Bulletin of Animal Science, Special Edition, 1995 ISSN 01260 - 4400

Towards Sustainable Ruminant Livestock Production in The Tropics Opportunities and Limitations of Rice Straw Based Systems

J. van Bruchem and G. Zemmelink[1]

Wageningen Institute of Animal Sciences, Department of Animal Production Systems, Wageningen Agricultural University, P.O. Box 338, 6700 AH Wageningen, Netherlands

Abstract: Ruminants serve a multiple of purposes in South-East Asian farming systems. In addition to the production of meat and milk, livestock provide essential farm inputs, such as manure and draught. In part, ruminant livestock production is based on low-quality residues from primary crop production. These materials can be converted into human consumable food, provided suitable supplements are available. From a farming system's perspective, the nutritive value derived from rice straw is discussed. Voluntary intake and digestibility of rice straw, *i.e.* nutritive value, varies between cultivars, independent of grain yield. In sheep, the nutrients derived from straw can be doubled through selection by offering excess straw. Moreover, individual animals show variation in voluntary intake, digestibility and performance. Livestock performance relies heavily on supplements. Particularly with basal feeds not sufficient for maintenance needs, *e.g.* untreated straw, the conversion of supplement into gain increases with level of supplementation. At system's level this means that the output is optimized by restricting the number of animals. In the dry season with limited amounts of supplement available, it is a useful strategy to impose feed quality restriction. During the subsequent wet season the animals compensate through increased feed intake and a more efficient conversion of nutrients. It is concluded that in mixed crop-livestock production systems largely geared towards the production of food crops, there are ample opportunities to attain moderate levels of ruminant livestock production. However, from a system's point of view, it is perhaps not the primary question how rice straw could be fully utilized for production, but how and to what extent the utilization of rice straw is optimized taking into account the total package of available feed resources.

Key Words : Sustainable Farming Systems, Livestock Production, Rice Straws, Supplement

Introduction

For reasons of efficiency of utilization of solar energy and nutrients in support of human food production, in densely populated regions in the tropics first priority has to be given to primary crop production. Nevertheless, in the small-scale mixed farming systems of South-East Asia, ruminant livestock play an important role, amongst others for the valorization of fibrous crop residues. These low-quality materials often constitute a major proportion of the basal feed, particularly in the dry season. Ruminant livestock serves a multiple of purposes. In addition to the production of meat or milk, livestock provide clothing and essential farm inputs, such as manure and draught. Animals also constitute a strategic source of cash which can be called on during the critical periods of the year. Animal produce may significantly contribute to the income of the farmers' household, thus helping to alleviate poverty and increase household food security throughout the seasons (Devendra, 1993).

In South-East Asia, rice straw is the most abundantly available crop residue. In Indonesia in particular, it is available in excess quantities relative to ruminant livestock requirements (Kossila, 1988). In addition, slopes and marginal lands can be used for planting grass with, relative to rice straw, a slightly higher nutritive value. Planting perennial grass or legumes may serve a dual purpose. On the one hand, this forage can be used in support of ruminant production. On the other hand, proper coverage of the soil contributes to preservation of the ecosystem through the prevention of erosion. Besides, through fixation of elementary N_2, legumes can improve the N status of the crop-livestock system.

ISSN 01260 - 4400

The nutritive value of fibrous feed is determined by voluntary intake, its digestibility and the mixture of nutrients rendered available for intermediary metabolism in support of tissue deposition and/or milk production. The short- and longer-term regulation of fibrous feed intake can be regarded as a multifactorially regulated process, eventually integrated at the level of the central nervous system. In addition to receptors in the wall of the gastrointestinal tract, receptors have been postulated in the portal drained viscera, the liver and the systemic circulation. Perceptive signals are mediated through hormonal and neural pathways. It is generally believed that intake of fibrous feeds is not simply physically regulated by the capacity of the gastrointestinal tract, *viz.* the reticulo-rumen. Seemingly, at higher nutrient requirements, reticulo-ruminal receptors are overridden by portal and/or systemic factors (Van Bruchem et al., 1994a).

Due to the low voluntary intake and digestibility, and the imbalance in the mixture of nutrients released, the nutritive value of fibrous feeds is low, both in terms of energy and protein. Usually the nutritive value can hardly support maintenance and significant quantities of supplement are needed to reach at a moderate level of production. As a matter of fact, it is questionable whether including the low-quality straw in the feeding system imposes a negative effect in respect of the overall output at the level of the farming system.

Sustainability, a multiple objective

In this paper, various options are discussed to improve productivity, taking into account the sustainability of the system. Productivity and sustainability are not necessarily complementary concepts. They may be even conflicting. Maximizing productivity and/or profitability may not coincide with longer-term sustainability. FAO (1992) defines *sustainable development as the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Sustainable development, including agriculture, forestry and fisheries, conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.*

Hence, sustainable development is of a considerably higher order than shorter-term objectives such as productivity or profitability. It combines incomparable objectives, tools and current problems with no clear hierarchy. The quantitative relations are only partly understood, while some aspects of sustainability, *e.g.* welfare of animals and people, are difficult to quantify. Sustainability implies to last indefinitely. This does not mean that a sustainable system should be seen as a static situation. The time dimension requires description of the system as a complex aggregate of dynamic processes, which need to be characterized in mutual relationship. Flexibility is a key characteristic of a sustainable system developing in harmony with the ever changing environmental conditions.

Livestock production systems, as currently practised under temperate and tropical conditions, often lack longer-term sustainability. Despite the progress made in the fields of breeding, management and diet formulation, the conversion of nutrients into produce must still be regarded as quite inefficient. Ruminants convert the ingested nutrients with an efficiency rarely exceeding 25 %. This is particularly true at lower levels of production, when a major proportion of the nutrients is utilized for maintenance. The nutrients not deposited in tissues or milk, are excreted in faeces and urine, constituting a valuable source of fertilization in integrated farming systems. It is of great importance that these nutrients are properly re-utilized as organic fertilizer for crop production. Insufficient recycling causes translocation of nutrients, combining soil depletion and environmental degradation in one area with an excess of nutrients and pollution elsewhere. This may occur even at the farm scale.

Moderate levels of ruminant livestock production, based on fibrous feeds, are only within reach provided higher-quality supplementary feeds are available. In non-industrialized countries, feeds can hardly be transported from elsewhere because of the costs involved. Moreover, to optimize utilization of higher-quality feeds, also non-ruminant production needs to be taken into account. In non-ruminants, a lesser proportion of the feed is lost as methane or heat of fermentation. Hence, they are capable of utilizing higher-quality feeds, *e.g.* agro-industrial by-products, more efficiently.

Livestock production implies the conversion of agricultural by-products into human consumable food. Improving its global contribution implies that a minimum of high-quality human consumable materials, *e.g.* grains and beans, is utilized for livestock production. Particularly, in the Western systems, this aspect is often neglected, *e.g.* in feed lots, where high-quality feeds are utilized to produce marbled beef. Hence, intensive Western systems cannot possibly serve as a model for sustainable livestock production in developing countries. This would result in a situation where livestock production competes with humans rather than supports primary human needs. Sustainable development aims at designing systems with an optimal contribution for the present and future global human population. Moreover, the principle of equity needs to be taken into account, a fair distribution of opportunities in terms of access to education, resources, income and purchasing power, both among and within nations. Unfortunately, it is still not understood how the free market system could contribute to a balanced development towards longer-term sustainability. So far, recent developments have not provided a better balance between urban and rural areas and have not been successful in bridging the gap between *north* and *south*.

Sustainable development combines longer-term economic viability with social acceptability, and must be largely based on regionally available natural resources. For preservation of the environment, systems need to be developed primarily depending on renewable sources of energy and an appropriate re-utilization of nutrients. For decreasing the emission of carbon dioxide, it is of an utmost importance that transport and the utilization of fossil energy are kept to a minimum. Hence, sustainable development does not necessarily coincide with higher investments. On the contrary, longer-term viability may be better served by lowering of costs, improving of employment, and renumeration of labour in a fair balance with return on capital.

At the level of the whole system, interventions should be geared towards optimization, rather than maximization. This means that we have to analyze the system in terms of the optimal number of animals in combination with an optimal level of productivity. This aspect can be dealt with based on the principle of a production function, in this case describing the longer-term productivity of the system in relation to stocking density and external inputs (Figure 1). The productivity of low-input systems may eventually decrease through overgrazing and depletion, while intensive non-integrated high-input systems may end up with environmental pollution. Longer-term sustainable systems need integration with primary crop production, ensuring a proper recycling of the nutrients at a level not beyond the carrying capacity of the soil. Irrespective of external inputs, neglecting these conditions eventually inevitably leads to environmental degradation.

Therefore, it is doubtful that the issue of sustainability could be solved by traditional experiments aimed at maximizing productivity at the level of the individual animal. Perhaps more efforts should be made to analyze the system in terms of the present use of the available feed resources aimed at defining objectives for future research.

Upgrading of low-quality fibrous feed based systems

In recent years, numerous attempts have been made to improve the nutritive value of straw, mainly through chemical treatment and/or supplementation (Sundstøl and Owen, 1984; Ibrahim et al, 1992; Kiran Singh and Schiere, 1993). Relatively less attention has been paid to genetic variation in the nutritive value of rice straw, while grasses have often been selected on the basis of dry matter yield, rather than nutritive value.

To serve the needs of both primary food production and secondary (livestock) production, breeding goals should be jointly formulated by crop and animal scientists. Quality and quantity of the grain produced remains the first objective. However, information is needed whether it is a viable option to breed rice varieties with higher nutritive straw avoiding an adverse effect on grain yield.

The nutritive value of straw can be increased by urea ammoniation. Unfortunately, the rate of adoption of this technology is usually poor. This is primarily related to the additional costs and efforts involved, in most countries being only partly offset by the additional revenues. Despite the increased intake and digestibility and the improved N availability in the reticulo-rumen, microbial biomass *de novo* synthesized in the rumen determines protein availability in the small intestine (SIDP). Relative to the ingested digestible organic matter (DOMI), this is insufficient for higher levels of production. To increase SIDP to a level, which can support acceptable levels of production, supplementary protein, partly escaping rumen degradation, is needed. This paper discusses the essential role of regional supplementary protein resources in ruminant livestock production systems, largely based on fibrous feeds. To avoid competition with non-

 ISSN 01260 - 4400

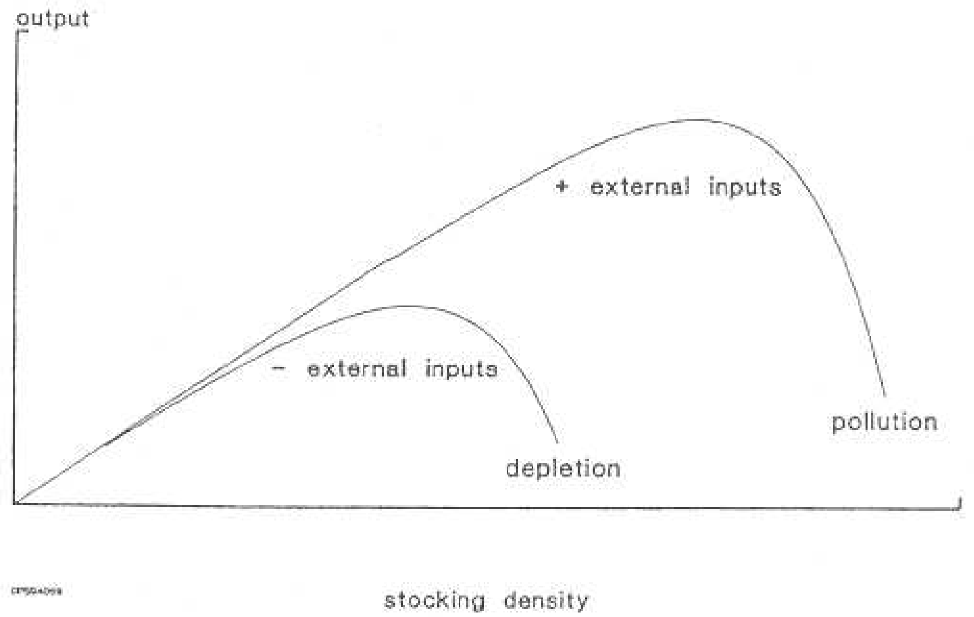

Figure 1. Whole system output in relation to stocking density and external inputs (arbitrary units).

ruminant production, it may be desirable to use forage protein supplements, *e.g.* Leucaena or Gliricidia. However, the availability of such supplements may vary throughout the seasons. In case of shortages, it is a viable option to withhold supplements for a certain period of time. Without supplements and a diet entirely consisting of low-quality fibrous feeds, a period of feed quality restriction is imposed. Subsequent realimentation may be followed by a period of compensatory feed intake and growth. The impact of this strategy will be discussed below.

Finally, in a situation where low-quality fibrous feeds are abundantly available, the issue needs to be addressed at which level of supplementation the longer-term whole system output is optimized. In order to most efficiently convert supplementary feeds into animal produce, maintenance requirements need to be largely met by basal low-quality feeds. In this respect, offering excess straw can make a considerable contribution. Small ruminants are capable of selecting the more palatable part, resulting in a marked increase in DOMI (Zemmelink, 1986).

Below, the various sources of variation in the feed and animal resource bases are analyzed. It is attempted to interpret the outcome from a farming system's point of view. The analyses are primarily based on the results of experiments carried out in the framework of a CEC/STD-supported project, investigating the options to improve the nutritive value of a straw based diet. However, from the perspective of the farming system, one should be aware of the fact that rice straw constitutes only part of the feed resource base for ruminant livestock production in Indonesia. Therefore, the outcome of this analysis cannot possibly be regarded as valid under all conditions. The situation on the outer islands of Indonesia is entirely different from more densely populated regions. The island of Java constitutes a special case, but even within Java we find a great variety of systems, depending on soil type, altitude, irrigation, the availability of slopes and marginal land for planting forage and the level and type of livestock production.

In some of these systems, rice straw plays only a marginal role. The issue needs addressed whether the whole system output would indeed benefit from increasing the input of straw. A straw based production system relies heavily on the availability of valuable supplementary feeds, part of which has to be used to meet the ruminant animal's maintenance requirements.

Below, various sources of variation in the nutritive value of rice straw are discussed, related to plant and animal genetics on the one hand and feeding practices on the other.

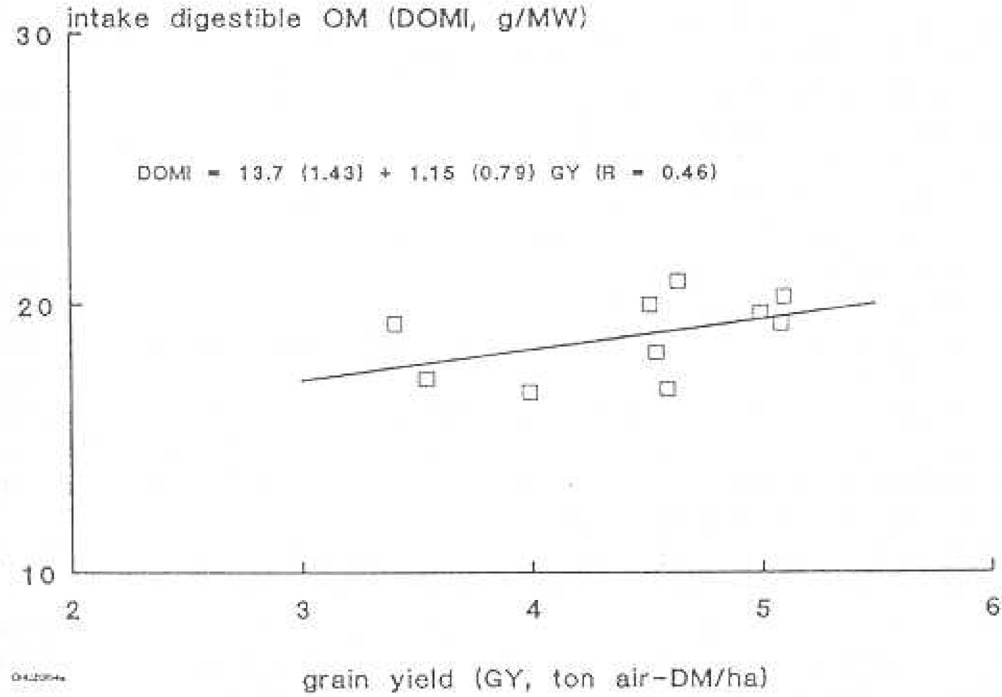

Figure 2. Nutritive value, *c.q.* intake of digestible organic matter (DOMI), of rice straw in relation to grain yield.

Variation between cultivars

Soebarinoto, et al. (1995) tested ten rice varieties in East-Java. Averaged over locations of growth and seasons, they showed a consistent variation in nutritive value. Voluntary intake nor digestibility could be related to chemical composition. However, *in sacco* degradation characteristics, particularly the truly undegradable fraction (U) and the rate of fermentative degradation of the potentially degradable fraction (D) emerged as accurate predictors of *in vivo* nutritive value in terms of digestible OM ingested. Non-structural carbohydrates stapled in the grain, are synthesized through the process of photosynthesis in leaves and stems. From there, monosaccharides are transported to the ear where they are polymerized, constituting starch. Against this background, one would perhaps expect a negative relationship between grain yield and straw quality. The data in Figure 1 indicate however that this is not necessarily the case.

Besides, time of harvesting may need consideration. Maximization of the output at the level of the integrated crop-livestock system in terms of a continued satisfaction of human needs means that an optimal time of harvesting needs to be defined. For this purpose an experiment should be designed aimed at determining the exchange value between straw quality and grain yield in relation to the physiological stage of the rice plant, *i.e.* the maturity of the grain, at harvesting.

Level of straw feeding and selection

In Indonesia, rice straw is available in excess quantities. Only part of it is utilized in support of ruminant livestock production. Another part is used as mulch for the protection of young crops or for manufacturing paper and packing materials. A significant part is burnt, causing environmental pollution, carbon dioxide emission and an irreversible loss of organic material and nutrients, particularly N. It is not entirely clear why farmers in specific regions of Java have adopted this practice. It could be a matter of limited labour. Perhaps, the threshing place needs to be cleared as soon as possible for the next crop. Hence, at that specific moment the straw could represent a negative value. The issue should be addressed whether this short-term objective matches with the longer-term goal, *i.e.* the technical/ economical sustainability of the system.

Particularly the upper lip and the mouth of small ruminants facilitate the selection of the more palatable parts. According to Soebarinoto et al. (1995), sheep prefer the lesser digestible leafy fraction, rather than the potentially better digestible stems. Nevertheless, according to Chuzaemi et al.

ISSN 01260 - 4400

(1995a), intake and digestibility increased with the feeding level of straw. Obviously, like shown by Zemmelink (1986) in other tropical feeds, selection took place not only between, but also within botanical fractions. Straw organic matter (OM) was offered in a range of 29.7-103.2 $g.kg^{-0.75}$, supplemented with 18 $g.kg^{-0.75}$ concentrate DM (15.3 $g.kg^{-0.75}$ OM) with ~20 % crude protein. Straw OM intake (OMI) ranged from 30.2-50.6 $g.kg^{-0.75}$ and straw OM digestibility (dOM) from 43.9-56.9 %. In response to the increase in straw DOMI (15.3 $g.kg^{-0.75}$), daily weight gain doubled (DWG: 3.2-6.3 $g.kg^{-0.75}$). Rumen retention time of the feed particles decreased only slightly (RTR: 29.5-27.7 h), while in relative terms rumen pool size increased (RPS: 0.94-1.06). The increased intake of rumen degradable OM failed to bring about an increase in the urinary excretion of purine derivatives (PDU: 170-155 $\mu mol.kg^{-0.75}$), perhaps indicating a weak response in rumen microbial protein production. This may explain the relatively low ratio dDWG/dDOMI of only ~0.2.

In these latter diets, the conditions in the rumen, *i.e.* protein availability, could not be held responsible for the low efficiency of rumen microbial biomass synthesis. Hofmann (1988) related the partitioning of digestion between the rumen and the hind gut to selective feed intake behaviour. Perhaps the proportion of OM digested in the large intestine increased with selection. This aspect needs further in-depth research in cannulated animals to study the conditions in the rumen and flows of dry matter and microbial biomass along the intestines. Alternatively, the low value for dDWG/dDOMI could be related to lower needs for maintenance at the lowest level of straw feeding. As indicated in Table 1, whole diet DOMI of 25.6 $g.kg^{-0.75}$ was still able to support a DWG of 3.2 $g.kg^{-0.75}$.

At the highest level of excess straw, DWG had almost doubled. As a result, the *costs* of concentrates per unit DWG decreased from 4.8 to 2.4 $kg.kg^{-1}$ DWG. As outlined in Table 1, the *costs* of straw (amount offered) increased from 9.4 to 16.4 $kg.kg^{-1}$ DWG. Values in the lower two lines are related by the equation OMC (kg) = 7.7 - 0.317 * OMS (kg). Thus 1 kg extra straw OM saved 0.317 kg concentrate OM. When we translate these data in Rupiah, *i.e* look at the production system in the way the farmer might do, we find that feeding excess straw may significantly reduce the costs of production.

Excess straw may also come in handy when we evaluate the system in terms of nutrient cycles. The straw refusals may be used as bedding for binding the N excreted in the urine. If bedding was not used, the C/N ratio in faeces/urine would be so low that a significant loss of N occurred. Using excess straw as bedding provides the extra C needed to bind the N. Thus feeding excess straw may contribute to both the economic and technical sustainability of the system.

When we look at concentrates per unit of DWG in this trial, one may wonder why farmers do not fatten more sheep on the basis of rice straw, offered in excess, and supplements. Whether this statement would also apply for large ruminants, remains to be investigated. Cattle are less able to select within the botanical fractions of rice straw. However, relative to metabolic size ($kg^{0.75}$) they have a more favourable gut capacity.

Table 1. Response of fat-tail sheep to selective consumption of rice straw.

straw OM offered[1]	30.2	48.1	66.5	84.8	103.2
straw OM intake[1]	30.2	36.8	40.4	53.8	50.6
straw dOM (%)	43.9	47.0	50.4	53.8	56.9
straw DOMI[1]	13.3	17.3	20.4	23.6	28.8
whole diet DOMI[1]	25.6	30.0	33.2	36.4	40.9
daily gain (DWG)[1]	3.2	4.1	4.8	5.4	6.3
concentrate OM (OM_C)[1]	15.3	15.3	15.3	15.3	15.3
straw OM $kg.kg^{-1}$ DWG	9.4	11.8	14.0	15.6	16.4
OMC $kg.kg^{-1}$ DWG	4.8	3.8	3.2	2.8	2.4

1) $g.kg^{-0.75}$

Variation between animals.

In the experiment described above, a remarkable variation emerged between individual sheep. Associated with the selection of the lesser digestible leaf blade/sheath fraction, straw dOM varied from 37.7-58.1 %, straw OMI from 32.3-47.9 $g.kg^{-0.75}$ and straw DOMI from 14.9-25.7 $g.kg^{-0.75}$. Related to this, RTR varied from 22.0-35.4 h, and RPS in relative terms from 0.75-1.25. It is concluded that there may be scope for selecting local fat-tail sheep for higher intake and digestibility. Repeatability values within sheep, to be regarded as an upper limit for heritability (h^2), were 0.48 for straw OMI, 0.52 for straw dOM, 0.36 for straw DOMI, 0.59 for RTR, 0.41 for RPS and 0.42 for PDU (Ani Nurgiartiningsih, 1993). PDU ranged 3.1-6.6 μmol g^{-1} DOMI. Hence, it seems that sheep differ genetically in terms of efficiency of rumen microbial protein synthesis, and small intestinal amino acid supply. Higher efficiencies were found in sheep with a lower RTR. This can presumably in part be attributed to a lesser predation of rumen microbes by protozoa (Dijkstra, 1993).

An effective selection of animals with higher roughage intake capacities requires a careful definition of the most optimal breeding strategy. Higher intakes could be related to various factors, both at and beyond the level of the gastrointestinal tract. At the latter level, the reticulo-rumen has been designated as the first limiting compartment (Weston and Poppi, 1987). Recently, Van Bruchem et al. (1994a) developed a conceptual rumen model, distinguishing small (SP) and large particles (LP), both particle pools being subdivided into a potentially degradable (D) and a truly undegradable (U) fraction. The model is driven by the quality of the feed ingested, in terms of the water soluble (S), D and U fractions. Rate constants are defined for comminution (k_c), fermentative degradation (k_d) and passage (k_p) to the lower gut. A sensitivity analysis revealed that the processing capacity of the rumen was most sensitive to rumen pool size, the D fraction in the feed ingested and its rate of degradation (k_d). The nutritive value in terms of DOMI was hardly affected by rate of passage (k_p), as an increased OMI was almost entirely offset by a decreased dOM (Figure 3). It would thus seem that rumen pool size (RPS) and rate of degradation (k_d), which may vary considerably among animals, need to be included in the breeding index. However, prior to this at the animal level the various components contributing to feed intake need to be validated, and the genetic proportion of the variation assessed.

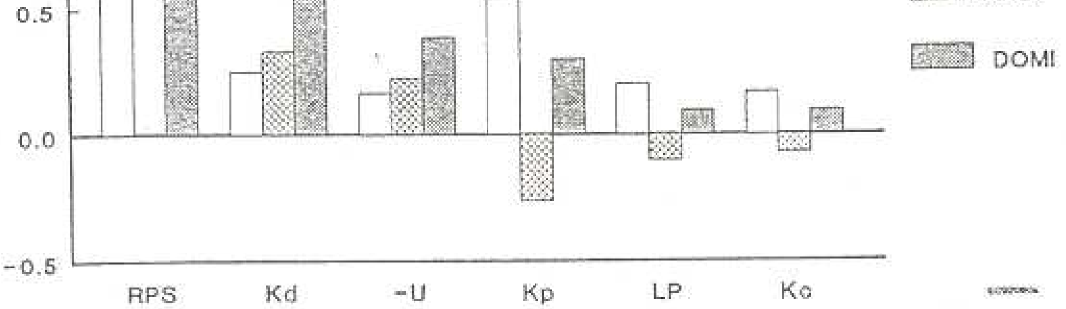

Figure 3. Sensitivity analysis of a conceptual rumen model with respect to organic matter intake (OMI), organic matter digestibility (dOM) and intake of digestible organic matter (DOMI) in relation to rumen pool size (RPS), fermentative rate of degradation (k_d), the truly undegradable fraction in the feed (U), rate of particulate passage (k_p), proportion large particles upon ingestion (LP) and physical rate of degradation (comminution, k_c).

Besides, to justify such a major breeding effort, the system needs a more detailed analysis, aiming at the identification of the primary constraints. Based on a mechanistic model describing the nutrient dynamics at system level, a sensitivity analysis could reveal whether the longer-term sustainability of the system would benefit from breeding ruminant animals with higher capacity to ingest coarse feeds. However, according to Taylor et al. (1986), animals with higher feed intake capacity may need more nutrients for maintenance (M). As a result, the increment in DOMI is seemingly less efficiently converted into DWG. Therefore, breeding efforts should aim at increasing DOMI/M.

Type and level of supplementation

In another trial in Indonesia rice straw, untreated (US) or treated with urea (TS), was supplemented with varying amounts of concentrates containing 20 % crude protein (Chuzaemi et al., 199*b). In terms of OM, concentrates ranged from 0 to 27.3 $g.kg^{-0.75}$. Averaged over treatments and inversely related to the level of supplement, the amount of rice straw ingested ranged from 35.4 to 43.6 $g.kg^{-0.75}$. The relationship between DWG (y) and level of concentrates (C, x) was as follows:

US-C: $y = -2.08 + 0.287\ x$

TS-C: $y = -0.96 + 0.285\ x\ (g.kg^{-0.75})$

In this case, the response to supplement DOM was quite acceptable (>0.36 g DWG g^{-1} DOM_C), especially when we consider that straw intake decreased by about 8 $g.kg^{-0.75}$ for both straws. With urea treated straw (TS), a markedly positive associative effect was noticed at concentrate OM levels of 3.9 and 7.8 $g.kg^{-0.75}$, respectively (Figure 4).

With the untreated straw (US), the major problem was that 7.1 $g.kg^{-0.75}$ concentrate supplement was needed to fully meet maintenance requirements, even though this straw contained about 1.5% N. This laid a heavy tax on the production costs. Reasonable conversion ratios were only obtained at the higher supplement levels. At 22.5 $g.kg^{-0.75}$ of supplement OM, DWG was 4.5 $g.kg^{-0.75}$, implying a *cost* of 5 kg supplement per kg DWG. While this conversion ratio may be acceptable, it should also be recognized that at this level 38% of the total OMI came from supplement. This implies that for every ton of straw eaten 0.6 ton of supplement would be needed. Also at lower levels of supplement feeding this ratio remained high. For instance at 12.5 $g.kg^{-0.75}$ supplement OM, DWG was 1.6 $g.kg^{-0.75}$. This implies a *cost* of nearly 8 kg supplement per kg DWG, while the consumed ration still consisted of about 25% supplement.

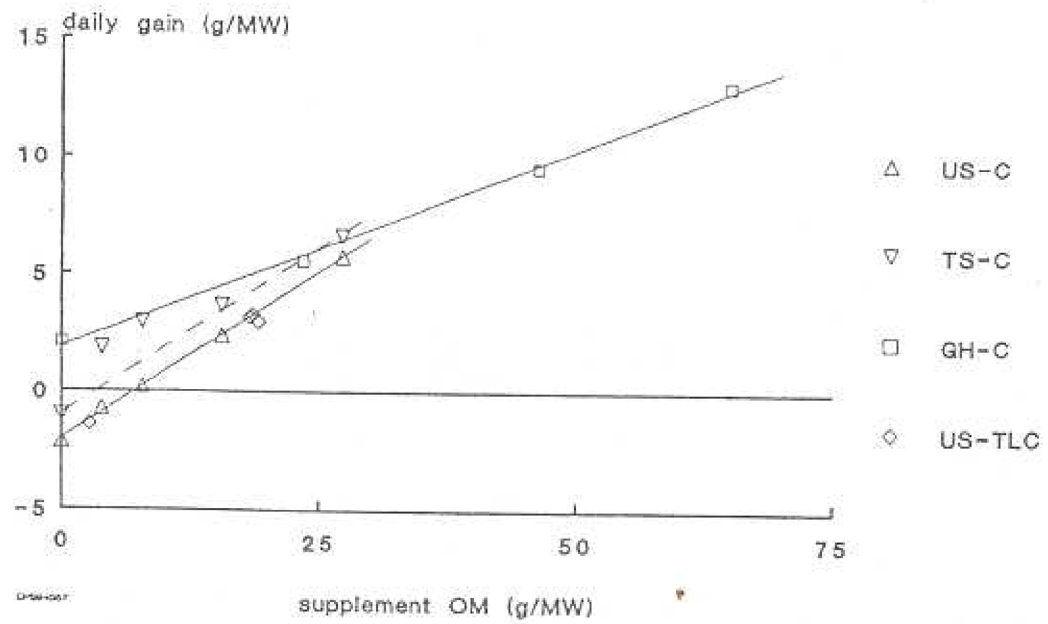

Figure 4. Daily gain (DWG) in relation to concentrate (C) OM offered, with US denoting untreated straw, TS urea treated straw, GH grass hay and TL tree leaves.

For the TS diets, these figures were more favourable. DWGs of 1.5 and 4.5 $g.kg^{-0.75}$ were obtained with 5 and 15 $g.kg^{-0.75}$ supplement, respectively. In both cases, the conversion ratio approximated 3.3 with rations containing 28 and 12 % supplement, respectively. The former is still high enough to cause the availability of supplements to be a serious limitation for the use of rice straw for animal production. At the lower level of production this may be the case to a lesser extent. Thus, due to the associative effect, the benefit of urea treatment is an improved supplement conversion at quite low levels of supplementation. However, for a proper evaluation, also the costs of treating rice straw have to be taken into account, in part at least, because with proper manure management, a significant part of this N may become available for crop production.

Similar conclusions follow from experiments in Sri Lanka where untreated rice straw was supplemented with tree leaves or a combination of tree leaves and cassava meal (TLC). In the first trial, a kg DWG required 7.6 kg leaf OM, and leaf OM amounted to 0.67 (0.50) * the straw OM ingested (offered) at a production level of 3.2 $g.kg^{-0.75}$ (Premeratne et al., 1992). In a second trial, 1.5 kg cassava meal plus 2.3 kg leaf OM were needed per kg DWG. This conversion ratio was quite as good as with tree leaves alone. However, again, cassava meal and tree leaves together constituted a large fraction of the ration: 0.52 (0.36) * the amount of straw ingested (offered). Averaged over tree leaves, *i.e.* Leucaena, Gliricidia and Tithonia, DWG (y) and supplement OM (x) were related as follows:

$$\text{US-TLC: } y = -2.15 + 0.285\,x \ (g.kg^{-0.75})$$

The output of livestock production systems based on rice straw and suitable supplements, seems to be squeezed between two problems. On the one hand, low levels of supplementation give only low levels of production with high *costs* of supplement per unit of animal production. On the other hand, higher levels of production require such high amounts of supplement that the limited availability of supplements may seriously hamper the incorporation of large amounts of untreated straw in the feeding system.

Conversion ratios, *i.e.* kg supplement kg^{-1} gain, become much more favourable when treated straw is used. This may be generalized by saying that favourable conversion ratios are only obtained when the basal ration approaches maintenance requirements (Figure 5). In this figure, conversion ratios are compared with those obtained in dwarf goats fed grass hay (GH) and graded levels of mixed concentrates (Zemmelink, et al., 1991).

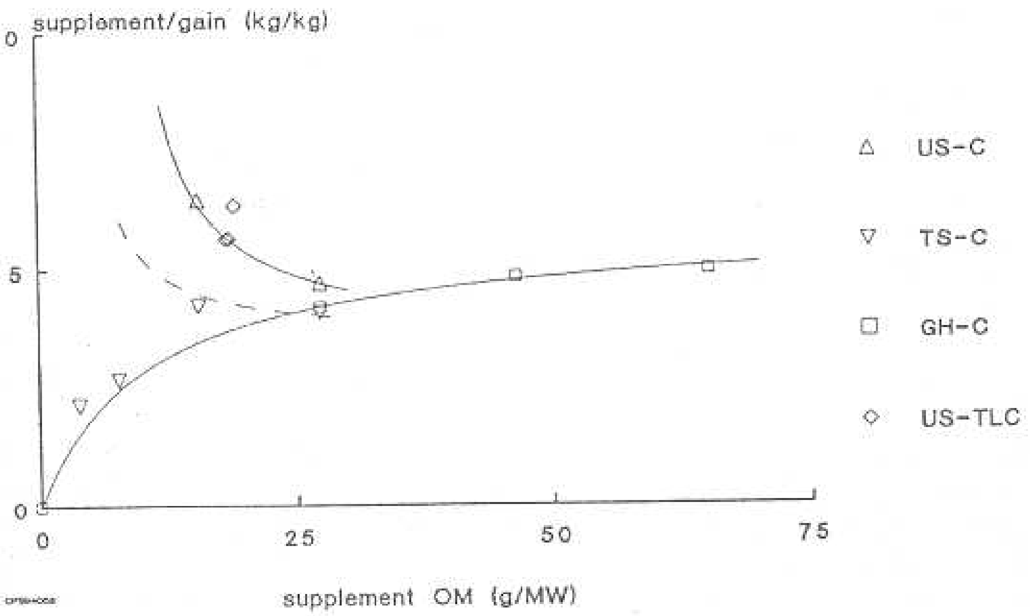

Figure 5.Supplement to gain conversion ratio in relation to concentrate OM offered (for abbreviations, see Figure 4).

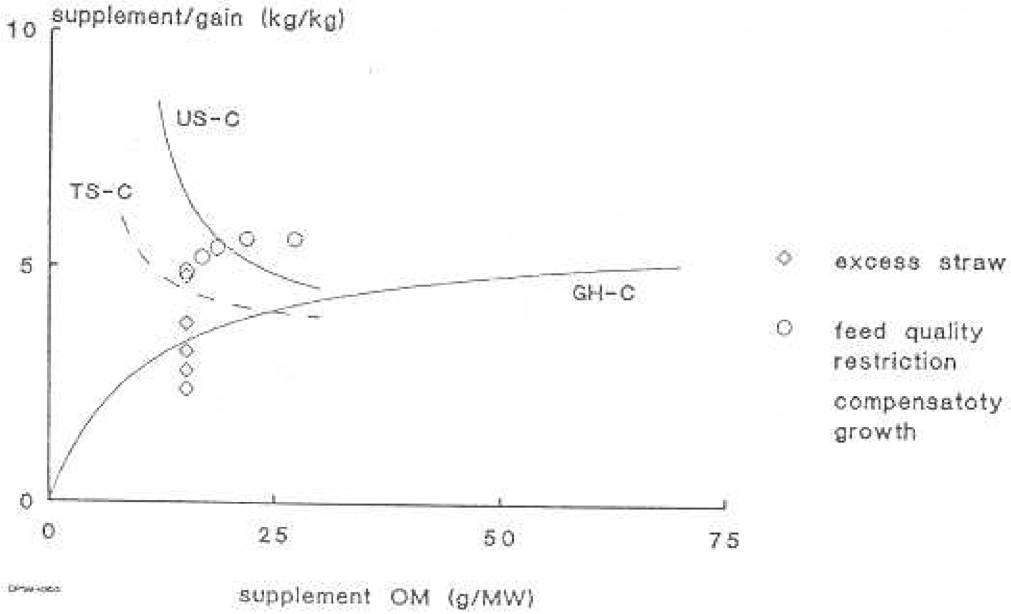

Figure 6. Supplement to gain conversion ratio in relation to feed quality restriction, realimentation and compensatory growth (for abbreviations, see Figure 4).

Feed quality restriction and compensatory growth

Supplement availability is often subject to seasonality. In such cases, it is an elegant strategy to benefit from the principles of compensatory intake and growth. With limited quantities of supplement available, the ration may consist for the larger part, or even entirely, of rice straw. This may occur particularly in lowland areas where rice constitutes the major crop with limited space for trees/shrubs. In other words, during the dry season a feed quality restriction is imposed. Without any or only a limited amount of supplement available, the voluntary intake of low-quality fibrous feed was found to gradually increase (Chuzaemi et al., 199*b). As shown by Van Bruchem et al. (1994b), part of this increased fibrous feed intake may persist after realimentation. Hence, the resultant compensatory growth can partly be attributed to higher voluntary fibrous feed intake. The other part has been suggested to be related to lowered maintenance requirements during restriction and the persistence of this during the first period after realimentation. Besides, a higher efficiency of conversion of absorbed nutrients has been suggested, perhaps partly due to a delayed deposition of protein. Hence, delayed growth does not necessarily lead to a decrease in carcass composition in terms of the protein to fat ratio. With this strategy, more favourable supplement conversion ratios may be within reach at, averaged over the seasons, a lower level of supplementation (Figure 6). This strategy results in an increased output at system level, relative to a situation where a significant part of the supplements would be used in the dry season. Besides, in this figure the impact of selection from excess straw is illustrated. The conversion of supplement became more favourable at higher levels of straw feeding, with the conversion decreasing from 4.8 to 2.4. Throughout the seasons, supplement conversion was improved at lower levels of supplementation during periods of scarcity, particularly at levels ranging 0-10 g.kg$^{-0.75}$.

Conclusions and Recommendations

It appears that in mixed crop-livestock systems largely geared towards the production of food crops, there are ample opportunities to attain moderate levels of ruminant livestock production. However, depending on the regional situation the most appropriate strategy may differ. A summary of the opportunities for improving the performance of ruminant livestock fed on diets largely based on fibrous crop residues, is presented in a cumulative way in Figure 7. It has to be noticed that in order to attain an acceptable conversion ratio of supplement, first priority needs to be given to meeting maintenance requirements with the basal fibrous feed. As indicated above, options for improvement are a.o. selection of rice varieties with higher-quality straw, urea treatment, selection of sheep with higher intake capacity or allowing selection in straw supplied in excess. It is as yet not entirely clear, to

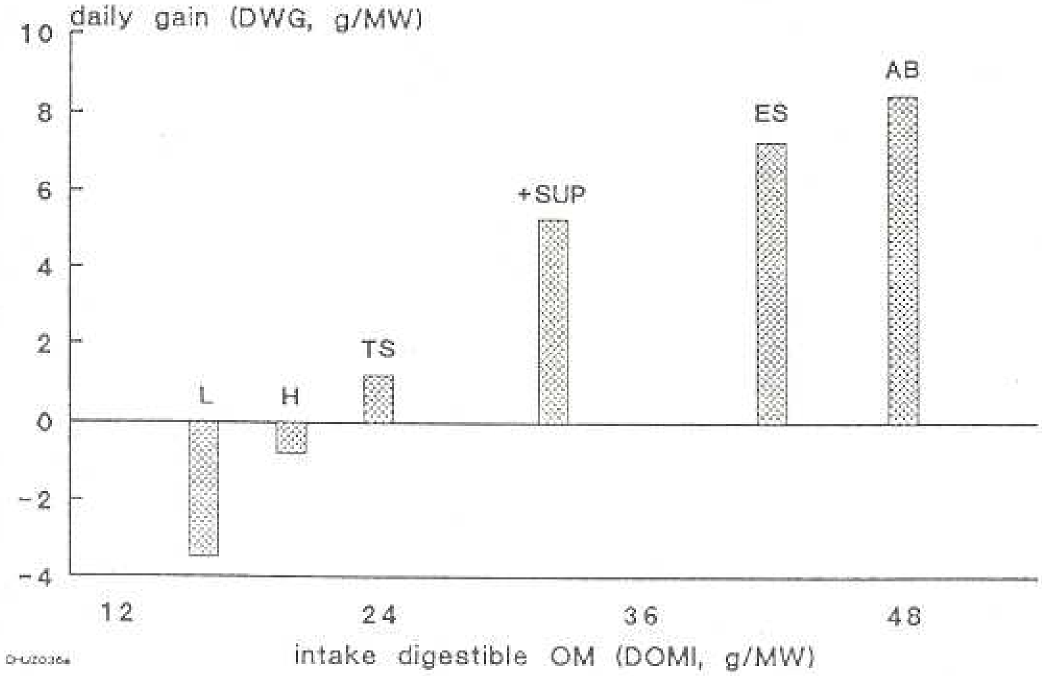

Figure 7. A summary of the opportunities to improve ruminant performance in systems largely based on low-quality fibrous feeds (L: low quality; H: high-quality cultivar; TS: urea treatment; SUP: 15 $g.kg^{-0.75}$ supplement; ES: excess straw; AB: impact animal breeding.

which extent the effect of these various measures is additive, in other words whether interactions occur. This latter aspect may need further research.

However, the question from a system's point of view, is perhaps not how we can fully utilize rice straw for production but how, and to what extent, rice straw could be used to optimize the utilization of the total package of available feed resources. This is a fundamentally different approach compared to conducting traditional trials. Feeding trials as described above provide very useful information, but may describe only a limited part of the overall production system because they isolate rice straw and higher-quality supplements from all other feed resources. If anything, they may indicate that it is not possible to design a production system fully utilizing the available rice straw, in view of the supplementary feeds in amounts that we can assume to be available.

Therefore, despite the considerable variation in the utilization of the basal feed, moderate levels of production are only within reach if reasonable quantities of a suitable supplement are available. Supplements provide an additional source of energy, but above all protein and minerals, essential nutrients for the rumen microbial ecosystem, resulting in an increased efficiency of microbial biomass production. It is desirable that part of the protein escapes from rumen degradation, improving the availability of protein in the small intesfine. As recently shown by Oosting, et al. (199*), such conditions may significantly influence the intake of low-quality fibrous feed.

Hence, a first appraisal in a farming system's perspective should aim at identifying the regionally available supplementary energy and protein resources. If desired, the options for the introduction of additional trees/shrubs should be considered in a way that an adverse effect on primary crop production is avoided. Moreover, multipurpose shrubs/trees may play an essential role in environmental conservation programmes through regreening, prevention of erosion, the production of fire wood and timber, and also constitute an important niche for forage production, particularly in the dry season (De Jong et al., 1993). Hence, their introduction may increase the welfare of the farmer's household and will contribute to a longer-term technically/economically sustainable rural development.

With the available supplements designated as a first constraint, the results of the above analysis suggest that in the tropics whole system's output may increase by lowering the number of animals. Under temperate conditions, with fibrous basal feeds available providing nutrients beyond maintenance, this analysis leads to the opposite conclusion. However, under both conditions, farmers follow the guidelines of the extension services, which seemingly point into the wrong direction. Under temperate conditions, it is aimed to lower the number of ruminant animals, while in the tropics policies are usually geared towards a steady increase of ruminant livestock. On the longer term, this may well lead to an irreversible degradation of the ecosystem.

In summary, it has been noticed above that only a small part of the rice straw available on the island of Java is utilized in support of animal production. Its main utilization is in the dry season, particularly in areas where during this season no green feed is available while in the wet season considerable quantities of green feed may be found. Rice straw is then primarily used as the survival feed, not with the objective of obtaining production directly. In areas closer to the mountains where even in the dry season some green feed is available, farmers may go to extremes to collect this green feed, rather than feed rice straw. It is only in the areas with an extreme seasonal scarcity of green feed that rice straw is stored.

Other areas where rice straw is fed to some extent are the intensive milk production areas. But also there, we cannot speak of a production system based on rice straw. The system is largely based on green feed and concentrates with only a limited amount of rice straw. Moreover, the rice straw used is carefully selected. Usually, it is newly harvested green material. This implies that farmers whose objectives are production are careful to select a roughage diet of reasonable quality.

Also in urban dairies some rice straw may be used. Farmers operating in these circumstances may even pay a rather high price for straw. But also there the function of rice straw is not to provide a major part of the energy, but rather to help maintain structure in the rumen on rations which due to scarcity of green feed are mainly based on concentrates.

Sustainable developments constitute an investment for the future, aiming at improving the longer-term resilience of a system. Such developments have to be focussed at continuity and optimization, at preservation of natural resources and appropriate recycling of nutrients, rather than at maximal output. In practice, decisions based on shorter-term considerations, are usually geared towards increasing profitability. However, the behaviour of individuals may well have a negative impact for the longer-term perspective. Hence, policies need to be defined in a way that farmers are encouraged/enabled to act in a fair balance with the interests of the community, safeguarding the longer-term continuity of a system.

Acknowledgements

The authors gratefully acknowledge financial support provided by the Commission of the European Communities: Contract TS2-0091-NL, 'Utilization of crop residues and supplementary feeds in tropical developing countries'.

Literature Cited

Ani Nurgiartiningsih, V.M., 1993. Breeding for intake and digestibility of rice straw based diets in fat-tail sheep. MSc. thesis, Wageningen Agricultural University, 55 pp.

Chuzaemi, S., J. van Bruchem, R.D. Sulastri, V.M. Ani N., S.C.W. Lammers-Wienhoven, X.B. Chen, M. Blümmel, S. Prawirokusumo, 199*a. Potential of rice straw for ruminant production in the tropics -Effect of variety, urea treatment and selection from excess straw on voluntary intake and digestibility, microbial protein synthesis and retention time in the rumen, and performance in fat-tail sheep. Animal Production, in press.

Chuzaemi, S., J. van Bruchem, A. Hidayati, Soebarinoto and S. Prawirokusumo, 199*b. The potential of rice straw for ruminant production in the tropics - Effect of variety, urea treatment and supplementation on compensatory growth in fat-tail sheep after a period of feed-quality restriction. Animal Production, in press.

De Jong, R., T. Nolan and J. van Bruchem, (eds.), 1992. Natural Resource Development and Utilization. Future Research and Technology Management in Soil-Plant-Animal-Human Systems. Proceedings of the Commission of European Communities Coordination Workshop, held at IAC, June 29 - July 2, 1992, Wageningen, The Netherlands, 168 pp.

Devendra, C., 1993. Sustainable animal production from small farm systems in South-East Asia. Food and Agriculture Organization of the United Nations, 143 pp.

Dijkstra, J., 1993. Mathematical modelling and integration of rumen fermentation processes. Doctorate thesis, Wageningen Agricultural University, 221 pp.

FAO, 1992. Sustainable development and environment: FAO policies and actions. Stockholm 1972 - Rio 1992. FAO, Rome, 88 pp.

Hofmann, R.R., 1988. Morphological evolutionary adaptations of the ruminant digestive system. In: (A. Dobson and Marjorie J. Dobson, eds.) *Aspects of Digestive Physiology in Ruminants*. Proceedings of a Satallite Symposium of the 30th International Congress International Union of Physiological Sciences, Cornell University, Ithaca, New York, 21-23 July, 1986. Comstock Publishing Associates, p. 1.

Ibrahim, M.N.M., R. de Jong, J. van Bruchem and H. Purnomo (eds.), 1992. Livestock and feed development in the tropics. Proceedings of an International Seminar held at Brawijaya University, Malang, Indonesia, 21-25 October, 1991. Agricultural University, Wageningen, The Netherlands, Brawijaya University, Malang, Indonesia, Commission of the European Communities, Brussels, 546 pp.

Kiran Singh and J.B. Schiere (eds.), 1993. Feeding of ruminants on fibrous crop residues - Aspects of treatment, feeding, nutrient evaluation, research and extension. Proceedings of an International Workshop held February 4-8, 1991 at the National Dairy Research Institute, Karnal, Haryana, India, Indian Council of Agricultural Research, Krishi Bhavan, New Delhi, India, and Wageningen Agricultural University, Netherlands, 486 pp.

Kossila, V., 1988. The availability of crop residues in developing countries to livestock populations. In: Reed, J.D., Capper, B.S. and Neate, P.J.H. (eds.), Plant breeding and the nutritive value of crop residues, pp.29-41. Proceedings of a workshop held at ILCA, Addis Ababa, Ethiopia, 7-10 December, 1987, ILCA, Addis Ababa, Ethiopia.

Oosting, S.J., J. van Bruchem & X.B. Chen, 199*. Intake, digestion and small intestinal protein availability in sheep in relation to protein supplementation to ammoniated wheat straw. British Journal of Nutrition, submitted.

Premaratne, S., H.G.D. Perera and J. van Bruchem, 1992. Effect of type and level of forage supplementation on voluntary intake and digestibility of rice straw in sheep. In: Livestock and Feed Development in the Tropics, M.N.M. Ibrahim, R. de Jong, J. van Bruchem & H. Purnomo (eds.), Proceedings International Seminar, 21-25 October 1991, Malang, Indonesia, pp. 156.

Soebarinoto, Siti Chuzaemi, Jaap van Bruchem, Hartutik and Mashudi, 1995. The nutritive value of rice straw in relation to variety, urea treatment, location of growth and season - *in sacco* degradability as predictor of digestibility and intake. Animal Feed Science and Technology, in press.

Sundstol, F. and E. Owen, (eds.), 1984. Straw and other fibrous by-products as feed. Developments in Animal and Veterinary Sciences, Elsevier, Amsterdam, 269 pp.

Taylor, St.C.S., R.B. Thiessen and J. Murray, 1986. Inter-breed relationship of maintenance efficiency to milk yield in cattle. Animal Production 43: 37.

Van Bruchem, J., S.J. Oosting & S. Tamminga, 1994. An outlook on prospects of fibrous feed based ruminant livestock production in the tropics through an improved rumen microbial environment and balancing of nutrients. Proceedings International Conference on Manipulation of Rumen Microorganisms to Improve Efficiency of Fermentation and Ruminant Production, 20-23 September 1992, Alexandria, Egypt, pp. 186.

Van Bruchem, J., A. Kamalzadeh, C.P. Leffering, M.J.N. Los, J. Baas and S. Tamminga, 1994. Compensatory development of growing sheep after prolonged feed quality restriction - Voluntary feed intake and rumen residence time. Proceedings Society of Nutrition Physiology 3: 140.

Weston, R.H. and D.P. Poppi, 1987. Comparative aspects of feed intake. In: The nutrition of herbivores (J.B. Hacker and J.H. Ternouth, eds.), Academic Press, Sydney, pp. 133.

Zemmelink, G., 1986. Measuring intake of tropical forages. In: Recent advances in feed evaluation and rationing systems for dairy cattle in extensive and intensive production systems (C.C. Balch and A.J.H. van Es, eds.), International Dairy Federation, Brussels, Bulletin 196: 17.

Zemmelink, G., 1991. Energy requirements for maintenance and gain of West African Dwarf goats. Small Ruminant Research 5: 205.