Urea-treated Straw With Limited Supplementation for Sustained Ruminant Production in Developing Countries

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ABSTRACT

The state-of-the-art of urea-treated straw feeding technology is presented, focusing on strategic supplementation to optimize animal productivity in sustainable production systems for developing countries.

The treatment procedure and the effects of urea incubation on the feeding value of rice straw are described, particularly on the improved digestibility and nitrogen content of straw. Comparative animal responses to urea treatment vis-a-vis urea-molasses supplementation are shown. An account of the efforts to extend the technology to farmers in selected Asian countries is given with special reference to the Philippines.

Practical supplements and appropriate supplementation strategies are discussed. Recent findings on milk and meat production of urea-treated straw fed livestock with limited supplementation are reviewed. Finally, sustainable animal production systems involving rice straw utilization are described.

INTRODUCTION

Abount 80% of the ruminants in developing countries are kept in mixed animal/cropping systems on small farms. The small-hold livestock producers are basically crop farmers keeping some goats/buffaloes/cattle as a major source of food for the family, as draft power as well as source of manure for the crops. Because of limited land holding expected to be able to support the cash requirement of the family, whatever the small piece of land the farmer tills is prioritized primarily for food/cash crop production. Improved pastures, therefore, do not exist and will never have a place among the small-hold farming systems in this part of the world. His animals have to be contented with crop residues supported with forages from marginal lands. From rice and corn alone, it can be computed from production data (**28**) that approximately 12 million metric tons of rice straw and corn stover are generated yearly. Trung (1987) pointed out that the current cattle and buffalo population in the country could be doubled through full utilization of fibrous agricultural residues which are currently being left rotten or burnt in the field.

This paper discusses the issues on sustainable livestock production systems in developing countries involving the utilization of fibrous agricultural residues with emphasis on urea treatment and limited supplementation. Research data generated by the Dairy Training and Research Institute (DTRI- UPLB) and other institutions in developing Asian countries wil constitute the scientific basis for this paper.

UREA TREATMENT: WHY? WHAT CAN IT DO?

1. Nutritional constraints of rice straw

Rice straw and other fibrous residues consist mainly of the structure components of plants. Lignin in fibrous residues is closely associated with cell wall polysaccharides and acts as a physical barrier to microbial breakdown, hence its low digestibility/energy values. Rice straw, likewise, contains very low crude protein (3-5%) which is below the critical level of 7% dietary protein required for acceptable voluntary feed intake. The ash content, although high, is made up largely of silica. The levels of Ca, P and Mg available from rice straw are usually lower than the range of 0.2-0.8% required for the normal growth and fertility of ruminants. The same is true with trace elements like Co, Cu, etc. (**9**).

Because of the poor nutritive value, rice straw alone could at most support liveweight maintenance. Pretreatments and/or supplementation of rice straw are, therefore, essential to bring about production. There are a number of chemicals-largely alkalis - that have been found to be capable of breaking down the lignopolysaccharide bonds (**39**).

The following discussion centers on urea, a ready source of alkali to farmers in developing countries. Urea has been used to treat straw in Bangladesh (**30**), India (**13**), Indonesia (**8**), Sri Lanka (**27, 33**), the Philippines (**19,40,41,42,43**) and Thailand (**46**). With adequate moisture and suitable temperature conditions, microbes which produce urease are capable of degrading urea to ammonia, which eventually forms into ammonium compounds (ammonium carbonate, bicarbonate or hydroxide) which then permeate the straw.

2. Exogenous urease: a past concern

Through plastic bag experiments on urea treatment, it was thought that the breakdown of urea into ammonia and, subsequently ammonium compounds, would take at least 21 days to realize the treatment effects. In this connection, research in the early '80s endeavored to identify natural sources of urease to cut down treatment time form 21 to 5 days (**11**, **15**). Along this line, we found that dried poultry manure (DPM) was a better source of urease compared to *Gliricidia sepium* leaves (**19**). With the inclusion of 4 - 12% of DPM in 4% urea-treated straw, within three days, straw digestibility was increased by 12 % while its crude protein content doubled (**19**).

Urea treatment of straw in large heaps/silos done in Sri Lanka indicated that because of higher temperatures maintained by the heaps compared to those in small plastic bags, full treatment effects can be achieved in 7 days (**11**) without additional source of urease. Although the issue of exogenous urease has been put to rest, the urease sources (e.g. *Gliridicida*, DPM) can always be regarded as valuable supplements to improve straw's feeding value.

With the present state of knowledge, the use of 4% urea, a straw to water ratio of 1:1 and airtight storage for at least 7 days seems to be suitable for the tropics (**11**).

3. Intake and digestibility

A good effect of ammoniation is nitrogen enrichment, i.e. N content of rice straw is roughly doubled after treatment (**15,19**). This, therefore, has a positive effect on intake (**20,39**). Increases in digestibility brought about by urea treatment have not been consistent; as low as 2-6 percentage units (e.g. **15,20**) or as high as 10 percentage units (**19**) have been recorded. The variation in digestibility may be attributed to differences in temperature, moisture content, urea concentration, treatment conditions and duration. These interrelated factors influence the growth of microorganisms responsible for degrading urea and hence the concentration of ammonium compounds.

4. Urea treatment vs supplementation

Several experiments were reviewed (**9**) in which urea treatment and supplementation were compared based on animal responses (Table 1). Supplementation has generally been found to increase the feeding value of straw compared to untreated, unsupplemented controls and, in some instances, as effective as pretreatment. The effect of urea treatment could not be felt, however, if both groups received relatively generous supplementation (e.g. 1% LW concentrate, **4**).

Urea treatment would generally increase the quality of straw to maintenance level and supplements would be required to bring about production. It is clear that as long as straw remains a substantial part of the diet, then urea-treated straw has substantial advantages over untreated material (**17,27,43**). On the other hand, the effects of treatment may be lost if straw constitutes only a small portion of the diet.

In terms of feed cost, it has been estimated that urea treatment costs 60% less than concentrate supplementation of untreated straw in order to get a similar energy intake (**20**).

FEED RESOURCES OF SMALL-HOLD DAIRY FARMERS AND ADOPTION OF UREA- TREATED STRAW TECHNOLOGY

The Philippines is perhaps one of the countries in Asia where feed resource potentials have not been fully exploited.

This could be grossly attributed to the dwindling cattle and buffalo population which is a consequence of low priority of the livestock commodity among the government's development programs. Nevertheless, with the introduction of dairy animals in some milkshed areas, the value of rice straw is gaining appreciation among dairy farmers. In a recent survey involving 32 small-hold dairy farmers, 22 (or 69%) actually used straw as feed for their milking cows (**25**).

In a urea-treated straw feeding project, feed resources of 22 adoptors were surveyed and shown in Table 2. Majority of the farmers depended heavily on straw feeding, followed by grazing under coconuts and marginal lands, while only 2.5% of the total feed DM was derived from improved pastures. Another important observation was that feed sourcing came largely from off-farm areas rather that within the farm proper (**44**).

As soon as the benificial effects of urea treatment of straws were discovered, animal scientists and extension workers lost no time in trying to bring the technology to the village level. Constrained by limited land to support a progressive livestock industry, Bangladesh was the first country (1980) to introduce urea treatment to small farmers with financial assistance from local and international sources. The adoption by farmers was evaluated (**32**). Assisted by the Dutch government, Sri Lanka launched a straw utilization project focusing on urea treatment in 1982 (**16**). The same effort was noted in India (**22**); Thailand (**29**), and the Philippines (**26,41**). Farmers in those countries readily accepted the technology at the beginning. Continued adoption, however, was not noted. For example, among 145 Bangladesh farmers in the Pabna milkshed area, only 13% fed urea- treated straw continuously in 1981 (32).

Through the financial assistance of PCARRD, researchers at the DTRI-UPLB attempted to introduce urea treatment to small-hold dairy farmers in Laguna on a limited scale in 1987. Among the 22 adoptors of urea-treated straw feeding technology, 7 carried on with the practice (32%) while the remaining 15 farmers (68%) tried only once or twice. The latter nevertheless stated that they would again do the treatment because apparently they were convinced about the feeding value of treated straw. Ninety-one percent (**20**) felt that they derived the following benefits from the technology: time saving (45%); good substitute for grass even during rainy months (25%); increased appetite of animals (15%); improved milk yield and quality (10%);

and fully utilized straw (5%). The same number of adoptors (20 or 91%) stated they would recommend that other farmers try the technology (**26**).

PRACTICAL SUPPLEMENTS

Because of poor nutritive value earlier pointed out, rice straw, when fed alone, could not support productive functions. Urea treatment improves straw quality to the level of fair quality grass, which may bring about low productivity. The use of supplements in such a feeding situation will further enhance animal performance. The subsequent discussion identifies supplements that are readily available at the village level while supplementation strategy will be dealt with thereafter.

1. Concentrate supplements

Unlike situations in developed countries where grains and protein meals are available at low costs for feeding livestock liberally, grains in the developing countries are widely used as human food and for monogastric animal feeding. Farmers raising ruminants, therefore, have to be contented with industrial by-products for which poultry and swine raisers also compete. It is, therefore, conceivable that small amounts of concentrate by-products may be used judiciously in feeding systems to promote production through maximized utilization of fibrous basal feeds.

A number of by-products are shown in Table 3. Although they are classified as energy and protein supplements because the latter group has crude protein values of more than 20%, both groups do provide not only energy and protein but also vitamins and minerals. The nutritive values of these ingredients vary considerably depending on the sources, methods of processing and the degree of adulteration.

Animal proteins have a higher by-pass value than protein supplements from plant sources. Among energy supplements, pulps, corn, sorghum and brans are more slowly fermented in the rumen compared to tuber meals and molasses, some of which also tend to escape rumen fermentation (**7**). Rice bran may contain from small amounts to as much as 50% of rice hull, hence its protein value may be as high as 14% or as low as 4%.

Likewise, protein meals left after the commercial extraction of oil from nuts/seeds have a lipid content of from 1 - 10%. Solvent extraction produces a meal of only 1-4% fat compared to 6-10% for mechanical extraction. While a protein meal with high fat content generally has lower than expected CP value, the loss in protein may be well compensated for. Fat has a gross energy content of about 2.5 times that of protein and carbohydrates of the same weight and a higher efficiency of utilization within the body. Intake of a given weight of fat provides approximately seven times more usable energy for growth than the same weight of mature roughage (**21**). O'Kelly (1985) compared two isonitrogenous and isocaloric diets having different fat contents (2.5 vs 9.2%) for 120-day steer fattening. He reported 20 kg heavier weight traceable from 10% higher net energy intake from the steers eating high fat diets. On the other hand, the disadvantages are: high fat concentrates being associated with developed rancidity and the high cost of fats versus other energy sources.

2. Green forage supplements

The principal constraint of using concentrates as a supplement at the village level is the cost involved in purchasing the feeds. Perhaps, this may be overcome in many instances if concentrates are replaced by green forages which are available on or near the farm at almost no cost, except for the time involved in cutting and hauling. Systems in which green forages can be generated for small farmers without the need for establishing permanent pastures have been discussed (**10,35,37,45**). It is inevitable that when green forages are considered in this context, attention is focused on the legumes. However, protein-rich crop residues, such as cassava tops, banana leaves, sweet potato vines, etc. should not be overlooked.

Tropical legumes generally contain high levels of protein and all minerals except sodium. Although the digestibility of legumes is not higher than grasses, voluntary intake is generally higher due to shorter rumen retention times (**36**).

While most legumes are high in protein, one important difference among them is the considerable variation in their solubility. The resistance to protein degradation in the rumen has been attributed to high tannin content (**10**).

Another variable feature among the legumes is sulphur content. This element, in adequate concentrations, is required to achieve optimum fiber breakdown in the rumen (**1**) and important not only for bacterial growth but also for development of fungi. By providing S and other rich substrates to the rumen, legumes could play an important role in promoting the activity of both bacteria and fungi which subsequently digest fiber of low-quality materials.

APPROPRIATE SUPPLEMENTATION

The two supplementation strategies, viz. liberal and limited, were presented in this forum a few years ago (**38**). While very good growth and lactation responses can be expected from liberal supplementation, their application is confined to situations wherein supplements are readily available at low costs, coupled with high cost of hauling crop residues, e.g. commercial dairy/beef operations. For production at the village level where animal holdings of small farmers constitute 70-90% of the livestock population in the Asian countries, consideration needs to be given to restricting the use of supplementary concentrates, as they are usually in short supply, to levels which maximize the use of fibrous feeds. In this regard, the use of "balanced rations" to meet nutrient requirements has been questioned (**12,38**). For small-holders, it is much more realistic to adopt the feed-budget approach whereby the use of supplements would be rationed to improve utilization of fibrous feed resources for optimizing livestock productivity.

1. Substitution effect of supplementation

The decrease in roughage DM intake per unit of supplement DM given is known as the substitution rate (SR), calculated as:

$$SR = \frac{\text{Decline in roughage intake (kg)}}{\text{Increase in supplement given (kg)}}$$

This SR may be negative when the supplement stimulates roughage intake, indicating a true supplementation effect. When supplements high in RFC are given, the substitution rate usually ranges from 0, where the concentrate has no effect on roughage intake, to 1.0 or more, where the roughage intake decreases by an amount equal to or more than the concentrate given.

2. Limited concentrate supplementation

In an attempt to compile available literature on straw supplementation, it was noted that, except at low levels of supplementation (10-20%), the amount of straw consumed decreased as the level of supplementation increased (**9**). Table 4 summarizes animal responses to urea-treated straw feeding with limited supplementation obtained from recent experiments conducted in Asian countries. These findings confirm an earlier statement made that urea-treated straw needs supplementation to support production with efficient feed utilization (**5,34**). Superiority of fish meal over oil cake or its combination with rice bran in promoting growth of young animals was demonstrated (**31**). Growth of older cattle (**42**) and milk production of dairy cows in late lactation (**11**), on the other hand, were not affected by protein sources (copra meal vs fish meal) or level of supplementation (0.3 vs 0.6% LW for the heifers and 1:2.5 vs 1:3.5 concentrate to milk ratio for the dairy cows).

3. Supplementation with green forages

Ideally, a legume supplement should maintain or increase voluntary intake rather than substitute for the basal ration. Experimental evidence, however, has shown that with untreated crop residues, forage supplements substituted for the basal feeds even when they were only 10-15% of the diet (Table 5). The situation was less clear with treated straw and more research in this area is needed. Perhaps the most pertinent point from the information presented is that, in some experiments, legume supplements had little effect on digestibility even when they comprised a significant proportion of the diet (Table 5). 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 RFC, nitrogen, minerals and vitamins. Considering the substitution effect, time availability and supply constraints, in so far as small-hold resources are concerned,green forages, particularly legumes, may be best included at levels of not more than 25% of the dry matter ration.

SUSTAINABLE RUMINANT PRODUCTION SYSTEMS INVOLVING CROP RESIDUES

With the population explosion taking place in most developing countries, resources, especially land, are being spread more and more thinly. This situation, aggravated by the debt burden, makes planning for development in this part of the world an extremely difficult task. Sustainable livestock production, along this line, must involve the full exploitation of cheap, lasting and locally-available resources with the maximum use of solar, not fossil fuel, energy. This necessitates the integration of ruminant production with crops. These two components complement and supplement each other in an integrated farming system. Large ruminants provide draught power and manure as fertilizer for crop production while crops provide residues and by-products for ruminant feeding.

1. Sustainability versus high input and productivity

Jackson (1981) proposed a realistic model for animal agriculture in Bangladesh (Fig. 1). The important feature of this system is the efficient utilization of the energy captured by vegetation -- nothing is wasted. It is self-reliant, not dependent on additional energy inputs, which is an asset for a country that must import much of its petroleum. By way of contrast, the Western system uses large inputs of fossil fuel energy in the form of fertilizers, hence its much higher yields. High crop yields, coupled with fewer people to feed, mean a surplus of cereals which are used for livestock feeding together with imported oilcake. This, coupled with a pleasantly conducive environment, brings about very high livestock productivity. Our attention in the past half century has exclusively focused on the positive aspects of Western agriculture - its high productivity per unit area of land and head of livestock. Needless to say, we have not succeeded in reaching this goal. Indeed, we can not succeed because among other reasons, petroleum costs too much (**12**). Although it may be true that the Bangladesh model is an exaggeration of the Philippine situation in terms of pressure on use of land and other resources, the message is that if we are not conscious about conserving resources and go on with the western model, bankruptcy is just around the corner.

2. Feed resource from rice production: An intervention

To support more livestock units in cropped lands, research in farming systems has successfully identified several strategies to augment feed supply. Intercropping, sequential cropping, ley farming and alley cropping involving food-forage crops were reviewed (**35,37**). Table 6 provides rough estimates of feedstuffs (crop residue and forages) generated from rice-based farming systems. Carrying capacity (animal unit equivalent to 450 kg liveweight) greatly increases with the introduction of forage crops after rice harvest; this is especially true with one rice crop a year. While grasses would yield twice as much biomass compared to legumes, the latter further provides food grain and enriches the soil. It should be pointed out that the introduction of forages after rice harvest does not reduce rice yield in the subsequent crop.

Feed resources for small-hold livestock production could further be augmented through the introduction of fodder trees, established as living fences. Calub (1988) estimated that 200 trees in a hedgerow or a living fence of Gliricidia planted 1m apart could provide 25% daily feed requirement of a 300 kg cattle on a year-round basis. This is premised on 0.47 kg DM/cut/tree for a 60-day cutting interval. The availability and utilization of tree fodders in the Philippines have been reviewed (**45**).

3. The three strata forage system (TSFS)

The TSFS is a technology of producing fodders from forage crops, shrubs and trees in a cash crop based area. One unit of TSFS (Fig. 2) is 2500 m^2 wide, consisting of: (1) 1,600 m^2 core area for cash crops (e.g. corn, soybean, cassava); (2) 900 m^2 peripheral area (first stratum) planted to grasses and ground legumes for wet season feeding; and (3) 200 m circumference area planted to alternating shrubs (2nd stratum) and trees (3rd stratum) for mid-dry and late-dry season feeding, respectively (**23**). Corn stovers and cassava tops are fed straight after harvest while soybean straw and cassava stems are stored for feeding during the late dry season.

In summary, one TSFS unit (good for a 300 kg cow) consists of 0.16 ha cash crop for human (with residues for livestock), 0.09 ha pasture, 2000 shrub legumes and 422 fodder trees. Stall-fed cattle is integrated in the second year after the establishment of the first two strata. The third stratum takes three years to establish.

Since more and better quality of forages are available, the cattle growth is 12% faster and feed conversion, 29% better compared to traditional practice by farmers. The system has been in operation since 1984 and has established 180 units in dryland areas of Bali, 10 units in East Java and 1 unit in Southeast Indonesia (**23**).

CONCLUSION

While it is true that fibrous agricultural residues are poor quality feedstuffs, their feeding values can be greatly improved through urea treatment and/or supplementation for meat and milk production. Appropriate supplementation involves the use of small quantities of legumes and/or concentrate to maximize voluntary intake of fibrous feeds for optimal production of the animal.

In the context of sustainable agriculture in developing countries of Asia, taking into consideration the high cost of energy and shrinking land resource, the most sensible approach is to integrate livestock with the current crop production systems involving smallholders. Feed resources in these systems can greatly be improved through technology intervention without compromising the yield of the primary crop.

Table 1. Responses of growing and lactating animals fed with urea treated vs untreated rice straw

PARTICULARS	UNTREATED STRAW	UREA-TREATED STRAW
Sahiwal heifers (166 kg) with 6 kg grass silage + 0.54 concentrate/day **(27)**		
Dry matter intake		
Straw, kg/d	2.1	2.8
Total, kg/day	3.8	4.6
Liveweight gain, g/d	73	346*
Feed/gain, g/d	53	13
Zebu (121 kg) with 1 kg grass + 0.42 kg concentrate/day **(17)**		
Straw, kg/d	2.9	3.7
Total, kg/d	3.5	4.2
Liveweight gain, g/d	125	310*
Feed/gain	28	14
Holstein grades (175 kg) with 1.6 kg 13% CP concentrate/day[1] **(4)**		
Dry matter intake		
Straw, kg/d	3.0	2.9
Total, kg/d	4.6	4.5
Liveweight gain, g/d	670	650
Feed/gain	6.8	6.9
Brahman grades (190 kg) with 1 kg fresh grass and 0.85 kg 16.6% CP concentrates/day[1] **(43)**		
Dry matter intake		
Straw, kg/d	4.4	4.8
Total, kg/d	5.3	5.7
Liveweight gain, g/d	190	290*
Feed/gain	28.5*	20.2
Surti buffaloes with 1 kg concentrate/day **(27)**		
Dry matter intkae, %LW	2.8	3.7
Liveweight change, g/d	-93	+59
Milk yield, kg/d	2.2	3.0*
Milk fat, %	6.7	7.5
Calf LW gain, g/d	165	295*
Calf milk intake, kg/d	0.95	1.03

1 Straw in the untreated group was sprayed with urea-molasses.

* : $P<0.05$

Table 2. Feed resources of dairy farmers practicing urea-treated straw feeding (N = 22)

Sourcing	Estimated available Tons/yr	feed dry matter Percent
Rice straw		
On farm	81.7	16.3
Off farm	195.2	38.9
Under coconuts		
On farm	45.1	9.0
Off farm	89.5	17.8
Marginal land	69.6	13.9
Improved pasture	12.5	2.5
Others	8.5	1.5
TOTAL	502.1	100.00

Table 3. Some commonly available agro-industrial by-products

Ingredients	DM (%)	CP (% DM)
Energy		
Molasses	75	4
Rice bran	88	11
Cassava chips	89	1.4
Corn bran	87	10
Sweet potato chips	90	12
Pineapple pulps	88	5.5
Soybean residue	46	6.8
Protein		
Copra meal	91	22
Brewer's spent grains	89	22
Soybean pulps	88	22
Soya oil meal	88	44
Meat and bone meal	94	54
Fish meal	89	60
Cassava leaf meal	91	25

Table 4. Dry matter intake (DM), average daily gain (ADG), daily milk yield (DMY) and feed conversion efficiency (FCE) of animals fed urea-treated straw (UTS) with limited supplementation[1]

Particulars	DMI, % LW Straw	DMI, % LW Total	ADG, g	FCE
Merino crossbred lambs, 28 kg LW-fish meal (FM) and/or Lucerne hay (LH) to UTS **(34)**				
UTS	1.6	1.6	-13	-
UTS + 75g LH	1.7	1.9	03	175
UTS + 75g FM	1.7	1.9	09	59
UTS + 75g LH + 75g FM	1.7	21	27	22
Cattle, 100 kg LW-Basal diet includes urea-lime treated straw (UTS) + 2 kg grass + minerals **(31)**				
Basal	-	-	150	21
Basal + 300 g oil cake (OC)	-	-	190	20
Basal + 300g kOC + 300g rice bran (RB)	-	-	250	15
Basal + 150g fish meal (FM)	-	-	360	10
Basal + 150g FM + 300g RB	-	-	350	11
Cattle, 175 kg LW-Basal diet includes UTS restricted to 2.2% LW + 1 kg napier grass **(5)**				
Basal	-	-	190	47
Basal + 200g OC	-	-	370	15
Basal + 600g OC	-	-	510	10
Brahman bulls, 200 kg LW-14% CP concentrate to UTS **(46)**				
UTS + 1 kg conc.	3.0	3.5	468	14.3
UTS + 2 kg conc.	2.8	3.6	840	9.5
Dairy replacement heifers, 270 kg LW-Basic supplements to UTS include 1 kg grass + minerals **(42)**[2]				
FM + RB, 0.7 kg/d	1.8	2.3	460	12.4
Copra meal (CM) + RB, 0.7 k/d	1.8	2.3	420	13.3
Late lactating cows - Basic supplements to UTS include 2 kg grass + mineral **(18)**[3]				
			DMY, kg	
FM + RB, 3.5 kg/kg milk	2.2	2.8	6.0	1.3
CM + RB, 3.5 kg/kg milk	2.1	2.8	5.3	1.5

[1] Urea-treated rice straw (UTS) was fed *ad lib* in all experiments unless otherwise indicated.

[2] No significant changes in response when the concentrate was doubled

[3] No significant changes in response when the concentrate intake was increased to 2.5 kg/kg milk

Table 5. **Dry matter intake (DMI), digestibility (Digest.), average daily gain (ADG) and feed conversion efficiency (EFC) of animals fed straw with forage supplementation (DM basis)**

	DMI, %LW		Digest.	ADG	FCE
Particulars	**Straw**	Total	%	g	
Rams, 20 kg LW - Rice straw (RS) vs urea-treated straw (UTS) with fresh Leucaena (L) **(4)**					
Para grass	3.4	3.4	51.1	86	9.0
UTS	3.3	3.3	45.7	37	18.6
RS - UM	3.7	3.7	50.4	40	19.4
UTS + 285g L	2.1	3.3	59.9	63	11.6
RS - UM + 285g L	2.5	3.7	49.2	60	13.4
Sheep 25 kg LW - RS with Cassava leaves (C) or Leucaena (L) **(6)**					
RS	2.5	2.5	44	-	-
RS + 0.25 g C	2.2	3.2	51	-	-
RS + 0.13 g L	2.1	2.6	47	-	-
RS + 0.40 g L	1.5	3.0	53	-	-
Bulls, 100 kg LW - RS vs UTS with Gliricidia (G) **(9)**					
RS	2.7	2.7	47	-113	-
RS + 0.6 kg G	2.5	3.1	49	-94	-
RS + 1.1 kg G	2.2	3.3	55	10	-
UTS	3.2	3.2	41	-28	
UTS + 0.3 kg G	3.1	3.4	45	63	-
UTS + 0.5 kg G	3.4	3.9	50	134	-
Steers, 150 kg LW - RS with Verano stylo (V) **(9)**					
RS	2.1	2.1	-	-165	-
RS + 0.3 kg V	2.2	2.5	-	11	332
RS + 0.6 kg V	2.2	2.9	-	60	78
RS + 0.9 kg V	2.21	3.0	-	104	45

Table 6. Feed resources from 1 hectare of paddy field (ton DM/ha/yr) and estimated carrying capacity (animal unit) with and without technology intervention

CULTIVATION METHOD	Rice Straw	Animal Unit	Green Forages[1] Bunds	Legumes	Grasses	TOTAL
Traditional						
One crop	2.5	0.7	0.2	-	-	0.2
Two crops	5.0	1.4	0.2	-		0.2
Three crops	7.5	2.1	0.2	-	-	0.2
Forage crops after rice						
One crop	2.5	1.7-2.4	1.0	2.5	5.0	3.5-6
Two crops	5.0	1.9-2.2	1.0	1.0	2.0	2-3
Three crops	7.5	2.4	1.0	-		1.0

Computed from (35) and (37).

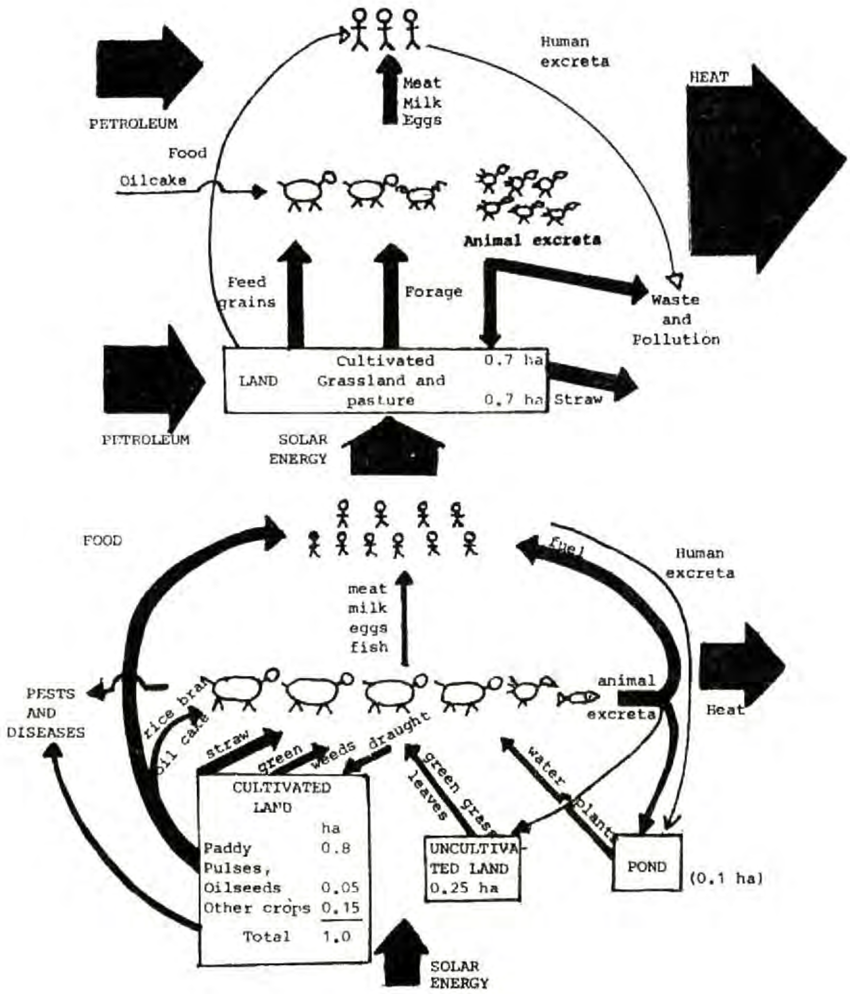

Figure 1. Comparative livestock production models: Western agriculture's (upper) vs Bangladesh's (lower). Adapted from Jackson (1981)

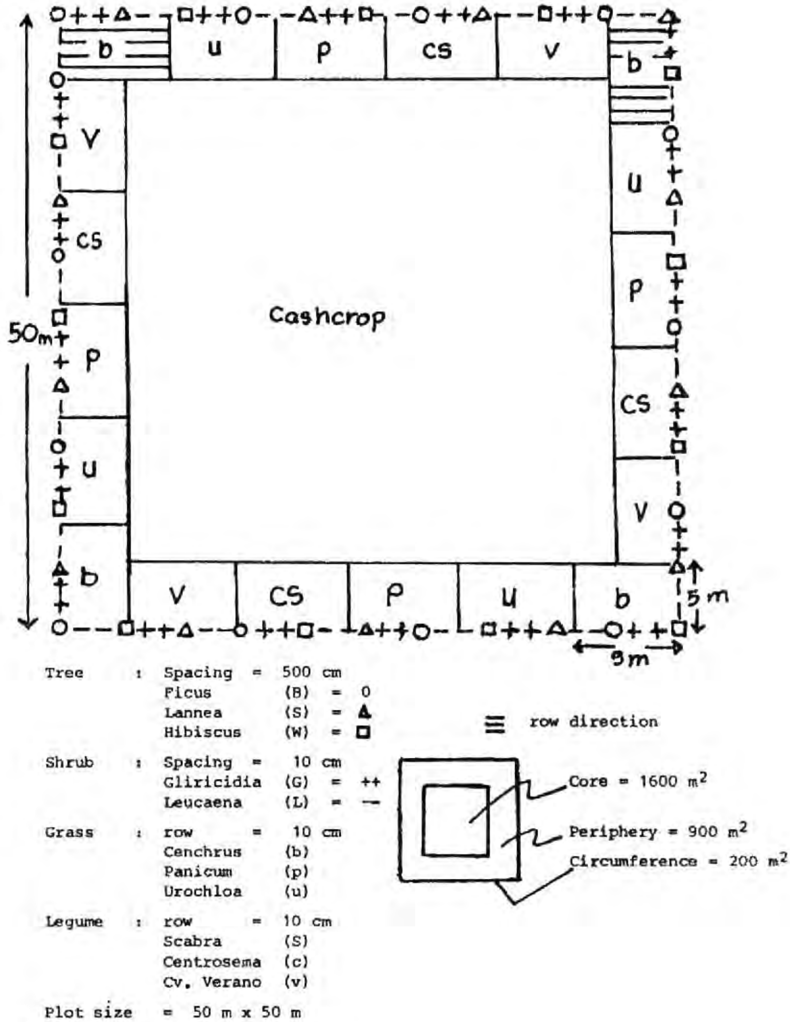

Figure 2. Planting arrangement of grasses, legumes, shrubs and trees in the TSFS

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