pretreatment with urea by adding urease sources. In laboratory experiments treatment time has been reduced to as little as 2 days (Jayasuriya and Pearce, 1983; Ibrahim *et al.*, 1984b), but the benefits of adding urease when treatment is practised on a large scale have not been clearly demonstrated. Kumarasuntharam *et al.* (1984) reported similar liveweight gains when bull calves were fed straw treated for 27 days or for 3 days with soybean powder added as a source of urease. However, 9 days treatment without urease additions also produced similar liveweight gains. The ammonium compounds formed, the degree to which pH is increased and the reactions that occur in urea-treated stacks of straw, with and without urease additions, requires better definition before conclusions can be drawn about beneficial effects from enzyme additions.

The urea present in animal or human urine may be an important source of ammonia for treatment. Whether or not such an approach to straw treatment is undertaken will depend on the development of simple methods of urine collection from animals or humans and ultimately on whether such a practice is socially and culturally acceptable. No doubt, consideration also needs to be given to the quantity of urea likely to be present in urine, which will be related to nitrogen intake of donor animals. The nitrogen concentration of urine from animals fed low quality diets will be low, but this may be overcome to some extent by increasing the amount of urine used or by increasing the treatment time.

Several laboratory studies have examined the efficiency of animal urine for straw treatment (Coxworth and Kullman, 1978; Mahyuddin, 1982; Saadullah, 1982). Urine application increases the nitrogen content and *in vitro* digestibility of rice straw (Mahyuddin, 1982) greater responses occurring with increasing amounts of nitrogen added, whether this was due to the nitrogen concentration of the urine or the amount of urine added. Saadullah (1982) also found that the efficiency of urine treatment of wheat straw depended on the amount of urea-nitrogen added. These laboratory experiments indicate that urine may be effective for straw treatment providing enough urea-nitrogen is applied or enough time is allowed for effective reaction.

Saadullah *et al.* (1980) found that when urine treated rice straw was fed to sheep, the pretreatment increased dry matter intake (by 28%), apparent organic matter digestibility (55 vs 45%), crude fibre digestibility (62 vs 56%) and apparent nitrogen retention (-1.2 vs -2.9 g/day). Subsequently, Haque *et al.* (1983) compared the performance of calves fed untreated, 5% urea-treated and urine-treated paddy straw-based diets over 105 days. All calves received 400 g rice bran, 200 g oilcake and 1 kg fresh grass each day. The intakes of straw were 2.6, 3.4 and 3.3 kg DM/100 kg LW for animals fed untreated, urea-treated and urine-treated straw, respectively, and they grew at 110, 181 and 166 g/day, respectively. No adverse effects on animal health of the sheep or calves fed straw treated with urine were reported in these experiments.

Simple methods of urine collection are unlikely to lead to quantitative collection from animals, or to prevent nitrogen losses from the urine. This, together with the fact that urine from animals fed low quality diets will be low in nitrogen, suggests that it may need to be fortified with small quantities of urea. Hence, the procedure may only reduce the amount of purchased urea required in the treatment process.

Urea treatment of rice straw has the potential to increase its feeding value whether the effects are due to the added nitrogen or the pretreatment *per se*. The possibility also exists to use this pretreatment to facilitate the storage of straw harvested at the onset of the wet season when it is not possible to dry it. Its effects are to increase the intake and to cause small improvements in digestibility of the straw. If the treatment is to be used, then full advantage should be taken of these effects. In Sri Lanka and Thailand it would seem that treatment of straw may be adopted by farmers with milk-producing animals. However, its adoption for use in feeding to draught animals in Asia, with the possible exception of Bangladesh, would seem to require a considerable extension effort and this should only be attempted when economic benefits to the farmer have been demonstrated.

6.3.1.3 *Calcium hydroxide.* Calcium hydroxide is a relatively cheap chemical reagent for treating crop residues as its precursor lime is cheaper than sodium hydroxide. Lime can be generated by burning limestone (calcium carbonate). However, to be effective the calcium hydroxide needs to be used at reasonable concentrations to compensate for its low alkalinity and it needs to be applied by a soaking method to allow for its low solubility.

This alkali has been found to be inferior to sodium hydroxide when spray treatment is used

(Verma and Jackson, 1975; Gharib *et al.*, 1975) unless long periods are allowed for the reaction (Gharib *et al.*, 1975). However, when calcium hydroxide is applied in a soaking process it is found to increase the *in vitro* organic matter digestibility of rice straw (see Table 6.6), sometimes to the same extent as spray treatment with sodium hydroxide (Winugroho *et al.*, 1984). The results of Shin *et al.* (1981a) indicate that under laboratory conditions reasonable effects can be obtained with spray treatment, but this does not seem to be the case when treating large amounts of straw.

A series of conclusions can be drawn from these and other studies about expected increases in *in vitro* digestibility after soaking in calcium hydroxide suspensions:

(i) Reasonable increases can be achieved by soaking for as little as 24 hours (Winugroho *et al.*, 1984).

(ii) Comparisons between different suspension to straw ratios (4, 8 or 12 times as much suspension as straw) have shown no differences in *in vitro* digestibility of treated rice straw (Winugroho *et al.*, 1984).

(iii) Treating by soaking results in losses of organic matter (Dumlao and Perez, 1976; Winugroho *et al.*, 1984) and washing of lime-treated straw is not desirable as the digestible dry matter available after treatment is reduced even further compared to unwashed-treated

Table 6.6. Effects of calcium hydroxide pretreatment on the digestibility of rice straw in laboratory scale experiments

Level of treatment (g $Ca(OH)_2$/ 100g straw)	Method of application	Digestibility (%)	Assessment method	Reference
		DMD		
0	soaked	53	*in vitro*	Dumlao & Perez (1976)
2.7	and	74		
5.4	washed	75		
8.0		74		
		DMD		
0	soaked	30-35	nylon bag	Haque *et al.* (1981)
4.0		37-49		
		OMD		
0	sprayed	39	nylon bag	Shin *et al.* (1981a)
3		48		
6		50		
9		53		
12		56		
		OMD		
0	soaked	40	*in vitro*	Winugroho *et al.*
5.0		52		(1984)
10.0		56		
20.0		58		
		OMD		
0	soaked	43	*in vitro*	Winugroho *et al.*
4.5	and	50		(1984)
4.9	washed	48		
9.0		56		
9.8		53		
18.0		56		
19.6		56		
4.5	soaked	48		
4.9	and	50		
9.0	pressed	58		
9.8		55		
18.0		60		
19.6		57		

Table 6.7. Effects of calcium hydroxide pretreatment of rice or wheat straws on feed intake, digestibility and liveweight change

Straw/Treatment	Animal	Total intake		Straw intake		Digestibility		Liveweight change (g/day)	Reference
		DM (kg/day)	OM (kg/day)	DM (kg/day)	OM (kg/day)	DM (%)	OM (%)		
Rice									
Untreated	Cattle	5.30		3.18				520	Pacho *et al.* (1977)
$Ca(OH)_2$ treated		5.48		3.27				720	
Rice									
Untreated	Cattle	5.66		3.40				520	Pacho *et al.* (1977)
$Ca(OH)_2$ treated		5.85		3.50				630	
Wheat									
NaOH–treated	Calves	86[3]				55		158	Verma *et al.* (1982)
$Ca(OH)_2$–treated (unwashed)		93[3]				41		38	
$Ca(OH)_2$–treated (washed)		98[3]				42		90	
Rice									
Untreated	Calves	1.8	1.6	1.7		40		35	Saadullah *et al.* (1982a)
Untreated[2]		1.8	1.6	1.7		46		75	
$Ca(OH)_2$ treated [2]		1.7	1.5	1.7		48		99	
Rice									
Untreated	Sheep	0.54		0.54		38			Saadullah *et al.* (1981a)
$Ca(OH)_2$–treated (washed)		0.45		0.45		49			
$Ca(OH)_2$–treated (washed)[1]		0.48		0.47		54			
Rice									
NaOH–treated[1]	Sheep	1.46	1.18	1.33	1.07	57	63		Winugroho *et al.* (1984)
$Ca(OH)_2$–treated (pressed)[1]		1.56	1.25	1.42	1.14	51	61		
Wheat									
Untreated[1]	Sheep	0.48	0.40	0.44	0.36	50	54	–140	Djajanegara *et al.* (1984/1985)
$Ca(OH)_2$–treated (pressed)[1]		0.84	0.69	0.76	0.63	50	62	–40	

[1]Supplemented with urea and molasses; [2]Supplemented with urea; [3]Intake values are g/kg $LW^{0.75}$ and it is not entirely clear from the reports of this experiment (Verma *et al.* 1982; Verma, 1983) when supplements of minerals and berseem were given.

straw (Verma, 1981). *In vitro* digestibility data indicate that washing is not necessary.

(iv) High amounts of calcium hydroxide (10 to 15 g/100 g straw) might need to be applied as it is a weak alkali of low solubility (Verma, 1981; Winugroho *et al.*, 1984). The reasons for the good response to low levels of application in a soaking process (Dumlao and Perez, 1976) or by spraying (Shin *et al.*, 1981a) are not clear.

The voluntary intake and digestibility of straw treated with calcium hydroxide has been examined in several experiments. The consumption of wheat bhusa by calves (Verma *et al.*, 1982) and wheat straw by sheep (Djajanegara *et al.*, 1984/1985) can be considerably increased by treatment with calcium hydroxide (see Table 6.7). In other experiments (Pacho *et al.*, 1977; Saadullah *et al.*, 1981a, 1982a) straw intake has not increased with the pretreatment, but digestibility and/or liveweight gains have been improved. Because of the large amounts of calcium used apparent dry matter digestibility may not be affected by treatment whereas organic matter digestibility is increased (Djajanegara *et al.*, 1984/1985). Verma *et al.* (1982) suggested that the lack of response in *in vivo* dry matter digestibility to calcium hydroxide treatment in their work was due to the high calcium content of treated wheat bhusa which, in turn, may have upset the ratio between calcium and other nutrients/minerals in general, and phosphorus in particular. More recently, it has been shown that this treatment did not adversely affect phosphorus utilization by sheep (Djajanegara *et al.*, 1984/1985) and as the intake of calcium hydroxide treated straw by calves was maintained over a 150-day period in the experiment of Verma *et al.* (1982) a mineral imbalance was also unlikely in that work.

Winugroho *et al.* (1984) found that sheep consumed similar amounts of digestible organic matter from rice straw spray-treated with sodium hydroxide or soaked in a calcium hydroxide suspension (Table 6.7). However, Verma *et al.* (1982) found that calcium hydroxide-treated straw, washed or unwashed, resulted in lower liveweight gains than sodium hydroxide-treated wheat straw.

The application of lime treatment to village situations in Asia is likely to be limited by the need for soaking vessels and the time required for daily treatment of the feed. However, in some areas of India where soaking is practised this treatment may have a place.

6.3.1.4 *Potassium hydroxide.* As assessed by *in vitro* digestibility, potassium hydroxide in equimolar amounts is as effective as sodium hydroxide in treating crop residues by the spray method. This has been shown with corn cobs (Rounds *et al.*, 1976) and barley straw (Wilkinson and Gonzalez Santillana, 1978).

Siebert (1974) reported that potassium hydroxide treated spear grass (*Heteropogon contortus*) was more palatable to cattle than sodium hydroxide treated or untreated material. In addition, steers consumed (3.6 vs 2.4 kg/day) and digested (58 vs 53%) more organic matter from potassium hydroxide treated than untreated grass. However, some of these effects may have been due to supplements of nitrogen and sulphur provided with the treated spear grass.

Potassium hydroxide has not been commonly used in attempts to improve the nutritive value of poor quality feeds due to its cost. However, wood ash and rice hull ash are sources of potassium hydroxide. While it may be possible to treat rice straw with solutions from ash, practical difficulties could be encountered due to variations in the alkalinity of solutions from these materials.

6.3.2 *Pretreatment with oxidative reagents*

Oxidative attack by chemical reagents on fibrous feed materials is known to reduce lignin content (Sherrod *et al.*, 1978; Ben-Ghedalia *et al.*, 1980; Ben-Ghedalia and Miron, 1981) and to break bonds between lignin and carbohydrates (Ben-Ghedalia and Miron, 1981; Tock *et al.*, 1982; Bunting *et al.*, 1984). However, pretreatment with oxidative chemicals, such as sulphur dioxide, ozone and chlorinated compounds, involves the use of sealed reaction vessels and the processes are generally carried out under controlled conditions. While the degradability of various fibrous residues have been shown to be increased by pretreatment with sulphur dioxide (Ben-Ghedalia and Miron, 1981, 1984b), ozone (Ben-Ghedalia and Miron, 1981; Tock *et al.*, 1982; Bunting *et al.*, 1984) and sodium chlorite (Itoh and Terashima, 1980; Terashima *et al.*, 1981) in *in vitro* studies, it has been observed that phenolic oligosaccharide compounds released may result in lowered digestibility of the cell soluble fraction (Ben-Ghedalia and Miron, 1984a).

In a feeding trial with sheep, Ben-Ghedalia and Miron (1984a) reported that the organic matter digestibility of a diet containing about 85% wheat straw was increased from 46 to 65% when this component was pretreated with sulphur dioxide. The main effects of the pretreatment were to solubilize cell wall constituents decreasing them from 79 to 56% of the straw and to increase the digestibility of residual cell walls from 49 to 78%. However, the digestibility of the solubilized cell wall fraction was apparently low.

In a study in which ozone-treated sorghum stover replaced untreated stover at 40% of a diet given to lambs, oxidative pretreatment had no effect on the digestibility of dry matter, acid detergent fibre or lignin, but resulted in a small increase in cellulose digestibility (45 vs 41%) (Bunting *et al.*, 1984). This effect was much less than the increase in *in vitro* digestibility (57 vs 45%), and the discrepancy may have been partly due to the low content of stover in the diets.

Yu *et al.* (1975) compared pretreatment of wheat straw with sodium chlorite, sodium hypochlorite, calcium chlorite and chlorine gas, when treated replaced untreated straw in diets given to goats. The digestibility of the untreated straw-based diet was 47% and this was increased to 56% with sodium chlorite treatment; the other treatments were either ineffective or less effective than sodium chlorite. Importantly, the voluntary intake of diets containing sodium chlorite-treated straw was only 0.5 kg/100 kg LW, compared to 1.4 kg/100 kg LW with untreated straw, but washing increased intake of the sodium chlorite-treated straw diet to 1.9 kg/100 kg LW. There was some indication that residual chlorine compounds, possibly chlorinated phenolic lignin residues, and/or low pH may have been toxic to rumen microorganisms. Goering *et al.* (1973) have also reported increases in organic matter digestibility (62 vs 55%) from pretreatment of the barley straw component of a diet given to sheep, but there was no increase in digestible organic matter intake.

The use of oxidative reagents mixed with organic materials can be hazardous and the costs involved in ensuring such processes are safe prohibit their use for improving the feeding value of rice straw. Further, it would seem that the treated products can be unpalatable when they comprise a large proportion of the diet. Oxidative pretreatment would be more appropriate in industrial or biotechnological processes concerned with increasing the biodegradability of fibrous residues.

6.3.3. *Pretreatment with acids*

Acid pretreatment of fibrous feeds hydrolyses the hemicellulose in cell wall material thereby releasing sugars. Also some lignin-carbohydrate bonds are acid-labile and may be broken during this treatment and with concentrated acid cellulose can be hydrolysed. Sulphuric acid treatment has been used as a preliminary step in single cell protein production systems using fibrous residues. Han (1978) outlined three types of process in which acid is used to hydrolyse fibre:

(i) dilute-acid hyrdolysis, without separation of products as they are formed,
(ii) a percolating process that continuously removed products as they are formed, and
(iii) a concentrated-acid process, followed by dilute-acid hydrolysis.

The first process has been used for hydrolysis of crop residues and involves treatment with 1-5% sulphuric acid at 120°C. When hydrolysis is carried out at higher temperatures or with prolonged heat not only is hemicellulose hydrolysed but breakdown of alpha-cellulose occurs. The sugars formed under these conditions can be further degraded to furfurals and insoluble resins (see Han, 1978). Balasubramanya and Bhatawdekar (1980) found that up to 30-34% of sugars were released when rice or wheat straws were heated at 121°C with 0.5N H_2SO_4 at a solution: substrate ratio of 3:1. The straws were then used as a growth medium for single cell protein production.

In a more recent study, Crosthwaite *et al.* (1984) investigated the effects of a pretreatment process referred to as acid-ageing as a means of improving the nutritive value of fibrous feeds. Treatment with hydrochloric or sulphuric acids followed by periods of storage was found to increase the rumen fluid digestibility of fibrous materials and this was associated with increases in water-solubility of the feeds. The cellulase (Onozuka P1500, which is more pure than that normally used in forage analysis) digestibility of rice straw was increased from around 26% to 36% after treatment with 1.7% HCl and storage for 3-4 weeks. Higher concentrations (3% HCl) and storage periods of 1-4 weeks increased digestibility to 39-45% and the effects were attributed primarily to hydrolysis of hemicelluloses. The authors suggested that acid-ageing may be a feasible process at the village level. However, the process would need to be investigated on a larger scale, bearing in mind the dangers involved with handling and transportation of acids, and the responses of animals to acid-treated straw would need to be studied. The low pH of the treated straw might be expected to reduce its palatability and it may need to be neutralized or diluted with other feeds before being given to animals.

6.4 **Physico-chemical pretreatments**

When physical and chemical pretreatment processes are used in combination they might be expected to be more effective in increasing the nutritive value of fibrous feeds. In this regard the effectiveness of alkali treatments might be increased if the surface area exposed to chemical action was increased by chopping or grinding or by steaming under pressure.

It is intended in this section to give an overview of the effects of combinations of physical and chemical processes on the nutritive value of fibrous residues. In order to do this it has been necessary, in the main, to use information based on the application of such pretreatments to fibrous residues other than rice straw.

6.4.1 *Particle size and chemicals*

Reduction in the particle size of a feed increases the exposed cellulosic surface area, but this increase may not be as large as expected (see Walker, 1984). A number of experiments have examined the effects of different chopping lengths on the responses in *in vitro* or nylon bag digestibility of crop residues treated with sodium hydroxide. Anderson and Ralston (1973) found no significant differences between three particle sizes (fine—60 mesh, 0.64 cm or 2.54 cm) of ryegrass straw in the efficiency of treatment by soaking in a sodium hydroxide solution. Similarly, Chandra and Jackson (1971) found that sodium hydroxide was as effective in increasing the nylon bag dry matter digestibility of chaffed and ground wheat straw, even though the initial digestibility of the chaffed feed was lower. In contrast to this, sodium hydroxide pretreatment was found to be more effective in increasing *in vitro* digestibility of rice straw as the particle size of the rice straw was reduced (Thiruchittampalam and Jayasuriya, 1978), but the differences reported were small. With wheat straw (Coombe *et al.*, 1979a) and barley straw (Coombe *et al.*, 1979b) chemical treatment appeared to be more effective with the chopped than with ground and pelleted materials in terms of potentially digestible dry matter measured by the nylon bag procedure.

The effects of reducing particle size by grinding combined with sodium hydroxide treatment on the intake and digestibility of fibrous feeds by ruminants have not always been found to be additive. Fernandez Carmona and Greenhalgh (1972) found that milling of barley straw led to a 39% increase (650 vs 470 g/day) in organic matter intake and a 34% increase (290 vs 220 g/day) in digestible organic matter intake by sheep when compared to chopped straw. When the straw was treated with alkali the increase in organic matter intake (890 vs 810 g/day) associated with particle size reduction was only 10% while digestible organic matter intake (570 vs 490) increased 15%. These results indicate that the effects of the physical and chemical treatments on digestible energy intake were not additive.

Coombe *et al.* (1979b) compared the intake and digestibility of barley straw-based diets in which the straws had been (i) chopped, (ii) ground and pelleted, (iii) treated with 4% sodium hydroxide, or (iv) ground, pelleted and treated with 4% sodium hydroxide. The organic matter intakes (kg/day) were 3.49, 6.01, 4.49 and 6.23, respectively, while the digestible organic matter intakes (kg/day) were 2.00, 2.99, 3.01, 3.74 and empty body weight changes (kg/day) were 0.08, 0.69, 0.83 and 1.38. As was found by Fernandez Carmona and Greenhalgh (1972), the two treatments together resulted in the greatest improvement in straw quality, but in this experiment the effects of the treatments when combined were nearly additive. Coombe *et al.* (1979a) reported similar findings for a wheat straw-based diet.

6.4.2. *Temperature and chemicals*

As with other chemical reactions the effect of different alkali treatments on the in vitro digestibility of fibrous residues has been shown to be influenced by temperature. Sundstøl *et al.* (1978) found that treatment of straw with 3 to 4% ammonia is more effective at temperatures of 17 to 25°C than at temperatures of 4°C or −20°C irrespective of the moisture contents of the straw during treatment. The slow reaction rate at low temperatures can be compensated for by allowing a longer treatment time. In this regard, Ololade *et al.* (1970) found that temperature affected the rate as well as the extent of *in vitro* digestibility response when barley straw was treated with sodium hydroxide. Sodium hydroxide treatment at 100°C for 90 min resulted in digestibility values 10% units higher than treatment at 23°C for 24 h.

When straw is heated with alkali in large heaps the heat produced during chemical reactions causes significant increases in the temperature of the stack. Rexen (1978) with dry treatment of straw measured temperatures in the middle and at the top of the heap of around 100°C, while the increase in temperature on the surface of the heap was low. Consequently, straw from the middle and top of the heap was about 50% digestible, while straw on the outside of the heap was less than 40% digestible. Increases in temperature to 65-70°C have been measured when rice straw is treated with urea in large stacks. This indicates that, provided straw treatment is undertaken on a sufficient scale, particularly in tropical areas, the temperature in stacks is likely to be sufficient for effective treatment with alkalis. In colder climates where very low temperatures are encountered the problem can be overcome to some extent by allowing longer treatment times.

Recently, Perdok and Leng (1985) reported that ammoniation of particular batches of rice straw at temperatures in excess of 70°C resulted in a condition of hyperexcitability in cattle. It is thought this condition arose from the formation of 4-methylimidazole during processing. Although, reports of these effects are rare they should be borne in mind when considering ammoniation treatment at high temperatures.

6.4.3. *Steaming and chemicals*

Hart *et al.* (1981) have found that rice straw, with an enzymatic *in vitro* digestibility of 26%, can be upgraded by steam treatment to a residue with a digestibility as high as 47%. The addition of sodium hydroxide to rice straw prior to steaming increased the *in vitro* digestibility for any particular set of treatment conditions studied with values as high as 60% being recorded. In contrast, the use of ammonia or urea in conjunction with steam treatment had no appreciable effects on *in vitro* digestibility. While these nitrogen additions did improve the crude protein content of the treated residues, the nitrogen might be more effectively and practicably provided as urea supplements.

Feeding trials in which sodium hydroxide steam-treated or untreated rice straw were fed at 65 or 72% of the diet of lambs indicated that lambs given the treated straw diets gained more weight (180 and 130 vs 130 and 90 g/day) (Garrett *et al.*, 1981). These increases in production were due to increased feed intake in one trial and increased digestibility of the diet in the second experiment. Incorporation of ammonia prior to steaming the straw only resulted in a feed of similar value to the untreated material.

Although the addition of sodium hydroxide prior to steam treatment has increased the effectiveness of treatment with some materials such as grass straws (Guggolz *et al.*, 1971), wood species (Millett *et al.*, 1970) and rice straw (Hart *et al.*, 1981), only small or no increases have been found with other residues, such as barley straw, pea straw, sugarcane bagasse and sunflower hulls (Ibrahim and Pearce, 1983a), and even negative effects have been reported when alkali was combined with high pressure steaming (Dhinsa and Donefer, 1976). These conflicting results emphasise the variability among crop residues, the fact that they respond differently to different steaming and temperature conditions and also that the inclusion of chemicals further complicates the establishment of optimum treatment conditions.

Given that it has been demonstrated (Section 6.3) that less expensive processes such as spraying straw with chemicals or soaking it in alkaline solutions can improve feeding value, it is inconceivable that the additional costs of an energy intensive steam treatment could be considered unless enormous increases in straw quality were achieved. The information available suggests that such increases are unlikely.

6.5 Biological pretreatments

As there is often a need to store rice straw after harvesting the opportunity exists to implement inexpensive biological pretreatments which might increase the nutritive value of straw. This section reviews some of the information on biological pretreatments which have been tested as a means of improving the feeding value of fibrous residues.

6.5.1. *Composting*

During composting, organic materials are decomposed through biochemical processes involving microorganisms. The first stage of composting involves a rise in temperature of the composted material, an increase in the number of certain microorganisms and decomposition of organic compounds. The degree to which the temperature rises, particular microorganisms multiply and the rate of degradation of the composted materials are dependent upon factors such as moisture content, oxygen availability, pH, the nutrient ratios in the composted materials and the prevalence of particular types of microbes. Straws are often composted with already rotting material or animal wastes which provide inoculum as well as moisture and additional nutrients. During the second stage of the process, slow organic matter degradation continues until equilibrium conditions are reached.

Han (1978) indicated that, while aerobic fermentations can increase the percentage of crude protein in straw, the more digestible components of the residue are metabolized leading to a decline in dry matter digestibility. In this regard, Vanselow (1983) found that, during 25 days, compositing of rice straw with small additions of previously rotted straw and cattle faeces resulted in a loss of 30% of the dry matter originally present. Despite partial metabolism of the neutral detergent fibre and pepsin-cellulase indigestible fractions of the straw, the losses resulting from degradation of the neutral detergent solubles fraction meant that the composted residue had the same *in vitro* digestibility as the untreated material. Hsieh *et al.* (1972) also reported losses in water soluble components, cellulose and hemicellulose and increases in lignin and crude protein in rice straw during both short and long composting periods.

Anon. (1982, 1983) reported that the microbial activity in composts of wheat straw, urea and coffee waste or of wheat straw and urea was greater when a small inoculum of already fermented straw was added and when regular turning was practised. After 12 days, up to 25% of the organic matter originally present and much of the nitrogen, particularly that added as urea, had been lost. While buffaloes were generally prepared to consume diets containing composted material turned at 3 day intervals, they consumed and digested more of a diet containing untreated wheat straw, urea, green grass and minerals (Anon., 1983). Diets containing composted straw prepared with less frequent turning were consumed in greater quantities and digested to the same extent as the control diet. Part of this effect with less frequent turning could conceivably have been due to urea pretreatment (see Section 6.3.1.2) or supplementation (see Chapter 7) as opposed to the effects of fermentation.

The losses of organic matter, in particular neutral detergent solubles, during composting with consequent increases in the ash and lignin content of the fermented residue indicates that this pretreatment process is unlikely to improve the feeding value of rice straw.

6.5.2. *Ensilage*

Ensilage generally refers to the preservation of green fodder in a silo or pit without drying, a process which involves anaerobic fermentation. A vast amount of literature exists on the ensiling process and its manipulation. More recently, this process has been employed to conserve a more diverse range of forage resources, including crop residues.

Vanselow (1983) reported that when rice straw, which had been composted for short periods, was ensiled the production of volatile or gaseous products almost ceased. The ensiling process appeared to allow some continuation of the conversion of pepsin-cellulase digestible neutral detergent fibre into neutral detergent solubles. In addition, ensiling of straw which had not been composted resulted in some conversion of pepsin-cellulase indigestible material into digestible compounds. However, it was concluded that ensiling was unlikely to improve *in vivo* dry matter digestibility of straw. Klopfenstein *et al.* (1972) had shown previously that ensiling straw with water did not appreciably improve the feeding value over that of non-ensiled materials.

Because of the low contents of available nitrogen and carbohydrates in rice straw nutrient additions to straw silage are essential. In Asia, attempts have been made to ensile paddy straw with other available feed resources such as berseem clover (Lal and Mudgal, 1967), water hyacinth (Chhibbar and Singh, 1971), potato haulm (Krishna, 1982), poultry litter (Neog and Pathak, 1976) and manures (Lee, 1985). Some of these silages have been reported to supply sufficient nutrients for maintenance of animals. Krishna (1982) found that straw and potato haulm (1:5 ratio) silage met the maintenance energy and protein requirements of cattle, and while Chhibbar and Singh (1971) observed no weight loss in cows fed paddy straw and water hyacinth (1:4 ratio) silage, it was suggested that some supplementation was appropriate. A silage containing chopped paddy straw, fresh poultry litter, chopped green maize and molasses (40:40:10:10 ratios on dry matter basis) was found to be 50% digestible in adult cows (Neog and Pathak, 1976) and calves (Pathak and Neog, 1977) and, while it was adequate in protein content, supplementation with energy was required to maintain the animals. Where alkali-treated straw-manure-bran silage comprised 50 to 60% of the dry matter consumed by beef (Lee, 1985) or dairy (Yoon *et al.*, 1985) cows acceptable levels of production have been reported.

Ensilage would seem to be a useful process for conserving the nutrient value of forages and, in the case of fibrous feeds, their storage with other forages or animal wastes should lead to a more balanced feed than the straw alone. This could be a valuable means of storing straw having a high moisture content at harvest. However, despite considerable research effort these processes have not been adopted in small farm systems in Asia. An exception to this is the use of straw manure silage which contains about 50% alkali-treated rice straw and is being used on over 400 farms in Korea (Lee, Nam-Hyung, personal communication).

6.5.3. *Fungal growth*

Many of the white rot fungi are known to metabolise lignin, cellulose and other fibrous components in wood species (Kirk and Moore, 1972). These organisms grow slowly but have been shown to metabolise lignin and cellulose in agricultural residues (Latham, 1979; Zadrazil, 1979; Ibrahim and Pearce, 1980), and to have modest effects on the *in vitro* digestibility of such materials (Ibrahim and Pearce, 1980). The fungus, *Coprinus cinereus* has been found to increase the digestibility of barley straw from 45 to about 55% after ten days growth at a pH of between 7 and 9 (Burrows *et al.*, 1979), but there was a 12% dry matter loss from the straw and the fungus attacked both cellulose and hemicellulose, but did not degrade lignin. When fungal growth was allowed to continue for more than ten days digestibility of the residue declined as *C. cinereus* began to rapidly utilize cellulose. Punj (1967-1981) reported that three strains of *Pleorotus* edible mushroom (*P. ostreatis, P. cajus* and *P. florida*) were lignolytic and could reduce the lignin content of rice straw from 6 to 3%, but there was also a 50% loss in organic matter. Recently, Kim and Lee (1985) found that five fungi (*Trichoderma viride, Chaetomium, Polyporus hirustus, Polyporus versicolor* and *Pleorotus astreatus*) used readily available nutrients in rice straw for their growth as well as degrading hemicellulose and cellulose and, consequently, they reduced digestibility of rice straw when grown for periods of less than six weeks.

Many Asian families grow edible mushrooms, often using cereal straws as the entire, or as a part of, the growth medium, to supplement their protein intake or monetary income. While only small amounts of straw are used in this way (Alicbusan, 1983), few investigations of the effects of these fungi on the feeding value of rice straw have been reported.

Langar *et al.* (1980a) reported that *Volvariella displasia* (straw mushroom) grown for 30 days on uncut paddy straw resulted in reduced organic matter (78 vs 85%) and neutral detergent fibre (76 vs 85%) contents in the spent straw and increased ash (22 vs 15%), crude protein (9 vs 5%) and lignin (11 vs 5%) contents in spent compared to untreated straw. When *Volvariella volvacea* was grown on paddy straw for a shorter period of 12 days, Vijchulata and Sanpote (1982) found that fungal growth had no effects on straw composition.

When spent straws from mushroom cultivation have been fed to ruminants variable effects have been observed. Vijchulata and Sanpote (1982) found that sheep consumed and digested similar amounts of untreated and spent rice straw when this material was supplemented only with minerals. In contrast, Langar *et al.* (1980b, 1982) found that complete replacement of wheat straw with spent straw was unacceptable to buffaloes even when molasses was added. In their experiments, straw was supplemented with green feed and concentrates, and it is not clear if the adverse effects of the spent straw were due to the fungus *A. bisporus* or to components of the composting mixture on which it was grown. They concluded that spent straw could replace 50% of the wheat straw in their diets without adverse effects.

It would seem likely that the effects of fungal growth on the chemical composition and hence nutritive value of fibrous residues is dependent on the type of fungus, the nature of the residue and the conditions of growth. Identification of specific fungi which selectively degrade lignin and some of the structural carbohydrates is indeed a possibility, but careful control of growth conditions including duration of incubation, temperature, pH, aeration, moisture content and nutrient additions are likely to be critical if worthwhile improvements in feeding value are to be gained. It would also be important that the fungi selected did not produce toxins. Conversion of a raw material which is already potentially useful into a marginally better feed would seem to be a waste of effort if high degrees of control and specialist monitoring are required. Nevertheless, the potential for biological upgrading of lignocellulosic materials has been discussed in detail by Zadrazil (1984) and it would seem that while such processes are feasible on a laboratory scale, they generally fail when scaled up for practical application.

6.5.4. *Enzyme additions*

Early studies (Leatherwood *et al.*, 1960; Ralston *et al.*, 1962) examined the effects of supplementation with enzymes, such as cellulases, proteases, amylases and pectinases, on the utilization of low quality roughages by ruminants. At best only small effects on the digestion of different components of the feed were achieved and little advantage was gained from this feeding strategy.

More recently, microbial enzymes have been used in pretreatment processes applied to fibrous feeds. Willis *et al.* (1980) reported that the addition of microbial enzymes, including hemicellulase, to rice straw without prior treatment with alkali reduced *in vitro* digestibility of the residue. When enzymes were added after treating the straw with 5% sodium hydroxide, they increased *in vitro* digestibility above that achieved with alkali treatment alone, particularly when the enzyme was added 3 days after chemical pretreatment. Rai and Mudgal (1983) investigated the effects of commercial cellulase produced from *Trichoderma viride* on the degradability of paddy straw treated with sodium hydroxide followed by neutralization of the alkali with dilute hydrochloric acid. Compared with the chemically-treated straw as a control, different amounts of the enzymes did not greatly influence the amount of cell wall or its components, cellulose and hemicellulose, in the straw. However, the addition of the enzyme increased *in vitro* digestion of dry matter, cell walls and acid detergent fibre by about 7% units while digestibility of hemicellulose was generally not affected.

The use of microbial enzymes in treatment processes is unlikely to be of practical significance for many reasons not the least of which are the availability and cost of the enzymes and the likelihood that animal response would be small.

6.6 **Economic evaluation of pretreatments**

Several review papers have dealt with the economics of pretreating fibrous materials for use as animal feeds (see Greenhalgh, 1984; Giaever, 1984; Smith and Balch, 1984; Schiere *et al.*, 1985). In any economic evaluation the costs of inputs need to be weighed up against the extra income earned. Inputs involved in the utilization of straw can involve labour (used in collection, transport and storage), transportation, and any cost involved if the straw is purchased. Pretreatments involve additional costs for labour, materials used in the treatment process (chemicals, inocula, treatment equipment) and storage of treated straw. These costs vary between countries and between villages within countries. Extra income can be in the form of increased draught power, better quality and more manure, or greater income from animal products, meat and milk. Again the relative values of these products varies enormously throughout Asia. Consequently, the comparative costs of the various pretreatments in different countries and the likely economic outcomes from such pretreatments need to be evaluated under specific local condition. However, several general points can be made.

Chemical pretreatments usually increase both the intake and digestibility of fibrous feeds and these effects may be reduced or lost if such feeds only comprise a small proportion of the diet. Thus, to be economic, maximum advantage should be taken of these effects of effective pretreatment. This point has been illustrated clearly by Schiere *et al.* (1985) when evaluating the economics of feeding urea-treated straw in Sri Lanka.

The fact that urea pretreatment has been adopted only by a small number of farmers in Asia raises many questions. In the first instance, has the technology been extended to farmers correctly and, if so, then why has it not been more widely adopted? Is this due to conditions of pretreatment which do not lead to significant improvements in nutritive value when the process is carried out on farms, or is it, in fact, because the process is not economical?

6.7 Concluding comments

Many pretreatments can improve the feeding value of straws, but only a few have even remote chances of application in small farm systems. Further research into pretreatments that have no chance of application is a waste of time and resources. To a large extent pretreatments should be considered as a last resort because they involve costs and place an additional burden on the farmer in that they are labour intensive and require forward planning.

Pretreatment of rice straw with urea as a source of ammonia would seem to have the most chance of practical application on small farms in Asia. However, its adoption had been limited to a small number of farmers with dairy animals who gain an immediate return for their investment through the sale of milk. This process had disadvantages, in addition to the extra labour requirements, in that there is a chance of spoilage when the treatment is carried out in stacks that are not properly sealed; a risk that Asian farmers cannot afford to take.

It has also been shown that the quality of the feed to be treated is important (e.g. Kernan *et al.*, 1979, 1981; Ibrahim and Pearce, 1983a) and there is a need to know more about the effects of processes, like urea pretreatment, on the feeding value of particular batches of straw. Finally, urea pretreatment only upgrades rice straw to a maintenance feed and supplementation with specific nutrients is required for production. Feeding systems which incorporate appropriate supplementation to alleviate nutrient limitations are more likely to be acceptable to the majority of Asian farmers than are pretreatments.

When comparisons have been made between supplementation of straw-based diets with green feeds compared to urea pretreatment of the straw component for growing (Cheva-Isarakul and Potikanond, 1985) or lactating (Promma *et al.*, 1984) animals the two approaches have been found to result in similar production levels. These alternatives need to be evaluated at the farm level and it is likely that the best option will vary between countries and farms.

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7. SUPPLEMENTATION AND FORMULATION OF PRACTICAL DIETS

7.1 Introduction

Ruminants fed rice straw as a high proportion of their diet lose weight and a major reason for this is a low voluntary intake. Contributing factors are the low digestibility and a limited supply of protein, minerals and vitamins in the straw. Both the level of intake and the digestibility of rice straw may be increased by providing supplementary nutrients. This is achieved when the additional nutrients remove limitations to fermentation of rice straw by the rumen microbial population or limitations to metabolism in the tissues of the host animal.

Some nutrients can be provided alone by giving specific supplements. For example, fermentable nitrogen can be supplied as urea or specific minerals can be provided in a discrete form. However, at the small farm level it is more likely that supplementary feeds, forages or concentrate by-products, providing a range of nutrients will be used. Except at very low levels of supplementation, it is also likely that these feeds will substitute for straw in the diet. Under these conditions, responses in animal production, or alterations in the intake and digestion of rice straw when supplementary feeds are given, are often difficult to interpret due to the combinations of energy, protein, minerals and vitamins that are provided.

In Asia, consideration needs to be given to restricting the use of supplementary forages and concentrates, as usually they are in short supply, to levels which maximize the use of available low quality feeds. Feeding to levels that meet the requirements of animals for production functions is generally not possible. In this regard, Jackson (1981) questioned the relevance of research into the use of supplements to meet the nutrient requirements of livestock, particularly in countries where supplies of concentrate feeds are limited. He suggested that a livestock feed-budget approach was more appropriate, whereby the use of supplementary feeds would be rationed to ensure maximum efficiency of their usage.

In this chapter, attention is given to general principles which can be used to assess whether or not particular nutrients are limiting the utilization of rice straw-based diets (Theoretical Considerations). It is not the intention to focus on the requirements of animals for such nutrients, although reference to such information is made to enable evaluation of the effects of supplementation. In addition, some of the numerous reports on the effects of supplementation of rice straw with different nutrients or feeds are reviewed (Practical Supplementation).

PART A: Theoretical Considerations

7.2 Energy supplementation

Because of low intakes and poor digestibility of cereal straws, absorbed energy is generally a major factor limiting the ability of ruminants to achieve maintenance or production when fed such materials. To illustrate this, examples of the energy requirements for maintenance of various ruminants are given in Table 7.1. These data were selected for use not because they are necessarily more accurate than other reported values of requirements, but simply because data for the four ruminant species were listed in the one publication.

From reports in the literature, it can be estimated that buffaloes, cattle, sheep and goats consume, on average, 2.0 kg DM/100 kg LW of rice straw (see Chapter 4, Table 4.3), while the organic matter content of rice straw is about 80% and is likely to be about 45% digestible (digestible organic matter (DOM) in dry matter of 36%). Thus, a 200 kg buffalo would be expected to consume 4 kg of straw or 3.2 kg of organic matter and 1.4 kg of DOM. This is less than the estimate of requirements for maintenance of about 1.75 kg DOM given by Kearl (1982). However, a 400 kg buffalo may, in fact, be able to consume sufficient energy from straw (2.9 kg DOM) to approach maintenance requirements. A similar situation would occur with 200 kg compared to 400 kg cattle. However, sheep and goats are unable to consume sufficient straw organic matter for maintenance at liveweights of 20 or 40 kg. It is important

Table 7.1. Requirements of energy for maintenance of buffaloes, cattle, sheep and goats (Source: Kearl, 1982)

Liveweight (kg)	Dry matter intake (kg/day)	Dry matter intake (kg/100kg LW)	Energy: Digestible organic matter[1] (kg)	Energy: Metabolizable energy (MJ)	Energy: Total digestible nutrients[2] (kg)
Buffaloes (maintenance)					
200	4.1	2.1	1.75	27.82	1.84
400	7.0	1.8	2.94	46.74	3.09
Cattle (mean values for steers and heifers for maintenance)					
200	3.9	2.0	1.68	26.76	1.76
400	6.5	1.6	2.83	45.02	2.97
Sheep (maintenance of ewes and lambs)					
20	0.55	2.8	0.23	3.68	0.24
40	0.93	2.3	0.39	6.19	0.41
Goats (maintenance of females)					
20	0.54	2.7	0.26	4.10	0.27
40	0.91	2.2	0.43	6.90	0.46

[1]Digestible organic matter was calculated as 1 kg DOM = 15.90 MJ ME
[2]TDN was calculated a 1 kg TDN = 15.15 MJ ME

to bear in mind that these estimates are based on average values for intakes and quality of straw and the errors associated with these assumptions can be large. Further, it is assumed that the animals consume straw at the same percentage of their liveweight and this is not always the case as younger growing animals are likely to ingest more feed per unit liveweight than older mature animals. Where liveweight changes in animals fed rice straw alone have been measured buffaloes (Wanapat *et al.*, 1984; Wongsrikeao and Wanapat, 1985), cattle (McLennan *et al.*, 1981; Wannapat *et al.*, 1982, 1984; Suriyajantratong and Wilaipon, 1985) and sheep (Vijchulata and Sanpote, 1982) all lost weight. This indicates that even if the animals consume sufficient digestible organic matter, the efficiency of use of the absorbed energy in the tissues may be limited by the supply of some essential nutrients resulting in loss in weight.

In developed countries, cereal grains are often used as energy supplements for animals consuming low quality roughages. The consumption of such concentrates usually decreases the intake of roughage, but the substitution rate varies proportionately with the quality of the roughage i.e. high substitution rates (SR) for high quality roughages and low SR for low quality roughages (Leibholz and Kellaway, 1984). Variation in the rate of substitution also depends on the nutritive characteristics of the supplement. Generally with high energy supplements the reduction is attributed to rapid fermentation of the readily available carbohydrates reducing rumen pH and, hence, rate of cell wall digestion. Mould *et al.* (1983) have show that when rumen pH is less than or about 6.2, cellulose digestion becomes increasingly inhibited. Where the intake of low quality roughages has remained the same or increased in response to small amounts of energy concentrates, the response may in fact have been due in part to the nitrogen supplied in the supplements in conjunction with the energy. Where molasses supplements, which supply readily fermentable carbohydrates and minerals but little nitrogen, have been given without additional nitrogen to animals on low quality diets the intake of roughage is generally reduced with no affect on losses in liveweight (e.g. Beames, 1959; Suriyajantratong *et al.*, 1974).

It can be concluded that supplementation with readily available energy sources at up to 10 to 15% of total dietary dry matter may increase the intake of low quality roughage only when nitrogen and minerals are not limiting microbial protein synthesis. It is desirable to feed the concentrate frequently, that is in two or more meals per day, rather than once daily to avoid depressions in rumen pH and hence cell wall digestibility and in intake of straw.

7.3 Nitrogen supplementation

Animal requirements for nitrogen are met by amino acids and small amounts of nitrogen-containing nucleotides and vitamins absorbed from the small intestines. In ruminants, these nitrogen-containing nutrients can come from dietary proteins which escape fermentation in the rumen, from microbial proteins synthesized in the rumen, from endogenous secretions of protein into the mouth and stomach and from epithelial cells sloughed from the wall of the digestive tract.

Dietary nitrogen can be considered in three categories:
(i) rumen degradable nitrogen (RDN) which is used for microbial protein synthesis,
(ii) undegraded dietary protein (UDP) which escapes fermentation in the rumen and which is digested in the intestines, and
(iii) UDP which escapes fermentation in the rumen, and which is not digested in the intestines.
These considerations indicate the need to consider nitrogen requirements as being of two types: that required by the microbial population and that required in the animal's tissues.

7.3.1 *Nitrogen and the microbes*

The RDN requirements are considered to be 30 g N/kg of organic matter apparently digested in the reticulo-rumen (ARC, 1980). Leibholz and Kellaway (1984) estimated that the minimum required crude protein content of a poor quality diet with a DOM in dry matter value of 50% would be between 6.1 and 7.4%. If a diet had a DOM in dry matter content of only 40% then the minimum crude protein content to meet RDN requirements would be between 4.9 and 6.8%. Thus, the amount of RDN required becomes less as the digestibility of the diet declines. Based on the data presented in Chapter 4, rice straws usually have a DOM in dry matter content of between 30 and 50%. As rice straws usually contain less than 4% crude protein, supplements of RDN should improve microbial protein synthesis.

Supplements of non-protein nitrogen or of feeds containing RDN can be given to alleviate this deficiency and these situations are discussed later in this chapter.

7.3.2 *Sources of protein at the small intestine*

Dietary proteins are partially degraded in the rumen, but the degree to which this occurs varies between protein sources (ARC, 1980). Recent work reported by Leibholz and Kellaway (1984) indicates that the degradability of forage protein in the reticulo-rumen of cattle is high, with a mean value of 0.76 of the total protein. This value did not vary greatly for three pasture species, paspalum, oats and kikuyu, at different stages of maturity and different levels of intake. Thus, graminaceous forages provide only small amounts of UDP to the small intestine and this is likely to be the case with rice straw. However, the degradability of protein in some temperate and tropical legumes may be lower than the above estimates.

Protein supplements vary in the extent to which they are degraded in the rumen and this is of importance when considering the mechanisms of responses in intake and animal production to by-product concentrate or forage supplements. Egan (1985) has recently reviewed work in this area and it may be of a particular importance in the Asian situation. The degradability in the reticulo-rumen of some legume leaf supplements, such as leucaena and glyricidia, has been shown to be low (Jayasuriya *et al.*, 1982). Subsequently, it has been postulated that these materials may be a valuable source of UDP in diets for livestock, but this is by no means certain.

Hogan and Weston (1981) have found that crude protein (CP) reaching the intestines of mature wether sheep fed temperate forages can be calculated from the relationship:
CP(g/day) reaching intestines = 0.16 DOM intake (g/day) + 0.36 CP intake (g/day) + 6.
This relationship is similar to that derived for grazing wethers (Corbett *et al.*, 1979) and Egan (1985) has pointed out that it should be valid for mature tropical forages. Hence, for this type of animal, an approximate supply of crude protein to the tissues can be estimated. The relationship is likely to underestimate crude protein flows where the mean residence time in the reticulo-rumen is reduced, as in pregnancy and lactation, and when feed intake increases. Further, providing the efficiency of microbial protein production in large ruminants is similar to that in sheep, the relationship should give reasonable estimates of crude protein flows in

buffaloes and cattle. However, it is desirable to establish these relationships for each species and for animals in different physiological states.

7.3.3 *Adequacy of protein at the small intestine*

The adequacy of protein at the small intestine is most usefully considered by relating the supply and requirements for protein to those for energy. Egan (1980, 1985) had presented such relationships and these are given in Figure 7.1. As indicated, straw when fed alone is unlikely to meet the protein requirements for maintenance.

Egan and Walker (1975) and ARC (1980) have drawn attention to dietary circumstances in which growth rate or production level are limited primarily by the supply of essential amino acids to the tissues. Thus, supplementary protein can act in several ways: it might alter nitrogen conditions in the reticulo-rumen and increase microbial protein synthesis and/or rate of cell wall digestion, but it might also provide additional amino acids in the small intestines as either microbial protein or as UDP. These extra essential amino acids may overcome specific amino acid deficiencies which are limiting production or they may be catabolized to improve the supplies of energy, gluconeogenic substrates and recycleable nitrogen (Egan, 1985), with more nitrogen also being excreted in the urine.

More information on the nitrogen requirements of ruminants can be obtained from NRC (1976), ARC (1980), Leibholz and Kellaway (1984) and Egan (1985).

7.4 **Mineral supplementation**

Like nitrogen, minerals are required by the microbial population of the reticulo-rumen and

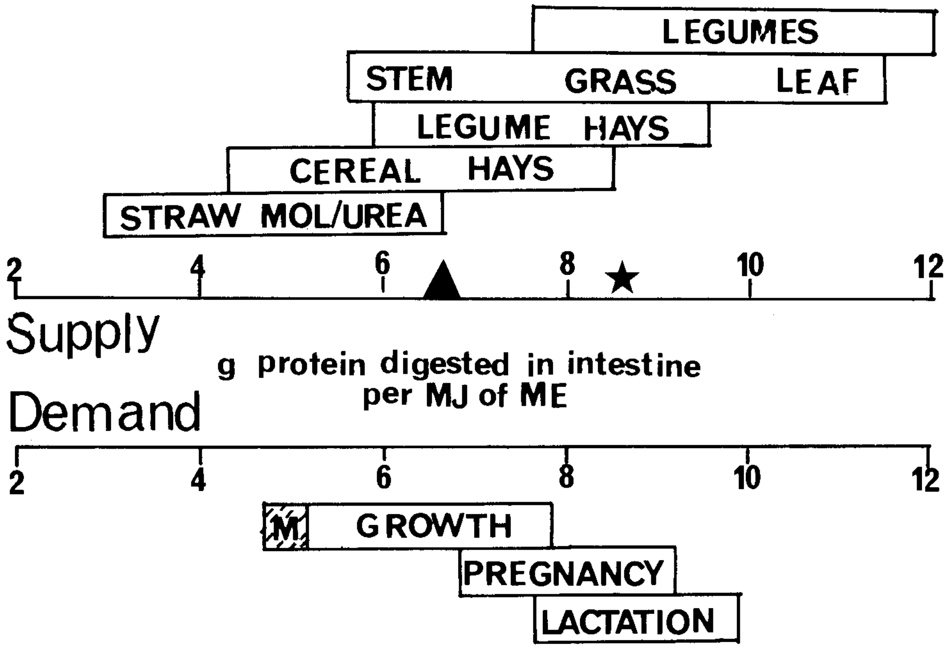

Figure 7.1. Relationship between protein: energy supply from a range of temperate feedstuffs, and the demand to be met in producing ruminants. The data were derived in experiments in which animals were fed at near to *ad libitum* (90%) and the flow of digesta was measured to allow calculation of digestible true protein reaching the duodenum. This was related to the energy derived by the animal from the same diet under the same conditions, expressed as metabolizable energy (ME). On the supply axis, the symbol ▲ indicates the average provision of microbial protein to the protein digested in the small intestine and * indicates the highest values recorded for microbial protein, each expressed relative to the ME provided on the respective diets. Similar data are needed for tropical feeds and animals.
(Derived from data presented by Egan and Walker, 1975; see Egan, 1980, 1985).

by the host animal. Seven macro-minerals or nutrients and fifteen micro- or trace-nutrients have been shown to be essential in animal nutrition. Of the macro-nutrients calcium, phosphorus, sodium, magnesium and sulphur may limit animal production in practical situations, while concentrations of potassium and chlorine in forages exceed requirements (ARC, 1980; Underwood, 1981). The trace minerals important in practice are copper, zinc, molybdenum, manganese, selenium, iodine, cobalt and iron. Deficiencies of the other essential trace nutrients are unlikely to occur, nor for that matter are deficiencies of iron because ingestion of soil usually provides more than sufficient of this mineral.

From a nutritional point of view, the primary deficiencies in animals fed rice straw are crude protein and energy and these limitations would have to be corrected before alleviation of mineral inadequacies will produce responses in animal performance. Recommendations of dietary mineral allowances have been published by the National Research Council (NRC, 1976), Agricultural Research Council (ARC, 1980) and Kearl (1982). Little (1985) concluded that, for animals fed tropical fibrous agricultural residues, routine provision of salt supplements was justified. Phosphorus and copper were considered the next most likely minerals to be limiting, but many more observations are required of the potential of feedstuffs in the Asian region to supply minerals. The information presented in Chapter 4 indicates that where rice straw is a major component of the diet then some other minerals, such as sulphur, may also be limiting.

Sulphur is particularly important in microbial protein synthesis as it is needed for the sulphur-containing amino acids, cystine and methionine. The efficiency of microbial protein synthesis is affected not only by the availability of nitrogen but also of sulphur. The optimum ratio of these nutrients (N:S) is about 10-14:1 (Moir, 1970; Bird, 1972). Thus, it is often necessary to provide sulphur when non-protein nitrogen supplements are given.

In practice, mineral supplements are usually expensive in Asia and are only provided where they are essential to maintain acceptable and economic levels of production.

7.5 Vitamin supplementation

Vitamins are required in small quantities for normal tissue function. They are often subdivided on the basis of their solubility in fat or water. One difference between the two groups is that fat-soluble vitamins are stored in body tissues, whereas the water-soluble vitamins, with the exception of vitamin B_{12}, are not stored in appreciable quantities. These nutrients all have specific functions, some being essential as coenzymes or metabolic catalysts while others are important in maintaining the integrity of cell membranes and in blood clotting.

Under conditions where animals are expected to produce at very high levels synthetic vitamins are often included in the diet to ensure that deficiencies do not occur. However, this is not likely to be the case in the small farm systems of Asia. The animals in these systems are largely dependent upon ingested plant materials for their vitamin supplies. Vitamins may also be ingested in animal by-products which are included in the diet and in the case of herbivorous animals the microbial populations of the digestive tract are known to produce water-soluble vitamins. It is often said that the effects of supplementing dry fibrous roughages with green forages is partly due to the vitamins supplied by the green materials. Although there is little direct evidence for this, it is likely to be a contributing factor.

PART B: Practical Supplementation

7.6 Supplementation of rice straw with non-protein nitrogen

Urea and molasses supplementation of low quality roughages has been found to reduce weight losses in cattle (Beames, 1959) and sheep (Coombe, 1959). These effects are due to increases in the intake and digestion of the basal diet in response to the provision of RDN (Redman *et al.*, 1980; Egan and Doyle, 1985). Other sources of non-protein nitrogen, such as biuret, have been shown to be as effective as urea in reducing or preventing weight losses in grazing cattle (Winks et al., 1979). As regards slow release nitrogen supplements, Ernst *et al.* (1976)

Table 7.2. Effects of supplementation of rice straw with non-protein nitrogen, minerals and low levels of molasses on dry matter intake (DMI), digestibility (DMD) and liveweight change*

Urea (% of total dry matter)	Other supplements	DMI Straw (kg/day)	DMI Total (kg/day)	DMD (%)	Liveweight change (g/day)	Reference
A. **BUFFALOES**						
0		5.02			−260	Suriyajantratong *et al.* (1974)
0	10% molasses	4.76	NA		−280	
1.0	10% molasses	5.68	NA		−160	
2.0	10% molasses	5.55	NA		−100	
3.0	10% molasses	5.57	NA		−100	
4.0	10% molasses	5.53	NA		−40	
0		4.68			−200	Intaramongkol *et al.* (1978)
0.85	minerals	4.60	4.70		20	
B. **CATTLE**						
0		4.78			−170	Intaramongkol *et al.* (1978)
0.85	minerals	4.78	4.88		0	
0		4.23	4.23		−149	McLennan *et al.* (1981)
1.24		4.84	4.90		−86	
1.17	60g molasses	5.03	5.14		−13	
1.17	120g molasses	5.00	5.15		−57	
1.21	240g molasses	4.71	4.95		−70	
1.17	7.5g Na_2SO_4	5.05	5.12		−42	
1.31	60g molasses, 5.5g Na_2SO_4	4.46	4.57		−77	
1.17	120g molasses, 3.7g Na_2SO_4	4.98	5.13		−26	
0	100g F, 20g minerals	1.70	1.80	40	35	Saadullah *et al.* (1982a)
2.55	100g F, 20g minerals	1.70	1.80	46	75	
0	1020g RB, 150g F, 100g minerals	2.48	3.79		103	Perdok *et al.* (1984)
1.38	1020g RB, 150g F, 100g minerals	2.84	4.28		213	
C. **SHEEP**						
0		0.40		37		Devendra (1978)
2.44		0.42		46		
3.14		0.43		47		
3.83		0.46		43		
4.23	100g C, minerals	0.43	0.52	53		Jayasuriya (1979)
3.14	100g C, 34g molasses, minerals	0.48	0.57	54		
3.08	100g C, 37g molasses, minerals	0.53	0.62	52		
3.10**	100g C, minerals	0.49	0.58	66		
2.72**	100g C, 40g molasses, minerals	0.57	0.66	61		
3.11**	100g C, 40g molasses, minerals	0.57	0.66	61		
0	28g molasses, 22g minerals	0.69	0.74	42	−138	Djajanegara *et al.* (unpublished data)
1.15	42g molasses, 33g minerals	1.04	1.11	49	−19	

*Some of the data presented in this table have been calculated from information given in the reports cited.
**Sodium hydroxide-treated straw
Note: supplement definitions: C = concentrate; F = forage; RB = rice bran
NA = not available

reported that biuret improved the intake of rice straw and liveweight performance of steers. Inclusion of a mineral mix containing sodium, phosphorus and sulphur with the biuret reduced the adaptation periods to the supplement. Further, uric acid, a component of poultry litter (Jacobs and Leibholz, 1977), and lactosyl urea (Merry *et al.*, 1982a, 1982b) which are more slowly degraded in the rumen provide RDN which is more efficiently used for microbial protein synthesis than urea. However, these compounds also have disadvantages in that adaptation to the supplements is necessary and the possibility of incomplete release of ammonia needs to be considered (see Merry *et al.*, 1982b).

In some circumstances, it is important to provide a source of readily available energy, such as molasses, to ensure efficient use of urea due to its rapid degradation. These energy-containing supplements are thought to provide energy at similar rates to the release of ammonia from urea. The release of energy from structural polysaccharides in straws will occur at a much slower rate. Also, when the sulphur content of the basal diet is low, supplements of this element can also improve the efficiency of use of urea-nitrogen (Siebert and Kennedy, 1972). This requirement for sulphur is related to its use in the synthesis of sulphur-containing amino acids by the microbial population.

The effects of supplementation of rice straw with urea are illustrated in Table 7.2. As with other low quality feeds, non-protein nitrogen supplementation increases the intake and/or digestion of rice straw resulting in improved animal performance. Responses to supplements of molasses or minerals in addition to urea have been variable; the reasons for this are unclear from the information available in published reports.

In practice, supplements of non-protein nitrogen can stimulate animal performance. However, to ensure efficient use of the supplementary nitrogen it should be supplied at a steady rate, as often as possible, rather than once daily, and should be given with small amounts of readily available energy (e.g. molasses or cassava chips) and sulphur bearing in mind this is supplied in molasses. Urea can be supplied at a steady rate by spraying it on to rice straw, or by giving it sprayed on to or mixed with readily available energy supplements. Care must be taken to avoid excessive intakes of urea as it can be toxic when small amounts are consumed rapidly or when large amounts are ingested even at steady rates. Recently, interest has returned to the possible use of urea/molasses blocks as a means of providing nitrogen and energy supplements to ruminants in Asia (Leng and Preston, 1983). Preliminary indications are that blocks have potential for use with stall-fed animals, but problems of acceptance can be expected with grazing animals. In addition, the formulation of ingredients to be included and manufacture of these blocks presents problems which are location specific. At present, non-protein nitrogen supplements are not widely used by farmers in Asia and the problems relating to the adoption of this technology in different areas should be identified. Adoption of the technology may have been constrained by the lack of consistent responses, unreliability of the products used or of the method of providing the urea, inadequate supplies of urea, or poor extension. It is also pertinent that the availability of supplements, such as molasses and cassava chips, in Asia is localized and that different systems might be needed for different areas. Further, Verma and Jackson (1984) have drawn attention to the practicalities of providing urea supplements to all animals in India which do not receive leguminous fodder crops. They estimate that the amount required would be two thirds of the total amount currently produced as fertilizer, indicating that wide adoption of urea-feeding by farmers would create problems in supply and probably increased prices.

7.7 Supplementation of rice straw with concentrates

In developed countries, the traditional approach to overcoming the low intake of fibrous feeds and the consequent low supply of nutrients to ruminants has been to dilute these feeds with large quantities of grain and protein. This strategy is not possible on small farms in developing countries where there are no excesses of grain for feeding to animals. In these countries, by-products of crop production high in energy or protein are usually exported to earn foreign exchange, or fed to monogastric animals which use the nutrients more efficiently than ruminants. Given these limitations, increased ruminant production will only occur if the utilization of available fibrous feed resources is maximised and in many instances these resources are also residues from crop production. It is conceivable, however, that small amounts of concentrate by-products may be used judiciously in feeding systems in order to maximise the use of fibrous basal feeds.

By-products from concentrates which are used as supplements are often classified as energy or protein feeds based on their chemical composition. Many of those available in Asia have been classed as non-conventional feed resources, because they have not been traditionally used for feeding livestock (Devendra, 1985). Some of these feeds which are available in certain areas of Asia are listed in Table 7.3. It should be remembered that those listed as energy supplements may also provide useful amounts of nitrogen, and those listed as protein supplements may also provide useful amounts of energy. Varying amounts of minerals will also be present. Consequently, their effects may be due to them providing more than one limiting nutrient. Apart from that, the quality of these feeds can vary enormously. For example, rice bran in Indonesia can contain from 0 to 45% hulls (Lowry *et al.*, 1983) which would undoubtedly affect its nutritive value. At present, little is known of the variability that exists in the composition and feeding value of many of these supplements. Besides these problems, some of the feeds are only available in localized areas or from mills and problems associated with transporting them to the farm can be important.

Table 7.3. Some by-product concentrate feeds which are found in Asia

Energy supplements		Protein supplements
Barley—	broken grain	Blood meal
	bran	Castor seed cake
Cassava—	chips	Coconut cake
	waste	Fish meal
Maize—	bran	Groundnut cake
	germ meal	Meat meal
Millet—	broken grain	Mustard seed meal
Rice—	broken grain	Palm kernel cake
	bran	Rape seed meal
Sago—	waste	Rubber seed meal
Sugarcane—	molasses	Sal seed cake
Wheat—	broken grain	Soyabean meal
	bran	

Crop by-products, such as copra cake, palm kernel cake, soyabean cake, groundnut cake, and animal by-products, such as fish meal, are valuable sources of protein. If not exported these feeds are frequently fed to pigs and poultry and seldom fed to ruminants, with the exception of dairy animals. None-the-less a considerable amount of research effort has been directed towards using these feeds as supplements for ruminants.

In many of the literature reports on supplementation of cereal straws in Asia, only one level of supplementation has been used. The reasons for this are usually limited facilities, manpower and funding which preclude larger experiments being conducted. In these cases, the decision to select a particular level of supplementation has often been based upon the calculated nutrient requirements of the animals being used. Although this may be appropriate theoretically it does not permit assessments to be made in terms of the most judicious use of the supplements and of the maximal utilization of the basal dietary ingredient. A "dose response" approach to experimentation is much more useful and this can be achieved in many situations simply by using appropriate experimental designs. Dose response experiments provide the following information:

(i) how each level of supplementation affects the intake and digestion of the basal diet,
(ii) how each level of supplementation affects production of the target animals.

Such information enables supplementation to be considered in terms of the availability of basal and supplementary feeds and provides the basis for economic evaluation. Experiments of this nature, which involve a number of levels of supplementation and in which the characteristics of the basal feed and the supplements are adequately described, are vital if reliable economic systems of feeding are to be extended to village situations.

Some specific examples of the effects of supplementation on the utilization of untreated

Table 7.4. Feed intake, digestibility, substitution rate (SR) of concentrate for straw and liveweight changes where different levels of concentrate have been given to cattle

	Treatment 1	2	3	4	5	6
1. Creek *et al.* (1983)						
A. Dry matter intake (kg/100 kg LW)						
Rice straw	2.0	1.9	1.7	1.7	1.6	1.5
Concentrate*	0.3	0.6	0.9	1.3	1.6	1.9
Total	2.4	2.5	2.7	2.9	3.2	3.3
SR		0.47	0.49	0.40	0.37	0.37
Liveweight change (g/day)	160	360	610	750	770	1010
B. Dry matter intake (kg/100 kg LW)						
Ammonia-treated rice straw	2.5	2.3	2.1	2.1	1.9	1.8
Concentrate*	0.3	0.6	1.0	1.3	1.6	1.8
Total	2.8	2.9	3.1	3.3	3.5	3.6
SR		0.67	0.63	0.46	0.50	0.50
Liveweight change (g/day)	620	730	780	990	1010	1170
2. Straw Utilization Project (unpublished data) (Bulls, 124-146 kg liveweight)						
A. Dry matter intake (kg/100 kg LW)						
Rice straw	2.4	2.0	2.0	2.1	1.9	
Grass	0.2	0.2	0.2	0.2	0.2	
Rice bran	–	0.3	0.6	0.8	1.0	
Total	2.6	2.5	2.8	3.1	3.1	
SR		1.52	0.61	0.32	0.43	
Liveweight change (g/day)	– 78	– 11	19	44	91	
B. Dry matter intake (kg/100 kg LW)						
Urea-treated rice straw	2.9	3.0	2.7	2.7	2.7	
Grass	0.1	0.1	0.1	0.1	0.2	
Rice bran	–	0.2	0.4	0.7	0.5	
Total	3.0	3.4	3.2	3.5	3.4	
SR		– 0.73	0.49	0.22	0.35	
Liveweight change (g/day)	112	163	262	258	165	
3. Kumarasuntharam *et al.* (unpublished data) (Steers, 115-124 kg liveweight)						
A. Dry matter intake (kg/100 kg LW)						
Urea-treated rice straw	2.5	2.3	2.5	2.4		
Concentrate**	–	0.4	0.7	1.2		
Total	2.5	2.7	3.2	3.6		
SR		0.53	0.08	0.08		
Organic matter digestibility (%)	45	52	60	65		
Digestible organic matter intake (kg/day)	1.11	1.48	1.91	2.26		
4. Saadullah (1984) (Calves, 51-68 kg liveweight)						
A. Dry matter intake (kg/100 kg LW)						
Urea-treated rice straw	2.6	2.3	2.4	2.3	2.4	2.3
Water hyacinth	0.2	0.1	0.1	0.1	0.1	0.2
Fish meal	–	0.1	0.1	0.2	0.3	0.3
Total	2.8	2.5	2.6	2.6	2.8	2.8
SR		5.50	1.67	1.68	0.76	0.87
Dry matter digestibility (%)	50	57	59	60	62	59
Liveweight change (g/day)	57	198	197	205	192	215

Table 7.4 cont.

	Treatment 1	2	3	4	5	6
B. Dry matter intake (kg/100 kg LW)						
Urea-treated rice straw	3.4	3.4	3.4	3.2	3.3	
Water hyacinth	0.2	0.2	0.2	0.1	0.2	
Fish meal	–	0.02	0.04	0.07	0.2	
Total	3.6	3.6	3.6	3.4	3.7	
SR		−1.50	−1.00	1.86	0.57	
Dry matter digestibility (%)	58	60	61	61	62	
Liveweight change (g/day)	80	142	151	203	206	
5. Robinson & Stewart (1968)						
A. Dry matter intake (kg/day)						
Rice straw	3.40	3.51	3.55	3.55	3.41	2.47
Whole cottonseed	0.28	0.56	0.83	1.11	1.39	1.67
Total	3.68	4.07	4.39	4.66	4.80	4.13
SR		−0.39	−0.27	−0.18	0	0.67
Dry matter digestibility (%)	47	45	48	49	47	47
Digestible dry matter intake (kg/dry)	1.73	1.83	2.11	2.28	2.26	1.94

*Concentrate composition: 35% undecorticated cottonseed cake, 25% wheat bran, 22% maize, 8% rice germ meal, 4% rice bran, 3% molasses, 2% lime, 1% salt
**Concentrate composition: rice bran, coconut poonac and minerals (proportions unknown); containing 83% OM and having an IVOMD of 74%

and urea-treated rice straw cattle are given in Table 7.4. The substitution rate of the supplement for rice straw has been calculated as:

$$\text{Substitution rate (SR)} = \frac{\text{Decline in rice straw intake}}{\text{Increase in the amount of supplement given}}$$

Where the SR value is negative, the intake of rice straw was not reduced by giving the supplementary feed, indicating a true supplementation effect.

Creek *et al.* (1983) demonstrated quite clearly that increasing the level of an energy-protein-mineral supplement from 1 to 7 kg DM/day decreased the intake of both untreated and ammonia-treated rice straw by cattle. The substitution rate was higher with treated straw, 0.55, than with untreated straw, 0.42, indicating that the value of treating the straw became less as the level of supplementation increased. As would be expected, increasing the level of the supplement resulted in greater weight gains by the cattle. This study was not designed to investigate levels of concentrate feeding lower than 1 kg DM/day.

Work from the Straw Utilization Project in Sri Lanka indicated that feeding an energy supplement, in this case rice bran, also decreased the amount of untreated or urea-treated rice straw consumed, except at the lowest level of supplementation (0.3 kg/day) of the treated straw. In this experiment the substitution rate appeared to be lower for treated than for untreated material, although the results were very variable. Kumarasuntharam *et al.* (unpublished data) also found low substitution rates when a commercial concentrate was fed with urea-treated straw at levels up to 1.4 kg/day. As organic matter digestibility of the diet increased linearly with the amount of concentrate given, it would seem that even at the highest level of supplementation (32% of diet) there were no adverse effects on digestion of the straw. Such effects might only be expected to occur when the supplement becomes a significant proportion of the total diet.

With a basal diet consisting primarily of urea-treated straw Saadullah (1984) found that small amounts of the specific protein supplement, fish meal, did not affect the amount of feed consumed (kg/100 kg LW), but markedly increased liveweight gains. In this instance, the supplement increased diet digestibility apparently through the provision of RDN and/or minerals required by the microbial population of the reticulo-rumen, and possibly also contributed to increased production through the provision of specific nutrients, amino acids and/or minerals, which improved the efficiency of tissue use of absorbed nutrients. Robinson and Stewart (1968) also found that a protein supplement, whole cottonseed, did not affect rice straw intake when it was included in the diet at up to 30% of dietary dry matter, and hence total intake increased (indicated by negative SR values). There was little effect of this supplement on digestibility of the diet and it would appear that its mode of action might be through the provision of nutrients at the tissue level.

Better definition of the substitution rates of different by-product supplements and of the mechanisms by which low levels of specific supplements increase the efficiency of rice straw utilization through either increased intake or digestion or improved use of absorbed nutrients are required if farmers are to be encouraged to give these feeds to ruminants. Insufficient information is available on variation in the composition and feeding value of these by-products or on their likely affects on straws utilization when provided at low levels. Selection of supplements which provide appropriate amounts of limiting nutrients to be used in feeding strategies which are location specific could have marked effects in improving the productivity of ruminants in small farm systems.

7.8 Supplementation of rice straw with green forages

There is a wide range of forage supplements available in the rice producing areas of Asia. When animals are allowed to graze during the day, they select and ingest unknown quantities and types of green feeds ranging from roadside grasses to leaves from trees and shrubs. Supplements of green forages are also given to animals kept in stalls. Ranjhan (1983) recommended that feeding straw mixed with green fodders, whether these are grasses or legumes, in the ratios of 3:1 or 1:1 should meet the requirements of ruminants for maintenance and growth, respectively. However, it is questionable whether farmers in many parts of Asia have access to the amounts of green forage that would be required to satisfy these recommendations during dry periods. Also they may not have adequate time available to harvest such amounts of these feeds for housed animals during the cropping season. Recently, Preston and Leng (1984) have suggested that green forage, preferably legume, be given at up to a maximum of about 0.7% (DM basis) of liveweight or about 25% of the diet.

Examples of the effects of supplementation with some forages on the intake of straw and diet digestibility are given in Table 7.5. With diets based on untreated rice straw, forage supplements substituted for straw even when they were only 10-15% of the diet. The situation was less clear with treated straw and more research in this area is required. Perhaps the most pertinent point from the information presented is that, in some experiments, supplements of leucaena had little effect on diet digestibility even when they comprised a significant proportion of the diet (e.g. Devendra, 1983; Moran *et al.*, 1983). This indicates that the quality of forage supplements might not always be high, and that they may be best included as small amounts of the diet to provide specific nutrients such as readily available energy, nitrogen, minerals and vitamins. It is apparent that the quality of these supplements can vary widely depending upon the amount of stems or twigs offered with the leaf material. These feeds can also contain compounds which are potentially harmful to livestock, such as cyanide in cassava leaves and mimosine in leucaena. It is also likely that they contain polyphenols which may affect their palatability or inhibit the digestibility of the cell wall and the cell contents. However, Vearasilp (1981) demonstrated quite clearly that when high quality leucaena or gliricidia leaf was included at between 10 and 12% of dietary dry matter of a rice straw-based diet, then liveweight losses by sheep were small over a 45-day period.

Forage supplements are already commonly fed on small farms in Asia because they are available on or near the farm; provide variety in the diet; provide specific nutrients; and they are cheap relative to purchased concentrates. It is commonly believed that some forage supplements, particularly the leaves of cassava (fed in Indonesia, Malaysia and Thailand), gliricidia (fed in Sri Lanka), leucaena (fed in the Philippines) and sesbania (fed in Indonesia) provide protein to the animals. However, their value in providing other nutrients such as minerals, vitamins, readily available energy and degradable structural carbohydrates should not be overlooked. More information is required on the feeding value of many of these supplements.

Table 7.5. Feed intake, digestibility and substitution rates (SR) of forage supplements for straw and liveweight changes where different levels of the supplement have been given to ruminants

	Treatment						
	1	2	3	4	5	6	7
1. Straw Utilization Project (unpublished data)							
(Bulls, 98-109 kg liveweight)							
A. Dry matter intake (kg/100kg LW)							
Rice straw	2.7	2.8	2.5	2.2			
Gliricidia	–	0.3	0.6	1.1			
Total	2.7	3.0	3.0	3.3			
SR		−0.25	0.41	0.46			
Dry matter digestibility (%)	47	46	49	55			
Liveweight change (g/day)	−113	−54	−94	10			
B. Dry matter intake (kg/100kg LW)							
Urea-treated rice straw	3.2	3.1	3.4	2.8			
Gliricidia	–	0.3	0.5	1.0			
Total	3.2	3.4	3.9	3.8			
SR		0.39	−0.33	0.44			
Dry matter digestibility (%)	41	45	50	52			
Liveweight change (g/day)	−28	63	134	130			
2. Moran *et al.* (1983)							
(Ongole and swamp buffalo bulls, 200-250 kg liveweight)							
A. Dry matter intake (kg/day)							
Rice straw	4.91	4.21					
Leucaena	–	1.81					
Total	4.91	6.02					
SR		0.39					
Dry matter digestibility (%)	37	40					
B. Dry matter intake (kg/day)							
NaOH-treated rice straw	3.48	4.33					
Leucaena	–	1.85					
Total	3.48	6.18					
SR		−0.46					
Dry matter digestibility (%)	48	49					
3. Suriyajantratong & Wilaipon (1985)							
(Steers, 140-150 kg liveweight)							
A. Dry matter intake (kg/day)							
Rice straw	3.02	3.21	3.32	3.37			
Verano stylo	–	0.44	0.96	1.36			
Total	3.02	3.65	4.28	4.76			
SR		−0.43	−0.31	−0.26			
Liveweight change (g/day)	−165	11	60	104			
4. Reddy & Murty (1972)							
(Bullocks, 318 kg liveweight)							
A. Dry matter intake (kg/100kg LW)							
Rice straw	1.5	1.4					
Sunnhemp hay	0.5	0.7					
Total	2.0	2.1					
SR		0.24					
Dry matter digestibility (%)	50	51					
5. Devendra (1983)							
(Sheep, 23-26 kg liveweight)							
A. Dry matter intake (kg/day)							
Rice straw	0.56	0.50					
Cassava leaves		0.25					
Total	0.56	0.75					
SR		0.22					
Dry matter digestibility (%)	44	51					

Table 7.5. cont.

	Treatment 1	2	3	4	5	6	7
B. Drymatter intake (kg/day)							
Rice straw	0.68	0.59	0.53	0.47	0.47	0.40	0.27
Leucaena	–	0.07	0.13	0.20	0.31	0.40	0.41
Total	0.68	0.66	0.67	0.68	0.78	0.79	0.68
SR		1.27	1.07	1.01	0.68	0.71	1.00
Dry matter digestibility (%)	43	49	47	50	51	53	50
6. Vearasilp (1981) (Sheep, 20-21 kg liveweight)							
A. Dry matter intake (kg/day)							
Rice straw	0.45	0.44	0.47	0.42			
Leucaena	0.06	0.04	0.02	–			
Gliricidia	–	0.02	0.03	0.05			
Total	0.51	0.50	0.51	0.47			
Dry matter digestibility (%)	58	57	54	51			
Liveweight change (g/day)	– 13	– 17	3	– 16			

7.9 Appropriate supplementation

The results of many experiments in which concentrate by-products or forage supplements have been given alone or in combinations with rice straw as the basal diet for ruminants are summarized in Table 7.6. It is difficult to interpret many of these results due to inadequate description of the experimental procedures, the rice straw and the supplements, and particularly as only a small number of animals have been used in much of the work. However, when data for straw intake (from Table 7.6) for non-lactating, non-pregnant cattle are plotted against level of supplementation (Figure 7.2) it can be seen that, except at low levels of supplementation

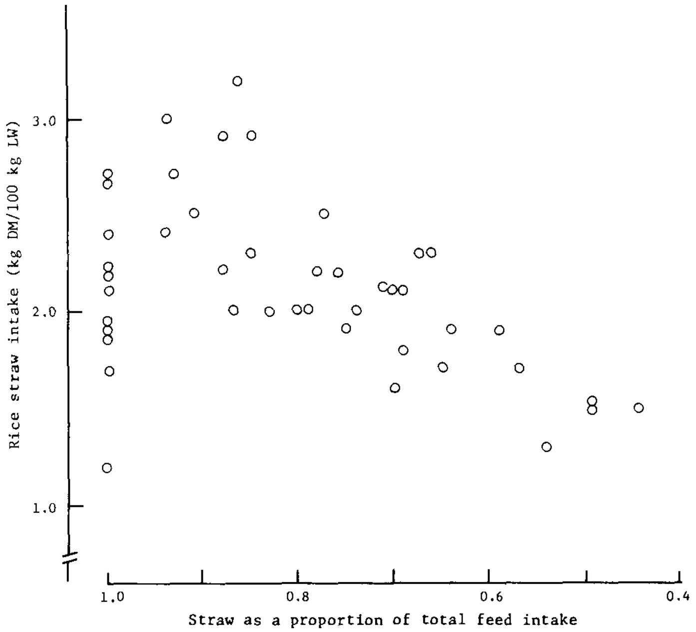

Figure 7.2. Rice straw intake by cattle versus amount of straw in the diet.

Table 7.6. Dry matter intake (DMI), digestibility (DMD) and production of animals fed untreated rice straw-based diets*

Liveweight (kg)	Total DMI (kg/day)	Total DMI (kg/100 kg/LW)	Total DMI (g/kg $LW^{0.75}$)	Straw DMI (kg/day)	Straw DMI (kg/100 kg LW)	Straw DMI (g/kg $LW^{0.75}$)	DMD (%)	Liveweight change (g/day)	Supplement	Location	Reference
A. **BUFFALOES**											
98				2.56	2.6	82				India	Ramachandra Reddy & Das (1982)
100				1.89	1.9	60					
109				2.19	2.0	65					
195				3.6	1.9	70	49			Thailand	Cheva-Isarakul & Cheva-Isarakul (1984a)
200				4.68	2.3	88		−200		Thailand	Intaramongkol *et al.* (1978)
200	5.30			4.30	2.2	81		10	F		
200	5.16			4.16	2.0	78		30	C		
200	4.70			4.60	2.3	86		20	M + U		
200				4.21	2.1	79	50	−182	M	Thailand	Wanapat *et al.* (1984)
250				5.02	2.0	80		−260		Thailand	Suriyajantratong *et al.* (1974)
250	Not reported			4.76	1.9	76		−280	C		
250				5.68	2.3	90		−160	C + U		
250				5.55	2.2	88		−100	C + U		
250				5.57	2.2	89		−100	C + U		
250				5.53	2.2	88		−40	C + U		
260				4.68	1.8	73	37			Indonesia	Moran *et al.* (1983)
270	5.45	2.0	82	3.82	1.4	57	39		F		
289				5.87	2.0	84	43	−130	M	Thailand	Wongsrikeao & Wanapat (1985)
300				5.64	1.9	78		−420		Thailand	Suriyajantratong *et al.* (1983)
300	7.22			5.22	1.7	72		240	C		
300	7.40			5.40	1.8	75		90	C		
309				7.62	2.5	105				Philippines	Castillo *et al.* (1982)
336	8.07	2.5	104	5.46	1.7	70			C + F + M		
321	6.04	1.9	80	4.68	1.5	63			C + F + M		
308	6.06	2.0	82	4.75	1.6	67			C + F + M		
411	7.95	1.9	87	6.20	1.5	68			C + F + M		
					1.7		55			Thailand	Wanapat (1985)
B. **CATTLE**											
56	1.8	3.2	87	1.7	3.0	83	40	35	F + M	Bangladesh	Saadullah *et al.* (1982a)
62	1.8	2.9	82	1.7	2.7	77	46	75	F + M		
65	2.88	4.4	126	2.53	3.9	111		102	C + F + M	Bangladesh	Haque *et al.* (1982)
61	2.85	4.7	131	2.49	4.1	114		122	C + F + M		
63	2.3	3.7	102	2.0	3.2	89		107	C + F + M	Bangladesh	Hamid *et al.* (1983)
75	2.79	3.7	109	2.16	2.9	87		207	C + F + M + U	Bangladesh	Saadullah *et al.* (1983)
100	2.6	2.6	82	1.8	1.8	57	49		C + M	Bangladesh	Hossain & Rahman (1981)
96				2.60	2.7	85	47	−113		Sri Lanka	Straw Utilization Project (unpublished data)
108	2.98	2.8	89	2.70	2.5	81	46	−54	F		
104	3.55	3.4	109	2.39	2.3	73	49	−94	F		
97	2.84	2.9	92	2.16	2.2	70	55	10	F		

Table 7.6. cont.

Liveweight (kg)	Total DMI (kg/day)	Total DMI (kg/100 kg/LW)	Total DMI (g/kg $LW^{0.75}$)	Straw DMI (kg/day)	Straw DMI (kg/100 kg LW)	Straw DMI (g/kg $LW^{0.75}$)	DMD (%)	Liveweight change (g/day)	Supplement	Location	Reference
114				3.03	2.7	87	44	− 34	M	Thailand	Wanapat *et al.* (1984)
118	3.9	3.3	109	3.4	2.9	95		224	C + F	Bangladesh	Saadullah *et al.* (1982b)
113	3.8	3.4	110	3.3	2.9	95		193	C + F + M		
120				3.00	2.5	83		50		Thailand	Suriyajantratong *et al.* (1983)
120	4.86			2.86	2.4	79		600	C		
120	4.89			2.89	2.4	80		590	C		
123	3.1	2.5	84	2.4	2.0	65		114	C + F	Bangladesh	Haque & Saadullah (1983)
124	2.9	2.3	78	2.4	1.9	65		132	C		
127	3.45	2.7	91	2.93	2.3	77		125	C + F + M	Bangladesh	Khan & Davis (1982)
126	3.16	2.5	84	2.96	2.4	79			F	Sri Lanka	Straw Utilization Project
159	3.78	2.4	84	2.86	2.0	64			C + F		(unpublished data)
124	3.38	2.7	91	2.50	2.0	67			C + F		
132	3.98	3.0	102	2.79	2.1	72			C + F		
128	3.91	3.1	103	2.49	1.9	65			C + F		
120	3.79	3.2	105	2.48	2.1	68		103	C + F + M	Sri Lanka	Perdok *et al.* (1984)
125	4.28	3.4	114	2.84	2.3	76		213	C + F + M + U		
159	4.85	3.1	108	3.34	2.1	75		303	C + F + M + U		
133				2.95	2.2	75				India	Ramachandra Reddy & Das
140				3.37	2.4	83					(1982)
141				3.05	2.2	75					
139	3.51	2.5	87	2.07	1.5	51		480	C + F + M	Thailand	Cheva-Isarakul & Potikanond (1985)
142				3.02	2.1	73		− 165		Thailand	Suriyajantratong & Wilaipon
146	3.65	2.5	87	3.21	2.2	76		11	F		(1985)
150	4.28	2.9	100	3.32	2.2	77		60	F		
158	4.76	3.0	107	3.37	2.1	76		104	F		
166	3.84	2.3	83	2.09	1.3	45		73	C + F + M	Sri Lanka	Perdok *et al.* (1982)
166	4.30	2.6	93	3.39	2.0	73		141	C + M	Sri Lanka	Kumarasuntharam *et al.* (1984)
62-164	4.7	2.8			—		45	111	F + M + U	India	Jaiswal *et al.* (1983)
62-164	4.5	3.2			1.9		49	473	C + F + M		
177	5.65	3.2	116	4.33	2.5	89		79-403	C	Thailand	Promma *et al.* (1985)
180				3.47	1.9	71	41			Sri Lanka	Ibrahim (1985)
191		Not reported		4.8	2.5	90		− 89	C + F	Bangladesh	Dolberg *et al.* (1981)
200	3.68	1.8	69	3.40	1.7	64	47		C	Australia	Robinson & Stewart (1968)
200	4.07	2.0	77	3.51	1.8	66	45		C		
200	4.39	2.2	83	3.55	1.8	67	48		C		
200	4.66	2.3	88	3.55	1.8	67	49		C		
200	4.80	2.4	90	3.41	1.7	64	47		C		
200	4.13	2.1	78	2.47	1.2	46	47		C		
200				4.78	2.4	90		− 170		Thailand	Intaramongkol *et al.* (1978)
200	5.60			4.60	2.3	86		− 20	F		
200	6.02			5.02	2.5	94		90	C		

200	4.88			4.78	2.4	90		0	M + U		
199				4.23	2.1	80		− 149		Australia	McLennan *et al.* (1981)
202	4.90	2.4	91	4.84	2.4	90		− 86	U		
206	5.14	2.5	95	5.03	2.4	93		− 13	C + U		
204	5.15	2.5	95	5.00	2.5	93		− 57	C + U		
203	4.95	2.4	92	4.71	2.3	88		− 70	C + U		
205	5.12	2.5	95	5.05	2.5	93		− 42	M + U		
203	4.57	2.3	85	4.46	2.2	83		− 77	C + M + U		
206	5.13	2.5	94	4.98	2.4	92		− 26	C + M + U		
235				2.8	1.2	46	51			Thailand	Cheva-Isarakul & Cheva-Isarakul (1984a)
245	6.30	2.6	102	5.04	2.1	81	52		C + F + U	Sri Lanka	Karunaratne & Jayasuriya (1984)
254[La]	Not reported			5.2	2.0	82		− 149	C + F + M	Bangladesh	Khan & Davis (1981)
264[La]	6.6	2.5	101	5.2	2.0	79		− 266	C + M	Sri Lanka	Perdok *et al.* (1982)
276				5.13	1.9	75	38			Indonesia	Moran *et al.* (1983)
286	6.58	2.3	94	4.61	1.6	60	42		F		
286				4.97	1.7	72	42	− 134	M	Thailand	Wanapat *et al.* (1982)
198	4.03	2.0	76	2.69	1.4	51	36	− 312	C + M		
319	6.22	2.0	82	4.66	1.5	62	50		F	India	Reddy & Murty (1972)
318	6.70	2.1	89	4.48	1.4	59	51		F		
316	7.43	2.4	99	6.46	2.0	86		160	C + M	Egypt	Creek *et al.* (1983)
321	8.10	2.5	107	6.08	1.9	80		360	C + M		
334	8.93	2.7	114	5.78	1.7	74		610	C + M		
339	9.93	2.9	126	5.64	1.7	71		750	C + M		
337	10.64	3.2	135	5.26	1.6	67		770	C + M		
348	11.55	3.3	143	5.07	1.5	63		1010	C + M		
C. **SHEEP**											
20				0.33	1.7	35	43			Malaysia	Sharif & Fadzil (1985)
23				0.45	2.0	43	40			Malaysia	Devendra (1976)
23	0.37	1.6	35	0.22	1.0	21			C + M		
23	0.47	2.1	45	0.28	1.2	27			C + M + U		
23	0.35	1.5	34	0.21	0.9	20			C + M + U		
23	0.52	2.2	49	0.43	1.9	40	53		C + M + U	Sri Lanka	Jayasuriya (1979)
23	0.57	2.5	55	0.48	2.1	46	54		C + M + U		
23	0.62	2.7	59	0.53	2.3	51	52		C + M + U		
23				0.40	1.8	38	37			Malaysia	Devendra (1978)
23	0.25	1.1	24	0.21	0.9	20	47		C		
23	0.40	1.8	38	0.30	0.4	29	53		C		
23	0.55	2.4	52	0.35	1.5	34	47		C		
23	0.38	1.7	37	0.33	1.4	31	42		C		
23	0.45	2.0	43	0.30	1.3	28	49		C		
23	0.50	2.2	48	0.25	1.1	24	46		C		
23	0.41	1.8	39	0.35	1.5	33	41		C		
23	0.45	2.0	43	0.33	1.4	32	47		C		
23	0.43	1.9	41	0.30	1.3	28	57		C		
23	0.40	1.8	38	0.38	1.6	36	41		C		
23	0.38	1.7	36	0.35	1.5	33	45		C		

Table 7.6. cont.

Liveweight (kg)	Total DMI (kg/day)	Total DMI (kg/100 kg/LW)	Total DMI (g/kg $LW^{0.75}$)	Straw DMI (kg/day)	Straw DMI (kg/100 kg LW)	Straw DMI (g/kg $LW^{0.75}$)	DMD (%)	Liveweight change (g/day)	Supplement	Location	Reference
23	0.47	2.0	45	0.35	1.5	33	47		C		
23	0.43	1.9	41	0.40	1.7	38	41		C		
23	0.43	1.9	41	0.37	1.6	35	45		C		
23	0.45	2.0	43	0.33	1.4	32	49		C		
23	0.46	2.0	44	0.41	1.8	39	47		C		
23	0.41	1.8	39	0.35	1.5	33	50		C		
23	0.44	1.9	42	0.37	1.6	35	54		C		
25				0.56	2.2	50	44			Malaysia	Devendra (1983)
25	0.75	3.0	67	0.50	2.0	45	51		F		
25				0.68	2.7	61	43				
25	0.66	2.6	59	0.59	2.4	53	49		F		
25	0.67	2.7	60	0.53	2.1	48	47		F		
25	0.68	2.7	60	0.47	1.9	42	50		F		
25	0.78	3.1	69	0.47	1.9	42	51		F		
25	0.79	3.2	71	0.40	1.6	35	53		F		
25	0.68	2.7	61	0.27	1.1	24	50		F		
25-28				0.36	1.5-1.0	33-24	40			Australia	McManus *et al.* (1972a)
29				0.54	1.9	43	43			Thailand	Cheva-Isarakul & Cheva-Isarkul (1984a)
30	0.46	1.5	36	0.41	1.4	32	54		C	Australia	Robinson & Stewart (1968)
30	0.49	1.7	39	0.36	1.2	28	49		C		
30	0.52	1.7	40	0.11	0.4	9	56		C		
26				0.56	2.2	50	48			Thailand	Cheva-Isarakul & Cheva-Isarakul (1984b)
27				0.64	2.3	53	50				
27				0.58	2.1	48	47				
31				0.67	2.2	51	55				
36				0.85	2.4	58	47				
37				0.38	1.0	25	35	−92		Thailand	Vijchulata & Sanpote (1982)
52				0.56	1.1	29	47			Australia	McManus *et al.* (1972b)
41	0.41	1.0	25	0.36	0.9	22	48		C + M		

*Much of the data presented in this table has been calculated from information given in the reports cited.
Note: supplement definitions: C = concentrate, F = forage, M = minerals, U = urea
animal classification: La = lactating

(10-20%), the amount of straw consumed decreases as the level of supplementation increases. This emphasises again that with both by-product concentrate and forage supplements, it is essential that the effects and advantages of low levels of supplementation be defined in experiments using adequate numbers of animals per treatment, in which the nutritive value of the supplement is well defined and the reasons for responses to it are identified. Such research needs to be location specific and to be carried out in relation to the actual feeding systems used at the village level.

7.10 Feeding other low quality residues

Throughout many parts of Asia large and small ruminants have access to grasses from communal grazing land, from roadsides and from paddy bunds. During the wet season such feeds are likely to be superior in feeding value to rice straw and the straw may be used mainly where farmers do not have access to sufficient grass or where they do not have sufficient labour to control grazing by their animals or to harvest forage for them. The situtaion in dry seasons can be quite different as the grasses available may, in fact, be of lower quality than straw. Hence, rice straw will retain its place in feeding systems for large ruminants in Asia.

In the integrated farming systems in this region many other fibrous crop residues are produced even though their occurrence is not as widespread as rice straw. Materials such as sugarcane tops, maize stovers and residues from leguminous crops, such as groundnut and cowpea vines, are potentially valuable feeds and some studies on their feeding value have been conducted. These resources should be considered when developing year round feeding strategies for particular areas. For example, Cheva-Isarakul and Cheva-Isarakul (1984a) have drawn attention to the timing of some multiple cropping systems used in northern Thailand, illustrating that on many small farms residues other than rice straw are available. Further, research has shown that peanut hay, if harvested by cutting the tops prior to uprooting the peanuts (Cheva-Isarakul, 1982), and sweet corn stalks (Cheva-Isarakul and Cheva-Isarakul, 1984a) are as good as or better than rice straw as a feed for ruminants when properly conserved.

Consideration needs to be given to the feeding value of these feeds and, if they are of higher quality than rice straw, then they should be used in preference to or with rice straw as the basal diet for ruminants. Some of these feeds contain more nitrogen or minerals than rice straw and could alleviate the need for supplements.

7.11 Concluding comments

Supplementation provides the most potential for improving the efficiency of utilization of rice straw by ruminants. The most pressing need is to develop and test year-round feeding strategies which are location specific and appropriate to particular types of animal and levels of production. Primary consideration should be given to removing nutrient limitations to the fermentation of straw through provision of rumen degradable nitrogen and minerals. These can be provided by urea and discrete forms of minerals, which requires development of appropriate technology for their use, or by small amounts of forage or by-product supplements. Recently, Preston and Leng (1984) have suggested the following priorities for supplementing poor quality roughage in developing countries: firstly, the fermentable nitrogen content of the diet should be raised to a minimum of 30 g/kg DOM, secondly green forage should be provided up to a minimum of about 0.7% of liveweight (25% of the diet) and thirdly, oilseed meal or an animal by-product given in amounts not to exceed 20% of the total dietary dry matter. While this approach is desirable for increased productivity of ruminants in the region, it is unlikely in most areas or countries that such a blanket approach to supplementation would be possible or economically viable. Green forage may only be available in restricted amounts, if at all, at critical times of the year and hence they will need to be used judiciously. In the more humid countries, where such forages are abundant, increasing usage in feeding systems should be encouraged. The supply of concentrate by-products can be even more limited than that of green forage, especially if they need to be purchased or competition for their use in feeding to non-ruminants exists. Thus, restricted feeding to supply specific nutrients would seem to be the most appropriate use of these feeds where they are available.

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8. FUTURE POTENTIAL AND RESEARCH NEEDS

8.1 Introduction

In the preceeding chapters the utilization of rice straw as a feed for ruminants has been discussed in detail. From these discussions three important conclusions can be drawn. Firstly, rice straw is, and will remain, an important component in practical feeding systems for large ruminants in Asia. Secondly, arising from the research conducted druing the last two decades, there is an accelerating and urgent demand to achieve a better understanding of the feeding value of rice straw and the roles it can play in different livestock production systems. Thirdly, there still remains a potential for improving the utilization of rice straw and a challenge to extend appropriate feeding strategies to small farm livestock systems.

While current feeding systems are obviously able to sustain low levels of production, there is a need to introduce new practices which will increase the output of animal products. The complexity and diversity of small farm systems in Asia, wherein ruminants have a variable degree of importance, where the prevailing management practices are variable, and where the role of rice straw is also variable, dictate that improvements in livestock production will be achieved only when problems or constraints specific to a location are identified and overcome. Generalized recommendations meant to apply to all of Asia are unlikely to be successful and, thus, much of the research and extension efforts towards straw utilization need to be location or system specific. At the same time, well developed support services that can deliver packages of innovative technology applicable to particular farms are essential to the process of improving straw utilization and livestock production.

In this context, it is relevant to discuss the potential of the vast amount of information already available and the future research needs. The areas that need to be addressed are those that are most likely to (a) result in progress at the farm level, and (b) provide basic information through cost-effective research on factors affecting the feeding value of straw. The sections following discuss briefly areas of importance.

8.2 Rice straw feeding value

It is imperative to continue research on the attributes and characteristics of rice straw which determine its feeding value. This is necessary if responses to supplementation or pretreatment are to be predicted with accuracy. Knowledge of the effects of genetic and environmental influences on straw quality is also important so that, on the one hand, it might be possible to select and breed varieties with improved straw and, on the other hand, so that predictions might be made as to the likely quality of straw from a growing crop. Such research is basic in nature and because it is expensive and resource intensive, it should be conducted at only a restricted number of research institutes.

8.3 Pretreatment of rice straw

Important advances have been made in developing simple, low-cost proceduress for pretreatment of rice straw with ammonium compounds derived from urea and this process is likely to be the only one accepted by small farm producers. Much of this research has been carried out in Asia and, while the technology is now quite well understood, several problems have not been resolved and the extent to which this pretreatment has a practical and economic role in feeding systems in Asia is still uncertain. Farm-level experiments are now required to evaluate the socio-economic constraints to adoption of urea pretreatment. The importance of research in this area far outweighs the need for further documentation of the effects of the technology. Perhaps the most important constraints to the adoption of urea pretreatment are the costs involved, the constraints it imposes on the farmer's time and the need for farmers to plan in advance to allocate labour resources to processing the straw.

One important aspect of urea-ammonia pretreatment, which is often overlooked, is that it may be a means of preserving straw which is harvested at the onset of the wet season. This approach is likely to be economically feasible only where very intensive cropping is practised and where there are shortages of alternative feeds.

If urea pretreatment is to be applied to rice straw, then the straw should remain as a major component of the diet to enable the effects of treatment, such as increased intake and digestibility, to be expressed. Where these effects are not able to be expressed then pretreatment will not be economical. At this time, the application of other pretreatment methods in the small-farm systems of Asia would seem to be impracticable.

8.4 Supplementation of rice straw

In most small farm systems, where livestock depend on straw at various times of the year, the most practical approach is to select supplementary feeds to provide limiting nutrients. Such feeds should be given in small amounts to optimize the utilization of straw and other low quality roughages in the diet.

In the first instance, the most effective and available supplements in particular regions need to be identified, and the amounts available and their quality determined. They should be evaluated in terms of the nutrients that they provide and of the effects of different but low levels of supplementation on the intake and digestibility of rice straw and on animal production.

Responses in animal production in different experiments where rice straw has been supplemented with specific nutrients, such as non-protein nitrogen and minerals, have been variable. Even greater variability exists between experiments where straw has been supplemented with particular forages or concentrates. This indicates a need to be better able to define the straw being used and also a need to define the mode of action of particular supplements in enhancing the supply of nutrients to the animal. Thus, a suitable balance should be maintained between applied and basic research, and importantly the description of experiments needs to be detailed to enable interpretation of the results in the light of existing knowledge.

8.4.1 *Non-protein nitrogen supplements*

Experimental evidence indicates that supplements of urea with small amounts of readily available carbohydrates and sulphur can increase the intake and/or digestion of rice straw. This technology has not been adequately understood and therefore has not been widely adopted in Asia. The reasons for this need to be investigated and increased support given to overcoming all the limitations of wider application.

The need to ensure that a relatively continuous supply of urea is ingested to achieve effective results and to avoid toxicity poses problems in small farm systems. Urea-molasses block licks may provide an approach which partially overcomes this problem and others such as the need to mix or spray urea on straw. However, it remains to be seen if the problems of variable intake can be overcome, and if the block licks can be provided with a uniform consistency at low cost so as to be accessible to small farmers. Institutional controls may be necessary to ensure that farmers receive blocks that are suitable and of proven quality.

8.4.2 *Concentrate supplements*

In the Asian region, concentrates are seldom given to non-lactating ruminants except in drought situations. Dairy buffaloes, goats and cattle are fed with concentrates to ensure acceptable levels of milk production. However, potential exists to incorporate small amounts of concentrate by-products into the diet of other ruminants providing that they complement basal roughages and do not substitute for, or depress the digestibility of, the roughage.

Information on the composition and digestion of these feeds is essential as their quality can vary greatly both within and between regions. Concentrates which provide specific limiting nutrients, such as those containing a mixture of rumen degradable and undegradable protein, are likely to be of most value.

8.4.3 *Green forage supplements*

The utilization of forages as supplements deserves much greater attention. In the more humid regions of South-East Asia there are abundant supplies of green forage, including legumes, while in the drier tropics such feeds may be available only in restricted amounts. Obviously, the feeding systems in areas with such different resources will not be the same.

Additional information on the nutrients supplied by the various forages, the acceptability of some of the leguminous feeds and the consequent effects of such supplements on roughage utilization are required. It can be expected that their feeding value will vary depending on factors such as age at harvesting, leaf to stem ratios, and harvesting and post-harvesting handling practices, but there is little information in these areas. For example, with legume tree leaves, which may be fed fresh or dried, there is little information on the effects of drying on content of soluble carbohydrates or the availability of the protein. There is also a need for more information on toxic principles or anti-metabolite factors in these legumes that may have deleterious effects on animal performance.

Importantly, it is likely that a low level of feeding of these materials will enhance the utilization of rice straw through the provision of limiting essential nutrients. However, possibly the greatest advantage in many areas is that they constitute the easiest and cheapest means of improving feeding practices at the farm level.

8.5 **Class of animal being fed rice straw**

Feeding systems for increased utilization of rice straw need to be tailored to the class of animal and appropriate production objectives. The energy requirements for maintenance accounts for much of that consumed by ruminants particularly when they are of low productivity. Hence, it is likely that improved systems of feeding will be adopted first for those animals which have a high potential for production, such as lactating animals, or those required to provide draught power. In milk producing animals, both excessive age at first calving and thereafter long calving intervals increase the proportion of non-productive life and the amount of maintenance feed required by such animals. This also applies to feeding other livestock for improved reproductive performance or to increase their energy reserves prior to working periods. Potential still exists in some Asian farming systems, where sufficient quantities of feed are available, to introduce dual purpose or multi-purpose animals. Such animals require higher planes of nutrition and the level of supplementation possible will largely dictate the animal production achieved. It is conceivable in situations where animals are kept not only for draught, but also for milk production, that pretreatment of fibrous residues could become economically viable.

In the case of goats and sheep, it has been found under experimental conditions that they can utilise rice straw-based diets reasonably well, although possibly not as well as large ruminants. However, in small farm systems little straw is fed to small ruminants. Undoubtedly more intensive use of straw by goats and sheep can be achieved in some situations with research on appropriate feeding systems. This strategy would enable large and small ruminants together, to have a most important function in converting rice straw to useful animal products of value to humans.

Thus, it is suggested that in the near future, the benefits arising from improved feeding practices are likely to be greatest where such innovations are applied to animals with the most potential to produce saleable products, such as milk, meat, offspring and importantly draught power. In this way feeding systems have to be tailored to suit the class of animal in question and to meet the needs of particular farmers.

8.6 **Socio-economic considerations**

The integrated crop-livestock systems found throughout Asia provide a diversity of farming operations which to some extent reduce the risks farmers face if one enterprise fails. Within these systems improvements in the output of livestock products will only come from more complete and efficient use of locally available feeds, and changes to the system should not have detrimental effects on crop production.

A most important constraint to the adoption of improved systems of rice straw utilization, through supplementation, pretreatment or a combination of these, is the cost of the response achieved in increased draught capacity or meat and milk production. Economic assessment of the costs of supplements or pretreatments in relation to the benefits gained cannot be made in isolation from social implications such as the constraints new systems impose on the farmer's time and allocation of resources.

Two major criticisms can be made of the research conducted on rice straw utilization hitherto. Firstly, most feeding trials that address treatment effects and production responses, have not involved cost: benefit evaluations. Far too often, significant responses have attracted more attention than they deserve, and may in fact have been misleading as the cost of inputs has been excessive. This situation needs to be corrected and it is imperative that the final step in the analysis is an economic assessment of the treatments under consideration. Until convincing evidence is produced to support the value of an improved rice straw-based feeding system, then the current situation of using straw will continue. Evaluations also need to bear in mind that improvements in crop yields or in animal production obtained on research stations are seldom achieved when such changes are implemented at the farm level.

Secondly, there is a great need for improved evaluation of new technologies through on-farm testing and demonstrations. On-farm trials are probably the only accurate assessment of whether new technology packages are acceptable both economically and socially to the farmers as they take into account all of the interacting components of unique small farm systems. They are a means of identifying and addressing the constraints to adoption of new feeding systems, and in many instances in Asia the importance of such trials far out-weighs the need for further documentation of the effects of supplementation or pretreatments.

8.7 Projected furture importance

The increasing populations in the rice producing areas of the world dictate the need for increased crop yields and also a greater use of animal products for human consumption. Improved animal production can only come from more complete and efficient use of the available feed resources and research in this area continues to warrant high priority.

The availability of accumulated knowledge, new approaches to improved utilization of the feed resources and real opportunities for application of what is already known have set the stage for a particularly challenging task for the future. In this context, more intensive utilization of rice straw and other fibrous residues by ruminants in Asia needs to be vigorously pursued.