THE EFFECT OF CHEMICAL TREATMENT OF BARLEY STRAW ON DIGESTIBILITY IN SHEEP AND GOATS

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1. ABSTRACT

The main object of the experiments described was to compare the digestibility in and acceptability to sheep and goats of barley straw and barley straw sprayed with sodium hydroxide (NaOH). In feeding trials involving six sheep and six goats, chopped untreated barley straw (US) was compared with straw chopped and spray treated with 5 g NaOH in 60 ml solution per 100 g straw. The treated straw (TS) was neither washed nor neutralized. Both US and TS were fed to appetite to sheep and goats with protein, mineral and vitamin supplements and ad libitum water. The TS was readily consumed and there were no metabolic problems.

Dry Matter Intake (g/kg $W^{.75}$) was significantly increased ($P < 0.05$) in sheep but not in goats following alkali treatment of the straw. Organic Matter Digestibility (OMD) of the diets was also increased ($P < 0.05$) after treatment. The energy digestibility of the TS-based diet was significantly increased ($P < 0.05$) in both species. The digestibility of Crude Fibre (CF) was markedly improved ($P < 0.01$) following treatment in both sheep and goats, but the improvement was significantly higher ($P < 0.05$) for sheep fed on US than for the goats fed US. The belief that goats digest CF more efficiently than sheep was not proved The interspecies difference in fibre digestibility may have been due in part to the relative immaturity of the goats compared with the sheep (5 months and 15 months respectively)

and also to the relatively short adaption period allowed before the trial commenced.

Highly significant increases ($P < 0.001$) in water intake occurred with both sheep and goats fed TS.

Values for the OMD and Metabolizable Energy (ME) of the US and TS were derived and both parameters were significantly increased ($P < 0.05$) following treatment of the straw with alkali. TS, if adequately supplemented with nitrogen, minerals and vitamins would appear to be capable of supplying the ME requirements for maintenance and limited production in sheep and goats.

2. INTRODUCTION

Ever increasing world food shortages have led to competition between man, monogastric animals and ruminants for available food particularly cereals. Consequently, there has developed a growing awareness of the importance of saving crop residues such as straw and making use of them as livestock rations. Large quantities of straw are produced each year from crops such as rice, maize, millet, barley or oats, but a substantial amount is wasted at present, often by burning.

As an animal feed, straw is of low feeding value being low in energy, very low in protein and high in fibre. However, it is possible to improve the feeding value of straw by the action of alkali which can raise organic matter digestibility and increase intake and production levels without causing metabolic problems. Alkalies such as sodium hydroxide are not expensive and since labour in many developing countries is often in plentiful supply, it seems likely that the alkali treatment of straw may have a valuable future role in producing a useful roughage for ruminants.

Sheep and goats are important ruminants in many parts of the tropics, and this work attempts to consider some of the effects of chemically treating straw on digestibility in these species.

3. LITERATURE REVIEW

3.1 CEREAL STRAW AS A FOODSTUFF FOR RUMINANTS

3.1.1 Composition of Straw:

Barley straw comprises the stem and leaves of the cereal plant after removal of the ripe seeds. It is extremely fibrous and bulky which limits its use as an animal fodder.

Using standard tables (MAFF, 1975), Crude Fibre values are shown to be much higher for spring and winter barley straw at 394 and 488 g/kg Dry Matter (DM) respectively compared with 250 and 53 g/kg DM for barley silage and grain. Crude protein is markedly low in straw with values of 38 and 37 g/kg DM compared with 95 and 108 g/kg DM for the silage and grain. There is wide variation in Metabolizable Energy (ME) values within the four foodstuffs with 7.3 and 5.8 MJ/kg DM for spring and winter straw comparing with 9.6 and 13.7 MJ/kg DM for silage and grain. These low ME values are a reflection of the poor digestibility of the energy of the straw.

Much of the energy present in the straw is derived from the cell-wall constituents (CWC) which make up 800 - 850 g/kg DM. A typical composition of barley straw CWC is cellulose, 400 - 450 g/kg DM; hemicellulose, 300 - 350 g/kg DM and lignin, 80 - 120 g/kg DM with a Dry

Matter Digestibility (DMD) average of 0.4 - 0.5 (Johnson, 1976).

During the ripening process, nutrients are transported from the stem and leaves to be stored in the ripening seed (Woodman, 1943). The composition of straw thus varies with the degree of ripeness at cutting. If harvesting is delayed until the grain is ripe, the straw will be of poorer feeding value than if it is cut earlier (McDonald, Edwards and Greenhalgh, 1966). Composition will also vary with many other factors such as the variety of cereal, application of fertilizer and soil type.

However, since over 75% of straw is made up of the polysaccharide carbohydrates cellulose and hemicellulose, which are digestible by rumen microflora, (Guggolz, Kohler and Klopfenstein, 1971), it is a potentially valuable source of food energy. The amount of lignin present in straw lowers its value as a foodstuff.

Lignin is not a carboydrate. It is an aromatic compound. Its main function is to supply strength and rigidity to plant materials. It is generally considered to be completely indigestible and, for practical purposes, is unaffected by rumen microorganisms (Pigden and Heaney, 1969). Lignin content of straw can be as high as 150 g/kg DM compared with 80 g/kg DM in alfalfa or 10 g/kg DM in barley grain (Van Soest, 1976). Lignin limits the digestion of cellulose and hemicellulose by combining with these substances in strong chemical bonds (Palmer, 1976) and by acting as an inert barrier between the carbohydrates and the digesting enzymes (Tomlin, Johnson and Dehority, 1965; Pigden and Heaney, 1969). This linkage between lignin and cellulose occurs during the process of lignification of the plant cell walls as the tissues mature.

3.1.2 Digestibility of Straw:

The carbohydrates present in the CWC are digestible by the ruminant if the association with lignin can be broken (Watson, 1941). It follows, therefore, that lignification is probably the major cause of low digestibility of straw and any improvement in digestibility is likely to be inversely related to the degree of lignification.

Other factors affecting straw digestibility include the highly crystalline nature of the cellulose which impedes its rapid availability to enzyme action (Siu, 1951; Baker et al, 1959; Cowling and Brown, 1969). In addition, the ash content of straw contains 30% Silica which is of no feeding value (McDonald, Edwards and Greenhalgh, 1966) and actually may inhibit carbohydrate digestibility (Van Soest and Jones, 1968).

Straw has a low apparent digestibility for Crude Protein which is probably a result of its very low protein content. Apparent Digestibility Coefficients for

Crude Protein may even be negative if the metabolic nitrogen excreted is greater than the nitrogen absorbed from the digestive tract, as is frequently the case with roughages like straw which have low Crude Protein levels (McDonald, Edwards and Greenhalgh, 1966). A diet of straw is unlikely to be able to supply a ruminant's maintenance requirement unless supplemented and may not even supply the nitrogen requirement of the rumen micro-organisms.

The addition of alkali as sodium hydroxide (NaOH) can increase Organic Matter Digestibility (OMD) so that at a concentration of 8 g NaOH/100 g Straw DM *in vitro* OMD values may be as high as 0.75, but being an inorganic compound, addition of the alkali causes a reduction in Crude Protein, Organic Matter and Gross Energy values and an increase in ash content (Johnson, 1976). Misleading results can be obtained by referring to Dry Matter Digestibility results and the unit of choice should therefore be Organic Matter Digestibility.

3.2 ALKALI TREATMENT OF CEREAL STRAW

3.2.1 Historical

The use of alkali to improve the digestibility of roughages has been known for many years. Kellner in 1900, and Lehmann in 1902 both experimented in this field (Godden, 1920). At the end of the last century, Kellner treated straw with alkali under high temperature and pressure and then filtered, washed, dried and ground the residue. He reported that the lignin and the silica were "dissolved" and that the remaining "straw concentrate" consisted largely of pure cellulose with a "digestibility" of 96% and a fattening value equal to starch (Woodman, 1943).

During the First World War, German workers treated straw with NaOH, again under high temperature and pressure (Hansen, 1917) but the process was uneconomical. Later, also in Germany, Beckmann (1921) converted grain straw into a food of high feeding value by soaking it in alkali solution. In Britain, Archibald (1924) described how NaOH improved the feeding value of grain hulls and other fibrous material.

There was a revived interest in alkali-treatment of straw during World War Two when animal feedstuffs were scarce (Watson, 1941; Sen, Ray and Talapatra, 1942; Woodman, 1943), but although workers appreciated how digestibility could be improved by alkali treatment, the processes used were laborious and expensive. In recent years, many efforts have been made to improve the technique with the aim of simplifying the procedure and making the process an economical proposition (Wilson and Pigden, 1964; Donefer, Adeleye and Jones, 1969; Singh and Jackson, 1971; Carmona and Greenhalgh, 1972; Rexen, Stigsen and Friis Kristensen, 1976).

3.2.2 Mode of Action of Alkali on Straw

The action of alkali on plant cells is considered to be due to a combination of:

(a) a physical effect whereby swelling of the cellulose microfibrils effected by absorption of the alkali (Tarkow and Feist, 1969) results in a disorganisation of the crystalline cellulose structure. This leads to the formation of a more amorphous type of cellulose which is more readily hydrolysed by cellulase enzymes (Siu, 1951; Baker *et al*, 1959; Cowling and Brown, 1969.).

(b) a chemical effect involving the hydrolysis of the ester linkages between lignin and cellulose and hemicellulose (Tarkow and Feist, 1969) which results in the exposure of the carbohydrate to enzymic attack.

3.2.3 Variable of the Process

3.2.3.1 Rate of Application of Alkali

It is important to determine the optimum concentration of NaOH which will both increase intake and digestibility of the straw but leave the residual alkali in the final product at a level harmless to ruminants.

It has been estimated that for every 10 g NaOH applied to 100 g straw, only 3.4 g can be removed subsequently by washing; the remainder having presumably reacted with the forage (Chandra and Jackson, 1971).

Intake of TS organic matter declined in ruminants if the alkali application rate exceeded about 7 g NaOH/100 g straw DM (Raine and Owen, 1976). The relationship between rate of alkali application and *in vitro* digestibility is curvilinear obeying the Law of Diminishing Returns. Robb (1976) has shown the effect of increasing the concentration of alkali on the *in vitro* digestibility of barley straw. OMD continued to improve with increasing concentrations of NaOH although the rate of response declined more rapidly above 6 g NaOH/100 g straw DM. Others have demonstrated that the *in vitro* DMD of treated straw increases with concentration of NaOH up to 8 - 9 g/100 straw DM (Wilson and Pigden, 1964; Ololade and Mowat, 1969; Ololade, Mowat and Winch, 1970).

The determination of digestibility by *in vitro* methods however is liable to overestimate animal response to alkali-treated straw (Owen, Jayasuriya and Mwakatundu, 1973) and the full "potential digestibility" in TS as suggested by *in vitro* studies is rarely attained *in vivo* (Krause, Klopfenstein and Woods, 1968) and particularly unlikely if the TS is fed at high levels of intake (Maeng, Mowat and Bilanski, 1971). Thus, too much reliance on *in vitro* results may be misleading.

When chopped barley straw was fed *ad libitum* to mature sheep in supplemented diets, it was found that the *in vivo* OMD of the untreated straws were 0.47 and 0.51 but that these values were increased to 0.66 by treatment of the straw with 7 g NaOH/100 g straw DM with higher levels of alkali giving virtually no improvement (Raine and Owen, 1976).

Much work has been undertaken to find the level of alkali required for obtaining maximum digestibility (Singh and Jackson, 1971; Saxena *et al*, 1971; Carmona and Greenhalgh, 1972; Wilson, 1974; Jayasuriya and Owen, 1975). This data supports the conclusions of Jayasuriya and Owen (1975) that the digestibility of straw must be considered before deciding the level of alkali to use. However, the apparently wide differences of opinion in the literature concerning the optimal levels of alkali to use are largely due to the variations in conditions of application of the alkali.

When chopped straw was spray-treated with 0, 3.3, 6.7 or 10.0 g NaOH/100 g straw DM and the unneutralized product fed with supplements to cattle, the 3.3 g level increased DMI and OMD values significantly, but above the 3.3 g level, voluntary intake declined and digestibility was not improved (Singh and Jackson, 1971). Some studies in sheep have shown that there is little, if any, significant increase in straw energy digestibility with alkali concentrations greater than 4 g NaOH/100 g straw DM (Mowat and Ololade, 1970).

It seems probable that higher quantities of NaOH may influence rumen fermantation and thereby restrict intake and cellulose digestibility (Maeng, Mowat and Bilanski, 1971).

3.2.3.2 Method of Application of Alkali

There are two basic methods of application. The straw may be soaked in a large solution of alkali or the alkali may be sprayed on to the straw and mixed thoroughly.

Early work mainly involved soaking the straw for varying periods of time in large volumes of alkali solution. The only soak method of any practical use was the Beckmann Process which was introduced into Germany around

1920 and later adopted in Norway (Beckmann, 1921; Homb, 1948) where it has been in use throughout the past thirty years. In this process, straw is soaked in 1.5% w/v NaOH and subsequently washed free of residual alkali. In 1972, 70,000 tons of "Beckmann Straw" were produced in Norway but the production levels are now declining due to high labour demands, effluent disposal problems and storage difficulties (Rexen, Stigsen and Friis Kristensen, 1976).

An alternative process involves spraying the straw with a relatively small volume of a concentrated solution of alkali, the residue of which may be subsequently neutralized with organic acids (Wilson and Pigden, 1964; Donefer, Adeleye and Jones, 1969; Greenhalgh, Carmona and Mehmed, 1973). The spraying process is much less laborious than soaking but is chemically less efficient, probably due to difficulties of adequately mixing the alkali and straw (Carmona and Greenhalgh, 1972). Thus, efficient distribution of solution through the straw is an essential prerequisite for effective treatment. Distribution is influenced by the thoroughness of the mixing procedure, the ratio of solution to straw and the physical form of the straw. It has been reported that milling before treatment (to about 15 mm) appears to increase OMD more than chopping (to about 30 mm) although grinding (through a 3 mm sieve) gives a much smaller improvement (Palmer, 1976). Conversely, Johnson (1976) asserts that there is no evidence to suggest that milling improves the response in digestibility to the addition of NaOH although intake may be increased.

Obviously, more effective distribution is likely if straw is soaked in a large volume of alkali than if the chemical is sprayed over the straw and then mixed in. It is not surprising that OMD values are consistently higher using the soak process than when a spray method is used (Carmona and Greenhalgh, 1972). In a large number of experiments in Norway between 1940 and 1950, OMD increased on average from 0.42 in untreated straw to 0.67 in soaked straw (Homb, 1956). In Britain, increases in OMD using a soak method were recorded from 0.52 to 0.69 by Ferguson (1942) and similarly in India, Sen, Ray and Talapatra (1942) found alkali soak treatment increased OMD of straw from 0.51 to 0.72.

Using chopped, sprayed straw, however, Carmona and Greenhalgh (1972) reported an increase in OMD of 0.154 and Singh and Jackson (1971), also using a spray method, increased OMD by 0.15. These values are somewhat lower than results obtained with the soak process. However, in soak methods, the washing procedure is difficult and repeated washings remove soluble compounds with a resultant loss of digestible nutrients (Godden, 1920). Some 20% of the dry matter may be lost by this leaching effect (Rexen, Stigsen and Friis Kristensen, 1976).

A critical aspect of the research

has been to determine whether it is necessary to neutralize the treated straw after reaction with alkali. When chopped barley straw was treated with NaOH and allowed to react over 24 hours, then neutralized with HCl and fed with concentrates to wethers, it was found that maximum intakes occurred when 30% of the alkali was neutralized with acid before feeding (Owen, Jayasuriya and Mwakatundu, 1973). Intake was also increased when treated barley straw fed to cows with concentrates was neutralized to pH 7 (Rexen, Stigsen and Friis Kristensen, 1976). Other workers conclude that straw treated with NaOH does not need to be neutralized before feeding to sheep (Raine and Owen, 1976) and Robb (1976) reports that no added nutritional benefit is supplied to sheep fed treated straw neutralized with either propionic acid or urea phosphate.

The optimal length of time that should be allowed for the alkali to react with the straw before feeding appears to depend on the method of treatment. The reaction may be completed in as little as 15 minutes (Wilson and Pigden, 1964) and Stigsen (1974) reporting on a "dry" commercial process in Denmark asserts that the increased temperature and pressure applied results in the reaction taking place during "those few seconds that the straw is in the pelleting machine". However, there are many processes and many different opinions as to optimal reaction time. Until the position is clarified, it would seem advisable for maximum digestibility to allow at least twelve hours between treatment and feeding although for some "on farm" processes, a minimum interval of 72 hours has been recommended (Taylor et al, 1977).

3.2.3.3 Temperature and Pressure during Application

When temperature and pressure were raised to 170C and 50 atm during treatment, OMD was increased from 0.53 to 0.6 using 3 g NaOH/100 g straw DM and from 0.62 to 0.73 using 6 g NaOH/100 g straw DM (Rexen, Stigsen and Friis Kristensen, 1976). But although elevated temperature and pressure accelerate the reaction time (Stigsen, 1974) and may increase food value, this can be achieved by using a higher rate of alkali application.

3.2.3.4 Choice of Alkali

Other chemicals besides NaOH can be used to improve the digestibility of roughages. NaOH can be replaced by KOH on an equimolar basis for the treatment of corn cobs for example (Rounds et al, 1976) and calcium hydroxide may also have potential as a partial replacement for NaOH as it is cheaper and would supply supplemental calcium ions.

Injection of ammonia into a sealed sack of straw has shown promising results (Tarkow and Feist, 1969; Waiss et al, 1972) and ammonia has the advantage that it contains no ash and raises the crude protein content of the TS (Johnson, 1976). The chief drawback to the use of the weaker alkalis to treat straw is that they tend to take months rather than minutes to react.

3.3 ALKALI TREATED STRAW AS A FOODSTUFF FOR RUMINANTS

3.3.1 Effect on Animals

Since alkali treatment of forages increases digestibility and rate of digestion, it would be expected that intake would also be increased providing that the diet is adequately supplemented with nitrogen to maintain a healthy population of rumen microflora.

Treated straw is generally considered palatable and is usually readily consumed by ruminants. Sheep are reported to have consumed TS faster than when fed a control diet of alfalfa silage (Maeng, Mowat and Bilanski, 1971). When mixtures of silage and either US or TS were fed to sheep and calves, the intake of the TS/silage mixture was greater than that of the US/silage mixture. When fed to pregnant ewes, the intake of the TS/silage mixture was double the intake of the US/silage mixture. This was probably due to the presence of acids in the silage serving to complement the alkalinity of the TS producing a neutral feed that was nutritionally complete (Young and Terry, 1976).

There is no evidence of ill-effects in sheep fed treated straw, and cattle which were fed diets containing 50% of the diet DM as alkali treated straw showed no abnormality in acid-base balance (Johnson, 1976).

It has been suggested that high levels of NaOH may adversely affect rumen physiology (Carmona and Greenhalgh, 1972; Ololade and Mowat, 1975) but little information seems to be available on this. Sheep can tolerate a diet pH as high as 12 without detrimental effect on intake or signs of ill-health although a moderate degree of alkalosis may occur (Greenhalgh, Carmona and Mehmed, 1973). The reasons for such a tolerance to high alkali levels are probably:

(a) most of the free alkali in the diet is converted to HCO_3^- and $CO_3^=$ by atmospheric CO_2

(b) the large reserves of acidity in the rumen exert a strong neutralizing effect.

It is not surprising that straw treated with NaOH has a high Na content. High sodium intake stimulates high water intake and compensatory increases in urine production (Bhattacharya and Warner, 1968; Donefer, Adeleye and Jones, 1969; Maeng, Mowat and Bilanski, 1971) and animals fed TS as the main ingredient in a ration excrete more urinary Na than control animals (Maeng, Mowat and Bilanski, 1971). Singh and Jackson (1971) however found that water consumption in calves was not significantly increased by alkali treatment of the straw fed to them.

It is reported that high levels of Na intake decreased OM and energy digestibility in wethers but did not affect the digestibility of the components of rations fed to steers (Nelson *et al*, 1955).

TS prepared by spray methods will obviously have higher sodium levels than processes which involve repeated washing of the straw after treatment. Na levels in TS may be as high as 55 g/kg DM (Carmona and Greenhalgh, 1972) compared with values for Na levels in average hay, average silage and straw of 1.8, 3.7 and 1.1 g/kg DM (ESCA, 1975).

Such high Na levels for TS are at a level similar to that of salt-accumulating plants such as *Atriplex* species (Wilson, 1966). Sheep have survived for ten weeks on an artificial diet simulating *Atriplex* and containing 15% NaCl (Squires and Wilson, 1971). These sheep consumed 70 g feed/kg $W^{.75}$/day and drank up to 10 kg water/kg feed consumed. Na intakes were approximately 6 g/kg $W^{.75}$/day which is higher than intakes of sheep fed on TS (Carmona and Greenhalgh, 1972).

3.3.2 Production Levels

Since alkali treatment of straw increases digestibility, it is expected that production will be comparatively increased. However, when young bulls were fed various diets based on US or straw treated with 5% NaOH, it was found that the weight gain was lower in the group fed TS than in the group on US, but the difference was not statistically significant (Rexen, Stigsen and Friis Kristensen, 1976).

However, Saxena <u>et al</u> (1971) compared liveweight gains in lambs fed on diets based on straw or alkali-treated straw. Cereals were included in each diet as were Nitrogen supplements as either crude protein (soyabean meal) or non-protein nitrogen (NPN). It was shown that alkali-treatment increased liveweight gain from 61.5 to 177.1 g/day in lambs fed soyabean meal and from 53.1 to 125 g/day in those fed a supplement of NPN.

Young and Terry (1976) found no significant effect on liveweight gain when feeding TS or US with silage to wethers and calves, but ewes fed the TS/silage diet gained an average of 8.3% in liveweight over the last 9 weeks of pregnancy while those fes US/silage only gained an average of 3.7%.

It is further reported that lambs fed on TS or US supplemented with protein, minerals and vitamins and molasses gave with TS an average liveweight gain of 0.14 kg/day, while the lambs offered an US ration lost weight (Javed and Donefer, 1970).

Dairy cattle are reported to give higher yields when fed TS diets plus a supplement compared with others fed US (Taylor *et al*, 1977; Wilson, 1977). But when diets based on straw and straw treated with 5% NaOH were fed to milking cows, it was found that there was no significant difference in milk yield or composition between either diet (Rexen, Stigsen and Friis Kistensen, 1976).

3.3.3 Feeding Alkali-Treated Straw to Goats.

There appears to be little information in the literature concerning the feeding of alkali-treated straw to goats. But, Saxena *et al* (1970) reported that soaking milled oat straw in a 1.5% NaOH solution increased DMD in goats from 0.42 to 0.6, 0.39 to 0.58 and 0.39 to 0.55 when supplemented with soyabean meal, urea and diammonium phosphate respectively.

Unpublished data cited by Robb (1976) shows the effect of feeding NaOH-treated straw neutralized with propionic acid to goats. OMD was raised from 0.42 to 0.59, apparent crude fibre digestibility from 0.44 to 0.65 and energy digestibility from 0.41 to 0.56.

Gihad (1976) conducted a digestibility and metabolism trial comparing the performance of sheep and goats fed tropical natural grass hay. The goats consumed significantly more DM then sheep and had a greater ability to digest Crude Fibre, but they were similar to sheep in their ability to digest other nutrients. This generally confirms the work of others that the digestibility of various feeds by goats is similar to that of other ruminants (Schneider, 1947; Piatkowski, 1958; Butterworth, 1967; Devendra, 1967b)and that the goat is more efficient at fibre digestion (Hossain, 1960; Pant, Rowat and Roy, 1962; Jang and Majumdar, 1962).

When alkali-treated aspen wood was fed to goats, the digestibility of the wood was higher when fed in a roughage ration rather than with concentrates (Mellenberger et al, 1971). This may be due to the general finding that the digestibility of energy in alkali-treated roughages is increased when it is fed in combination with an untreated roughage which reduces the amount of alkali fed (Maeng, Mowat and Bilanski, 1971).

3.3.4 Commercial and Economic Considerations.

A detailed consideration of these aspects is beyond the scope of this review. It is obvious, however, that if a valuable feedstuff can be produced economically from material which is at present largely wasted, the commercial and economic considerations will be considerable.

Much work has been done in exploring commercial potential (Robb, 1976; Rexen, Stigsen and Friis Kristensen, 1976; Wilson and Brigstocke, 1977). Several purpose-built machines are currently available for alkali treatment of straw offering the producer large outputs and safety of operation. The TS thus produced is mainly incorporated into compound feeds. However, the machines are expensive (Minister, 1977) and are at present only suitable for use by feed producers, contractors or large-scale units. Taylor et al (1977) have costed out the use of treated straw in Britain and have concluded that, at the present time, it is uneconomic to use TS as the sole bulk feed unless processing costs can be reduced. The economics of the commercial processes are dependent on the availability and cost of the straw and transport costs from Farm to Factory (Young and Terry, 1976).

3.3.5 Relevance in the Tropics

The biggest opportunity for exploiting alkali-treated straw may lie overseas in developing parts of the tropics where ruminants must be fed without competing with man for available food resources.

Some useful work has already been done in India (Sen, Ray and Talapatra, 1942; Singh and Jackson, 1971; Chandra and Jackson, 1971) and a graphically illustrated method for producing alkali-treated straw by a labour-intensive soak method has been prepared for Indian farmers (Kehar, 1953).

3.4 CONCLUSION

Cereal straws are generally available world-wide and in many areas represent a large untapped energy source. NaOH is relatively cheap. Often labour is in an embarrassing surplus in developing countries. Thus it is felt that the production and feeding of alkali treated straw may have a valuable contribution to make.

4. MATERIALS AND METHODS

4.1 ANIMALS

To study the effects of chemical treatment of barley straw with the alkali sodium hydroxide (NaOH) on digestibility in sheep and goats, two successive digestibility trials were conducted during the summer of 1977.

In Trial I, six male, castrated Suffolk x Half-bred sheep (wethers) were used weighing an average of 42.8 kg and approximately 14 - 15 months of age.

In Trial II, three male, castrated Saanen-cross and three male, castrated Toggenburg-cross goats were used. The goats weighed an average of 25.5 kg and were approximately 4 - 5 months of age.

4.2 METABOLISM CAGES

The animals were each secured in an individual, elevated metabolism crate, fitted with a harness for the collection of faeces and a funnel system for urine collection. The harnesses were based on those described by McDonald (1958).

4.3 DIETS

The diets consisted of straw or alkali-treated straw supplemented with soyabean meal and a mix of minerals and vitamins. The straw to be fed was prepared during the week immediately preceding each trial in the following way:

(a) Untreated Straw (US): previous season's barley straw was chopped into approximately 8 cm lengths using a Morcambe Electric 4 h.p. MCL 1 machine and was stored in plastic bags. The straw was of clean appearance and was not excessively dusty.

(b) Alkali-treated Straw (TS): barley straw from the same batch as (a) was similarly chopped and spread thinly on the floor in 25 kg batches. The straw was then sprayed with a solution of sodium hydroxide (NaOH) from a garden watering-can fitted with a rose sprinkler. Approved safety clothing and face protection was worn throughout. As the solution was applied, the straw was mixed thoroughly by repeated turning with a fork over a period of thirty minutes per batch. The TS was stored in sealed plastic bags for 48 hours at ambient temperature and pressure before being offered to the experimental animals.

Preliminary *in vitro* trials indicated that the optimum rate of NaOH application was 5 - 6 g per 100 g straw applied in at least 500 litres of solution per tonne of straw (Lewis, 1977).

The alkali solution was made up by dissolving 5 kg of commercial caustic soda flakes in water to make 60 litres of solution containing 83 g/litre of NaOH. The aim was to apply 5 g NaOH to each 100 g straw fresh weight, or 5.81 g NaOH to each 100 g straw dry matter. Thus, 15 litres of solution were applied to each 25 kg batch of straw to give the required level of application.

The straw was supplemented by the daily addition of 150 g of extracted, decorticated soyabean meal (SBM), and 9 g of copper-free mineral mix. This mix supplied 1.8 g calcium, 1.35 g phosphous, 0.675 g sodium chloride, 0.45 g magnesium, 1.35 mg cobalt, 39.6 mg manganese, 10.8 mg zinc, 0.36 mg iodine, 0.036 mg selenium and 3960 i.u. Vitamin A, 396 i.u. Vitamin D_3 and 3.96 i.u. Vitamin E /day. A copper-free mix was selected owing to the scant difference between adequate and toxic levels of this mineral in sheep.

Fresh, clean drinking water was provided at all times.

4.4 EXPERIMENTAL DESIGN

In each trial, animals were randomly allocated on the basis of liveweight to the two experimental groups.

After a preliminary ten-day adaptation period, the animals were weighed individually in their harnesses.

A two-day lag was then allowed to clear the tract of residues prior to recording. After this lag, measurements continued in accordance with the regime outlined in APPENDIX I.

4.5 EXPERIMENTAL PROCEDURES

Both US and TS were fed *ad libitum* to the animals in amounts exceeding the previous day's intake. The feed was added to the trough twice daily at 0830 and 1600 and every attempt was made to follow a daily routine throughout the trial as advocated by McDonald, Edwards and Greenhalgh (1966).

The SBM was fed in two lots of 75 g to each animal before the morning and the evening feed and the animals were allowed to consume all of the SBM before straw was added to the trough.

The troughs were cleared every morning and the residues collected, placed evenly on trays in a Unitherm hot air oven at 100C for 24 hours after which time the DM weights were recorded.

The copper-free mineral/vitamin mix was sprinkled over each animal's morning supply of forage.

Water intake was recorded daily.

Faeces were collected daily in accordance with APPENDIX I, bulked and stored individually at -18C until the conclusion of the experiment. Faeces were then weighed, macerated and sampled for chemical analysis.

Samples of TS and US were taken daily during the experimental feeding period, bulked and at the end of the experiment the composite was thoroughly mixed and sampled for chemical analysis. Both US and TS and SBM samples were dried in the hot air oven for 24 hours to obtain DM weights and the samples were then milled for analysis.

The urine was collected daily and stored in large polythene bottles. 100 ml of 25% w/v (5-N) sulphuric acid was added daily as preservative. The total urine production for each animal was measured and mean values calculated for daily output. At the conclusion of the experiment, the urine was thoroughly mixed and sampled for analysis.

Pressure of available space only permitted an 8-day trial to be conducted with the sheep whereas a full 10-day trial was possible with the goats as shown in APPENDIX I.

4.6 CHEMICAL ANALYSIS OF SAMPLES

The US, TS, SBM and faeces samples were analysed for content of Nitrogen, Ash, Gross Energy and Crude Fibre by the following laboratory techniques:

(a) Nitrogen: by the method of Crooke and Simpson (1971). Nitrogen estimation was carried out using "fresh" faeces to prevent losses in hot air drying of volatile N as ammonia and amides etc.

(b) Ash: as described in HMSO (1973).

(c) Gross Energy: using a Gallenkamp adiabatic bomb calorimeter.

(d) Crude Fibre: by the method using trichloroacetic acid ("TCA-Fibre Method") as described by Whitehouse, Zarow and Shay (1945).

The urine Gross Energy was determined using a freeze drying process (Nijkamp, 1965) modified by Crooks (1977).

4.7 STATISTICAL ANALYSIS

Standard statistical procedures using Student's t-test for paired samples were used to analyse the significance of the results (Bailey, 1972). Using a Monroe 1265 Programmable Calculator and standard tables (Fisher and Yates, 1963) probabilities were determined. A result was considered statistically significant at $P < 0.05$.

5. RESULTS

5.1 GENERAL

The animals in both experiments remained in good health throughout and ruminated normally. Transient diarrhoea was noticed in two sheep (S5 and S6) and one goat (G4) on treated straw diets. One goat (G3) fed on untreated straw remained somewhat "blown" during the trial but did not appear to be suffering any discomfort.

There was either no liveweight change or small increases in liveweight shown by sheep and goats on both dietary regimes (APPENDIX II). However, the increases were slight and the length of the trials too short to attach any significance to these findings.

5.2 ANALYSIS OF FEEDSTUFFS

The diets were analysed for chemical composition (TABLE 1)

The soyabean meal (SBM) used in both trials was similar in composition but there was slightly more fibre in the sample fed in Trial II (75.6 g/kg DM compared with 62.4 g/kg DM).

TABLE 1.

Chemical composition of untreated straw (US), alkali-treated straw (TS) and soyabean meal (SBM) fed to sheep and goats in TRIALS I and II.

	DRY MATTER (DM) g/kg	Analysis of Dry Matter g/kg				GROSS ENERGY (GE) MJ/kg DM
		ASH	ORGANIC MATTER (OM)	NITROGEN (N)	TCA-FIBRE* (TCA-F)	
(1) TRIAL I						
US	858.0	52.8	947.2	5.21	432.0	18.49
TS	539.0	139.5	860.5	6.54	386.0	17.12
SBM	855.0	67.0	933.0	78.02	62.4	19.92
(2) TRIAL II						
US	838.1	61.7	938.3	6.07	402.0	18.63
TS	525.3	129.5	870.5	5.47	381.0	17.14
SBM	888.6	66.2	933.8	75.50	75.6	19.65

* Crude Fibre was determined by the trichloroacetic acid (TCA) method of Whitehouse, Zarow and Shaw (1945) and is designated TCA-F in all tables.

The untreated straw (US) came from the same batch for both trials and, as expected, variations were small, although the Crude Fibre (CF) value was 30 g/kg DM higher in the US sample fed in Trial I. There was more ash and less Organic Matter (OM) in the Dry Matter (DM) of the alkali-treated straw (TS) in Trial I compared with that of Trial II, but as these differences are only of the order of 10 g/kg DM they are not considered to be of much importance.

The DM content of straw following treatment in both trials was conducive with the volume of water added.

Ash content of TS was more than doubled compared with US with values of 52.8 and 61.7 rising to 139.5 and 129.5 g/kg DM in Trials I and II with corresponding falls in the OM in the DM.

Nitrogen (N) in the DM of the straw in Trial I was shown to have a higher value following treatment (6.54 compared with 5.21 g/kg DM) and a lower value following treatment in Trial II (5.47 compared with 6.07 g/kg DM). This anomaly is attributed to an error of sampling.

CF content of straw decreased following treatment in both trials, falling from 432 to 386 g/kg DM in Trial I and from 402 to 381 g/kg DM in Trial II.

5.3 EFFECT OF ALKALI TREATMENT OF STRAW ON FAECES COMPOSITION

The chemical composition of the faeces of the sheep and goats fed on US and TS in Trials I and II was determined and the results are presented as means in TABLE 2 and for individual animals in APPENDIX III.

DM was significantly lower ($P < 0.01$) in the faeces of sheep fed TS compared with faeces from sheep fed US. Although mean DM values were similar for the faeces of goats fed on both US and TS, wide variations were shown (272.5 - 428.1 g/kg) as may be seen in APPENDIX III. The DM in the faeces of the goats fed TS was significantly higher ($P < 0.05$) than that in the faeces of sheep fed on TS.

OM in the DM faeces was similar for all groups as was Gross Energy. However, ash in the faeces DM was significantly higher ($P < 0.01$) for sheep fed TS than for those fed US. The difference in ash content in the faeces of goats fed TS or US was not significant. There was significantly more ($P < 0.001$) N in the faeces DM of sheep, and more ($P < 0.05$) N in the faeces of goats fed TS compared with those fed US. The faeces from sheep fed TS showed a highly significant reduction ($P < 0.001$) in CF following treatment in Trial I and the CF content of goat faeces was significantly reduced ($P < 0.05$) following treatment in Trial II.

TABLE 2.

Chemical composition of the faeces excreted by sheep and goats fed on US and TS expressed as means.

	DM g/kg	Analysis of DM g/kg: ASH	DM	N*	TCA-F	GE MJ/kg DM
(1) TRIAL I						
Sheep fed US	308.5	103.2	896.8	15.02	311.6	18.92
**S.D. ±	6.49	4.85	4.85	0.157	3.05	0.223
Sheep fed TS	200.9	120.3	879.7	25.54	235.0	19.97
S.D. ±	22.05	3.45	3.45	0.516	14.00	0.131
(2) TRIAL II						
Goats fed US	340.2	98.8	901.2	17.45	320.0	19.35
S.D. ±	6.67	2.25	2.25	2.480	8.72	0.152
Goats fed TS	353.9	108.8	891.2	24.54	282.6	20.03
S.D. ±	78.05	6.20	6.20	2.015	14.57	0.191

* Laboratory determination of faecal nitrogen gave results in terms of "fresh" faeces. These figures were converted to DM for uniformity.

** In all tablesS.D. = Standard Deviation

5.4 EFFECT OF ALKALI TREATMENT OF STRAW ON DM CONSUMPTION

The mean daily food consumptions expressed in g DM/kg $W^{.75}$ were compared for sheep and goats fed on US and TS in Trials I and II and the results are shown in TABLE 3 expressed as mean values. Responses by individual animals are shown in APPENDIX IV.

In Trial I, significantly more ($P < 0.05$) TS than US was consumed by sheep, but in Trial II the consumption by goats of TS was not significantly higher than their consumption of US. There were wide standard deviations within all groups.

5.5 EFFECT OF ALKALI TREATMENT OF STRAW ON APPARENT DIGESTIBILITY

The Apparent Digestibility Coefficients (ADCs) of the various fractions of the US- and TS-based diets fed to sheep and goats in Trials I and II are presented as mean results in TABLE 4 and for individual animals in APPENDIX V. All values for digestibility considered below are apparent values since these are reported to be satisfactory for organic constituents of foods (McDonald, Edwards and Greenhalgh, 1966).

TABLE 3.

Effect of alkali treatment of straw on mean daily dry matter consumption by sheep and goats in TRIALS I and II expressed as mean values.

	MEAN DAILY FOOD CONSUMPTION g DM/kg $W^{.75}$
(1) TRIAL I	
Sheep fed US	53.53 ± 1.133
Sheep fed TS	66.97 ± 6.025
(2) TRIAL II	
Goats fed US	56.59 ± 10.724
Goats fed TS	59.82 ± 6.949

TABLE 4.

Mean Apparent Digestibility Coefficients of the various fractions of the US- and TS-based diets fed to sheep and goats in TRIALS I and II.

	Mean Apparent Digestibility Coefficients				
	DM	OM	GE	N	TCA-F
(1) TRIAL I					
Sheep fed US	0.53	0.55	0.53	0.55	0.61
S.D. ±	0.015	0.015	0.015	0.012	0.015
Sheep fed TS	0.65	0.65	0.60	0.38	0.77
S.D. ±	0.025	0.031	0.026	0.056	0.025
(2) TRIAL II					
Goats fed US	0.53	0.54	0.52	0.61	0.54
S.D. ±	0.015	0.012	0.015	0.026	0.010
Goats fed TS	0.66	0.66	0.62	0.58	0.70
S.D. ±	0.042	0.046	0.046	0.075	0.042

In both trials, Dry Matter Digestibility (DMD) and Organic Matter Digestibility (OMD) were significantly increased ($P < 0.05$) following alkali-treatment of the straw and by similar amounts for sheep and goats. Energy digestibility of the diet was significantly increased ($P < 0.05$) in sheep and goats following treatment of the straw. The ADC of the N fraction of the diet fed to sheep in Trial I was significantly decreased ($P < 0.01$) following treatment of the straw with alkali, but the decline following treatment in Trial II was not significant.

CF digestibility of the diet increased following straw treatment in both trials. This increase was very significant ($P < 0.01$) in both trials. Sheep had a significantly higher ($P < 0.01$) CF digestibility than goats when the US-based diet was fed but there was no appreciable difference in CF digestibility between the species when the TS-based diet was fed.

5.6 EFFECT OF ALKALI TREATMENT OF STRAW ON WATER INTAKE AND URINE EXCRETION

Water consumption and urine excretion by sheep and goats on US- and TS- based diets were compared in both trials. Mean values are given in Table 5 and individual responses by animals in Appendix VI. The sodium (Na) contents of US and TS were also compared (TABLE 6A). By assuming that SBM has a Na content of 3.4 g/kg DM (McDonald,

TABLE 5.

Average water consumption and urine excretion per kg $W^{.75}$ of sheep and goats fed on US- and TS-based diets in TRIALS I and II expressed as means.

	AVERAGE DAILY WATER CONSUMPTION g/kg $W^{.75}$	AVERAGE DAILY URINE EXCRETION g/kg $W^{.75}$
(1) TRIAL I		
Sheep fed US	152	51
S.D. ±	13	9
Sheep fed TS	443	304
S.D. ±	34	17
(2) TRIAL II		
Goats fed US	146	51
S.D. ±	20	6.7
Goats fed TS	263	178*
S.D. ±	5	34*

* This result is low and the S.D. high owing to one goat adopting a persistent habit of urinating when lying down which led to a malfunction of the collection funnel and spillage of urine.

TABLE 6.

Sodium (Na) content of US and TS in TRIALS I and II and calculated approximate total mean daily Na intakes/kg $W^{.75}$ for sheep and goats fed US- and TS-based diets in each trial.

A. Na analysis:

	TRIAL I	TRIAL II
	g/kg DM	g/kg DM
US	0.3	0.6
TS	34.0	31.2

B. Total mean daily Na intakes/kg $W^{.75}$ *

(1) Sheep on US: 0.078 g/kg $W^{.75}$

(2) Sheep on TS: 2.069 g/kg $W^{.75}$

(3) Goats on US: 0.083 g/kg $W^{.75}$

(4) Goats on TS: 1.551 g/kg $W^{.75}$

* allowing for a Na content of 3.4 g/kg DM in extracted SBM and assuming that the mineral mix supplement provided daily 0.675 g NaCl per animal.

Edwards and Greenhalgh, 1966) and by calculating the intake of Na consumed in the mineral mix from the mix analysis provided, the total mean daily Na intake per kg $W^{.75}$ was estimated for sheep and goats (TABLE 6B).

One goat, G6, adopted the habit of urinating when lying down which resulted in the urine collection funnel overflowing with partial loss of urine and explains the unexpectedly low urine output for this animal.

Intake of water was significantly increased in those animals with high Na intakes. The increases were highly significant ($P < 0.001$) in both sheep and goats when fed TS instead of US. However, goats on the TS diet drank significantly less ($P < 0.01$) water/kg $W^{.75}$ than the sheep on TS diets and excreted correspondingly less urine.

5.7 EFFECT OF ALKALI TREATMENT OF STRAW ON DIGESTIBLE ENERGY (DE) AND METABOLIZABLE ENERGY (ME) OF THE DIETS AND ON THE ORGANIC MATTER DIGESTIBILITY AND METABOLIZABLE ENERGY OF THE STRAW AND ALKALI TREATED STRAW

Calculated values for DE and ME of the diets fed in Trials I and II and the derived values of the OMD and ME calculated for US and TS in both trials were compared (TABLES 7 and 8; APPENDICES VII and VIII). The results were obtained using the equations shown in APPENDIX IX.

The results of these calculations show that the increase in DE of the diet just failed to reach significance following alkali treatment of the straw in both trials. The ME of the diet was significantly increased ($P < 0.05$) in both experiments.

TABLE 7.

Digestible Energy (DE) and Metabolizable Energy (ME) (MJ/kg DM) of the US- and TS-based diets fed to sheep and goats in TRIALS I and II. Results expressed as means.

			DE MJ/kg DM	ME MJ/kg DM
(1)	TRIAL I			
	Sheep fed US		9.80	7.92
	S.D.	±	0.260	0.298
	Sheep fed TS		10.52	8.84
	S.D.	±	0.488	0.456
(2)	TRIAL II			
	Goats fed US		9.70	7.71
	S.D.	±	0.293	0.186
	Goats fed TS		10.94	9.39
	T.S.	±	0.868	0.931

Treatment significantly increased ($P < 0.05$) both OMD and ME values of the straw in both trials. ME and OMD of US were higher ($P < 0.05$) in the sheep trial than in the goat trial but values for TS were similar in both experiments.

TABLE 8.

Derived Organic Matter Digestibility (OMD) and Metabolizable Energy (ME) of the US and TS fed to sheep and goats in TRIALS I and II expressed as means.

		OMD	ME MJ/kg DM
(1)	TRIAL I		
	Sheep fed US	0.51	7.19
	S.D. ±	0.021	0.344
	Sheep fed TS	0.62	8.41
	S.D. ±	0.035	0.484
(2)	TRIAL II		
	Goats fed US	0.46	6.38
	S.D. ±	0.025	0.381
	Goats fed TS	0.61	8.70
	S.D. ±	0.051	1.030

6. DISCUSSION

6.1 GENERAL

The aim of the two experiments was to assess the effect of chemically treating chopped barley straw with NaOH on digestibility in sheep and goats. Interspecies comparisons should be treated with caution, however, since two separate trials were involved and, although attempts were made to minimise variables, differences between the experiments did arise which may have influenced results.

6.2 EFFECT OF ALKALI TREATMENT ON STRAW COMPOSITION

The effects of alkali treatment on the composition of the straw are in general agreement with those reported by Carmona and Greenhalgh (1972). The action of the NaOH raised ash content of the straw DM thus reducing OM in the DM. The Gross Energy in the DM of TS was reduced after treatment due to the diluting effect of the non-combustible NaOH. There was also a marked fall in CF content following treatment as the alkali exerted its effect on the plant cells.

6.3 EFFECT OF ALKALI TREATMENT OF STRAW ON COMPOSITION OF FAECES

The presence of significantly less DM in the faeces of sheep fed TS was also reported by Maeng, Mowat and

Bilanski (1971). This may have been an osmotic effect promoted by high levels of residual sodium ions in the digestive tract. Although no faecal Na levels were measured, it is noteworthy that the sheep had significantly more ash in the faeces DM when fed TS. Alternatively, it is also possible that the presence of the residual alkali in the diet consumed may have induced a mild irritation and inflammation of the intestinal mucosae of the sheep which would have resulted in an increased rate of caudal flow and a reduction in fluid absorption from the tract (Blood and Henderson, 1968). On the other hand, goats did not have significantly more ash in their faeces following treatment of the straw and mean faecal DM values were similar for goats on both diets.

6.4 EFFECT OF ALKALI TREATMENT OF STRAW ON DRY MATTER INTAKE (DMI)

Sheep consumed more DM of the TS than of the US. This confirms the general view that treatment raises palatability and intake (Singh and Jackson, 1971; Saxena *et al*, 1971; Javed and Donefer, 1970; Jayasuriya and Owen, 1975). The increase in DMI by sheep on TS was of the same order as that found for lambs by Saxena *et al* (1971), for sheep by Carmona and Greenhalgh (1972) and for cattle by Singh and Jackson (1971).

Although the increase in DMI per kg $W^{.75}$ failed to reach significance when goats were offered TS instead of US, there was considerable variation between animals and no reliable conclusions can be drawn from this finding.

6.5 EFFECT OF ALKALI TREATMENT OF STRAW ON APPARENT DIGESTIBILITY

6.5.1 Crude Fibre Digestibility (CFD)

CFD was significantly increased in both species following alakli-treatment of the straw. This result was anticipated since alkali treatment was expected to break the association of cellulose and hemicellulose with lignin thus rendering more fibre available for digestion. The results were in accord with the work of Maeng, Mowat and Bilanski (1971), Ololade and Mowat (1975) and Rexen, Stigsen and Friis Kristensen (1976) in sheep and with the work of Robb (1976) in goats.

However, it was surprising that CFD was lower in goats than sheep when both US and TS was fed. Goats are reported to be more efficient at CF digestion (Hossain, 1960; Pant, Rawat and Roy, 1962; Jang and Majumdar, 1962; Gihad, 1976) and it was expected that goats would show higher digestibility coefficients for fibre than sheep. The lower efficiency may be explained in part by the younger ages and less mature rumens of the goats (5 months compared with 15 month old sheep) and also by the relatively short (10 days) adaptation period allowed for the rumen microflora in the goats to readapt from a lush pasture diet to one of straw with concentrates. The sheep had been fed by a hay-based diet prior to the start of their experiment.

6.5.2. Organic Matter Digestibility (OMD)

OMD values were measured for the diets and derived for the straws.

Following alkali treatment of the straw, OMD of the diets was significantly raised from 0.55 to 0.65 in sheep and from 0.54 to 0.66 in goats. This generally confirms the results *in vivo* of Singh and Jackson (1971), Klopfenstein *et al* (1972), Jayasuriya and Owen (1975) and Rexen and Vestergaard Thomsen (1976).

Increases in OMD are generally greater if the straw is soaked in alkali rather than if it is treated by a spray method. Carmona and Greenhalgh (1972) found OMD improved by 0.14 when US was spray treated with alkali and by 0.26 when the straw was soaked. This confirms the findings in the present experiments where OMD increases of 0.10 - 0.15 are considerably less than the improvements of 0.15 - 0.25 reported by workers using processes based on the original Beckmann system (Sen, Ray and Talapatra, 1942; Ferguson, 1943; Homb, 1956). The differences are not surprising in view of the much larger amounts of NaOH used in the soak methods and the fact that most systems which soak the straw in alkali also thoroughly wash out alkali residues. In spray processes, the lignin which has been rendered soluble by the alkali is not removed by washing and thus depresses the digestibility of the dietary OM (Singh and Jackson, 1971).

Klopfenstein *et al* (1972) found that the *in vivo* OMD of corn stalks fed to lambs increased by 0.11 after treatment with 5% NaOH but by 0.21 compared to untreated stalks when fed in combination with ground alfalfa stems. This would imply that the NaOH was exerting a depressing effect on OMD which was reduced by diluting the effect of the alkali. Since Macleod, Wilkins and Raymond (1970) have shown that high acidity also limits intake, it would seem a logical step to mix alkali-treated straw with foods such as acidic silage with the aim of obtaining a neutral feedstuff. This has been done by Young and Terry (1976) who reported that they obtained a nutritionally complete food adequate for maintenance and moderate liveweight gain in sheep.

The derived straw OMD was calculated in the current experiments and found to be significantly higher following treatment of the straw with NaOH in both trials. This agreed with the findings of Raine and Owen (1976) in sheep and those of Robb (1976) for goats.

The OMD of US was found to be significantly higher for sheep than goats. This may be due to the same reasons cited for variations in CFD but Krause, Klopfenstein and Woods (1968) have emphasised that there is high animal variability in the digestion of alkali-treated forages.

6.5.3. Digestibility of Gross Energy

The digestibility of the diet OM is higher than the digestibility of diet energy in both sheep and goats fed TS and US, but the difference was more marked when the TS diets were fed. This was also found by Carmona and Greenhalgh (1972), but when they calculated their digestibility coefficients, they excluded from the calculations the SBM supplement by assuming that it would be completely digested.

The variation between diet OM and energy digestibilities is probably due to the presence in the faeces of indigestible lignin which has a high energy content (Pigden and Heaney, 1969). TS diets increased DMI which resulted in a corresponding increase in lignin and elevated faecal energy values.

In the current trials, diet energy digestibility was raised by 0.10 in goat and by 0.07 in sheep. These values are less than the 0.17 increase reported by Carmona and Greenhalgh (1972) when they fed chopped and sprayed straw with SBM, minerals and vitamins to sheep.

6.5.4 Nitrogen Digestibility

The decrease in N digestibility in Trial I was expected since, for the same intake of SBM, more metabolic faecal nitrogen would be produced when TS was fed due to increased DMI and excretion. DMI of goats was not significantly increased when TS was offered and there was no significant fall in N digestibility in Trial II.

6.6 EFFECT OF ALKALI TREATMENT OF STRAW ON WATER METABOLISM

Water metabolism results obtained in Trial II must be considered with a certain amount of caution in view of the losses of urine from the collection apparatus of one goat fed on TS.

Water intake was highly significantly increased in both sheep and goats fed TS-based diets which was in accordance with the work of Maeng, Mowat and Bilanski (1971), Bhattacharya and Warner (1968) and Donefer, Adeleye and Jones (1969) although Singh and Jackson (1971) found that the water consumption of calves fed on sprayed TS did not increase. It is probable that the raised water intakes by animals fed on TS are directly due to the increased Na intakes and to some extent increased DM intakes (Robb, 1976).

In the current experiments it was found that goats fed on TS drank significantly less water than sheep fed TS. This was expected since mean Na intake in g/kg $W^{.75}$/day was less for goats fed TS than for sheep fed TS (1.551 compared with 2.069 g Na/kg $W^{.75}$/day) and since the ratio of water intake (g/kg $W^{.75}$/day) to Na intake (g/kg $W^{.75}$/day) for sheep fed TS was considerably higher than the ratio for goats fed TS (214.1 compared with 169.6).

Na levels of the TS fed in the current experiments (34 g/kg DM in Trial I and 31.2 g/kg DM in Trial II) were considerably lower than the level of Na in the DM of the chopped and sprayed straw fed to sheep by Carmona and Greenhalgh (1972) at 55.0 g/kg DM.

It is interesting to note that the relationship between DMI and water intake suggested for goats by Mackenzie (1967) and Devendra (1967a) of 4-5 : 1 is met in the current experiments but only by goats fed on TS-based diet (mean results produced a ratio of 4.5 : 1 when measured in terms of intake/kg $W^{.75}$) whereas the goats on US have a ratio as high as 2.6 : 1. However, water intake depends on many other variables besides Na intake, including the physical nature of the food, physiological condition, ambient temperature and whether the animals are penned or roaming (Devendra and Burns, 1970). Ambient temperatures were high during the sheep trial which may have raised the water consumption of these animals. With the exception of the work of Shkolnic et al (1975) who demonstrated the exceptional water storage capabilities of the black bedouin goat, there seems to be little positive evidence that the goat is more efficient than sheep at water conservation.

6.7 EFFECT OF ALKALI TREATMENT OF STRAW ON DIGESTIBLE AND METABOLIZABLE ENERGY CONTENTS OF DIETS AND STRAW

The Metabolizable Energy (ME) content of the diet was significantly increased following alkali treatment of the straw in both trials. The low values for the ME derived for US reflect the poor digestibility of the energy of US, but, following treatment with alkali, the derived ME values for TS approach those given for hay (MAFF, 1975).

The failure of the improvement in Digestible Energy (DE) to reach significance in either trial following alkali treatment is surprising and may be explained by an increased production of methane energy following raised DMI and digestibility values after treatment of the straw.

ME values for forages may also be calculated from given DE values by the formula, ME = 0.81 x DE (MAFF, 1975). Taking the mean results for dietary DE given in TABLE 7 for sheep fed US and TS and using the above equation, values for dietary ME content are obtained which compare well with the results calculated using the formulae in APPENDIX IX (7.94 and 8.52 compared with 7.92 and 8.84 MJ/kg DM respectively). If the same procedure is carried out for the goats wider variations are found (7.86 and 8.86 compared with 7.71 and 9.39 MJ/kg DM) but S.D.s of the means are also larger.

6.8 USE OF ALKALI TREATED STRAW FOR MAINTENANCE AND PRODUCTION IN SHEEP AND GOATS.

TS, if adequately supplemented with nitrogen, minerals and vitamins would appear to have potential as a supplier of ME requirements of sheep and goats for maintenance and even for limited production. Using the formulae published by MAFF (1975) for the prediction of liveweight gain (LWG) of growing sheep reared indoors and taking mean values for liveweight and ME intake and an assumed value for ME content of SBM (12.3 MJ/kg DM), it was found that predicted LWG was negligible for sheep and goats when fed US diets. However, it was predicted that a 45 kg sheep on TS would have a daily LWG of approximately 65 g and a 25 kg goat a daily LWG of 50 g. These results assume, in the absence of alternatives, that the formulae presented for growing sheep reared indoors apply to 15 month old sheep and 5 month old goats.

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9. APPENDICES

INDEX TO APPENDICES

APPENDIX I.

LAYOUT OF TRIALS.

Days	1	2	3	4	5	6	7	8	9	10	11	12	13
	TS_1[a]	TS_2	TS_3	TS_4	TS_5	TS_6	TS_7	TS_8*	TS_9	TS_{10}	-	-	-
	-	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8*	R_9	R_{10}	-	-
	-	-	PREP[b]	FU_1	FU_2	FU_3	FU_4	FU_5	FU_6	FU_7	FU_8*	FU_9[c]	FU_{10}

* Pressure of space only allowed an 8-day trial with sheep. The full 10 day trial was conducted with goats. In both trials a 10-day preliminary adaptation period was allowed.

Notes:

a Animals weighed in harness and weight recorded

b Clean faecal collection bags fitted. Urine collection bottle weighed empty.

c Animals weighed in harness and weight recorded. Urine bottle plus urine weighed.

Abbreviations:

TS - Straw or treated straw fed. Subscript indicates days fed.

R - Weight of food residues recorded (fresh and DM)

FU - Faeces collected and stored. 100 ml acid preservative added to urine bottle.

PREP - Preparation day preceeding collection of faeces and urine.

APPENDIX II.

(A) Changes in liveweight of individual sheep during TRIAL I, plus means (kgs).

TRIAL I (8-days)

		INITIAL WEIGHT	FINAL WEIGHT	CHANGE IN WEIGHT
(1) Sheep fed US				
	S1	43.0	44.0	+ 1.0
	S2	40.5	40.0	- 0.5
	S3	46.0	46.0	0
	MEANS	43.17	43.33	+ 0.5
	*S.D. ±	2.753	3.050	
(2) Sheep fed TS				
	S4	42.8	43.0	+ 0.2
	S5	45.0	45.2	+ 0.2
	S6	49.8	50.0	+ 0.2
	MEANS	45.87	46.07	+ 0.2
	S.D. ±	3.580	3.579	

* In all appendices, S.D. = Standard Deviation of the mean.

Notes:

In all appendices US = untreated chopped barley straw

TS = alkali-treated chopped barley straw.

S1-6 = sheep numbers 1 - 6

G1-6 = goat numbers 1 - 6

APPENDIX II continued

(b) Changes in liveweight of individual goats during TRIAL II, plus means. (kgs).

TRIAL II (10 days)

		INITIAL WEIGHT	FINAL WEIGHT	CHANGE IN WEIGHT
(1) Goats fed US				
	G1	26.1	28.0	+ 1.9
	G2	22.0	23.0	+ 1.0
	G3	25.5	27.0	+ 1.5
	MEANS	24.53	26.00	+ 1.47
	S.D. ±	2.210	2.646	
(2) Goats fed TS				
	G4	32.5	33.5	+ 1.0
	G5	22.0	23.5	+ 1.5
	G6	23.0	23.0	0
	MEANS	25.83	26.67	+ 0.83
	S.D. ±	5.795	5.923	

APPENDIX III.

(A) Chemical composition of the faeces excreted by individual sheep fed on US or TS in TRIAL I, plus means.

TRIAL I			Analysis of DM (g/kg)				
		DM g/kg	ASH	OM	*N	**TCA-F	GE MJ/kg DM
(1) Sheep fed US							
	S1	315.5	100.7	899.3	14.90	315.0	19.09
	S2	302.7	108.9	891.1	15.20	309.0	19.01
	S3	307.2	100.0	900.0	14.97	311.0	18.67
	MEANS	308.5	103.2	896.8	15.02	311.6	18.92
	S.D. ±	6.49	4.85	4.85	0.157	3.05	0.223
(2) Sheep fed TS							
	S4	224.9	123.8	876.2	25.79	229.0	20.09
	S5	196.4	116.9	883.1	24.95	251.0	19.83
	S6	181.5	120.2	879.8	25.89	225.0	19.99
	MEANS	200.9	120.3	879.7	25.54	235.0	19.97
	S.D. ±	22.05	3.45	3.45	0.516	14.00	0.131

Notes:

* In all appendices, laboratory determination of faecal N gave results in terms of "fresh" faeces. These figures have been converted to DM for uniformity.

** In all appendices, TCA-F refers to the trichloroacetic acid method of determining Crude Fibre content.

APPENDIX III continued.

(B) Chemical composition of the faeces excreted by individual goats fed on US or TS in TRIAL II, plus means.

TRIAL II			Analysis of DM (g/kg)				
		DM g/kg	ASH	OM	N	TCA-F	GE MJ/kg DM
(1) Goats fed US							
	G1	338.5	96.5	903.5	15.07	326.0	19.22
	G2	334.6	101.0	899.0	20.02	310.0	19.33
	G3	347.6	99.0	901.0	17.26	324.0	19.52
	MEANS	340.2	98.8	901.2	17.45	320.0	19.35
	S.D. ±	6.67	2.25	2.25	2.480	8.72	0.152
(2) Goats fed TS							
	G4	272.5	109.1	891.9	23.49	289.0	19.81
	G5	361.1	102.5	897.5	23.26	293.0	20.13
	G6	428.1	114.9	885.1	26.86	266.0	20.15
	MEANS	353.9	108.8	891.2	24.54	282.6	20.03
	S.D. ±	78.05	6.20	6.20	2.015	14.57	0.191

APPENDIX IV.

(A) Effect of alkali treatment of straw on mean daily dry matter consumption by individual sheep in TRIAL I, plus means.

TRIAL I		MEAN DAILY FOOD CONSUMPTION	
		g DM	g DM/kg $W^{.75}$
(1) Sheep fed US			
	S1	890.8	53.0
	S2	879.8	54.8
	S3	930.8	52.7
	MEANS		53.53
	S.D. ±		1.133
(2) Sheep fed TS			
	S4	1121.3	67.0
	S5	1267.4	72.9
	S6	1142.2	60.9
	MEAN		66.97
	S.D. ±		6.025

APPENDIX IV continued.

(B) Effect of alkali treatment of straw on mean daily dry matter consumption by individual goats in TRIAL II, plus means.

TRIAL II		MEAN DAILY FOOD CONSUMPTION	
		g DM	g DM/kg $W^{.75}$
(1) Goats fed US			
	G1	766.3	66.3
	G2	458.2	45.1
	G3	661.7	58.3
	MEAN		56.59
	S.D. ±		10.724
(2) Goats fed TS			
	G4	788.1	57.9
	G5	685.0	67.4
	G6	567.1	54.0
	MEAN		59.82
	S.D. ±		6.949

APPENDIX V

(A) Apparent Digestibility Coefficients of the various fractions of the US- and TS-based diets fed to individual sheep in TRIAL I, plus means

		DM	OM	GE	N	TCA-F
(1) Sheep Fed US						
	S1	0.52	0.54	0.51	0.54	0.60
	S2	0.55	0.57	0.54	0.56	0.62
	S3	0.53	0.55	0.53	0.54	0.61
	MEANS	0.53	0.55	0.53	0.55	0.61
	S.D. ±	0.015	0.015	0.015	0.012	0.015
(2) Sheep Fed TS						
	S4	0.68	0.68	0.63	0.44	0.79
	S5	0.63	0.62	0.58	0.33	0.74
	S6	0.65	0.64	0.59	0.37	0.77
	MEANS	0.65	0.65	0.60	0.38	0.77
	S.D. ±	0.025	0.031	0.026	0.056	0.025

APPENDIX V continued

(B) Apparent Digestibility Coefficients of the various fractions of the US- and TS-based diets fed to individual goats in TRIAL II, plus means.

		DM	OM	GE	N	TCA-F
(1) Goats Fed US						
	G1	0.51	0.53	0.50	0.59	0.54
	G2	0.53	0.55	0.53	0.64	0.53
	G3	0.54	0.55	0.52	0.60	0.55
	MEANS	0.53	0.54	0.52	0.61	0.54
	S.D. ±	0.015	0.012	0.015	0.026	0.010
(2) Goats Fed TS						
	G4	0.63	0.62	0.58	0.50	0.67
	G5	0.65	0.65	0.61	0.58	0.69
	G6	0.71	0.71	0.67	0.65	0.75
	MEANS	0.66	0.66	0.62	0.58	0.70
	S.D. ±	0.042	0.046	0.046	0.075	0.042

APPENDIX VI

(A) Average Water consumption and urine excretion by individual sheep fed on US and TS in TRIAL I, plus means.

	AVERAGE DAILY WATER CONSUMPTION (g)		AVERAGE DAILY URINE EXCRETION (g)	
	per sheep	per kg $W^{.75}$	per sheep	per kg $W^{.75}$
(1) Sheep Fed US				
S1	2310	137	810	48
S2	2560	159	700	44
S3	2810	159	1100	62
MEANS		152		51
S.D. ±		13		9
(2) Sheep Fed TS				
S4	6930	414	5320	318
S5	7560	435	4960	285
S6	9000	480	5820	310
MEANS		443		304
S.D. ±		34		17

APPENDIX VI Continued

(B) Average water consumption and urine excretion by individual goats fed on US and TS in TRIAL II, plus means.

	AVERAGE DAILY WATER CONSUMPTION (g) per goat	AVERAGE DAILY WATER CONSUMPTION (g) per kg $W^{.75}$	AVERAGE DAILY URINE EXCRETION (g) per goat	AVERAGE DAILY URINE EXCRETION (g) per kg $W^{.75}$
(1) Goats fed US				
G1	1950	169	545	47
G2	1350	133	600	59
G3	1530	135	540	48
MEANS		146		51
S.D. ±		20		6.7
(2) Goats fed TS				
G4	3620	266	2400	176
G5	2700	266	2150	212
G6	2700	257	1520*	145*
MEANS		263		178*
S.D. ±		5		34

Note:

* This result is low due to the goat G6 adopting a persistent habit of urinating when lying down which led to malfunction of the collection funnel and spillage of urine.

APPENDIX VII

(A) Digestible Energy (DE) and Metabolizable Energy (ME) (MJ/kg DM) of the US and TS diets fed to individual sheep in TRIAL I, plus means

		DE MJ/kg DM	ME MJ/kg DM
(1) Sheep fed US			
	S1	9.54	7.60
	S2	10.06	8.19
	S3	9.81	7.97
	MEANS	9.80	7.92
	S.D.	± 0.260	0.298
(2) Sheep fed TS			
	S4	11.05	9.35
	S5	10.09	8.48
	S6	10.42	8.68
	MEANS	10.52	8.48
	S.D.	± 0.488	0.456

APPENDIX VII Continued

(B) DE and ME (MJ/kg DM) of the US and TS diets fed to individual goats in TRIAL II, plus means.

		DE MJ/kg DM	ME MJ/kg DM
(1) Goats fed US			
G1		9.38	7.50
G2		9.95	7.80
G3		9.78	7.84
MEANS		9.70	7.71
S.D.	±	0.293	0.186
(2) Goats fed TS			
G4		10.23	8.65
G5		10.69	9.10
G6		11.91	10.44
MEANS		10.94	9.39
S.D.	±	0.868	0.931

APPENDIX VIII

(A) Derived Organic Matter Digestibility (OMD) and Metabolizable Energy (ME) of US and TS fed to individual sheep in TRIAL I, plus means:

		OMD	ME MJ/kg DM
(1) Sheep fed US			
	S1	0.49	6.81
	S2	0.53	7.48
	S3	0.50	7.28
	MEANS	0.51	7.19
	S.D. ±	0.021	0.344
2) Sheep fed TS			
	S4	0.66	8.96
	S5	0.59	8.05
	S6	0.62	8.22
	MEANS	0.62	8.41
	S.D. ±	0.035	0.484

APPENDIX VIII Continued

(B) Derived OMD and ME of US and TS fed to individual goats in TRIAL II, plus means

		OMD	ME MJ/kg DM
(a) Goats fed US			
	G1	0.46	6.49
	G2	0.43	5.96
	G3	0.48	6.70
	MEANS	0.46	6.38
	S.D. ±	0.025	0.381
(2) Goats fed TS			
	G4	0.57	7.90
	G5	0.60	8.33
	G6	0.67	9.86
	MEANS	0.61	8.70
	S.D. ±	0.051	1.030

APPENDIX IX

Calculation of Digestible Energy (DE) and Metabolizable Energy (ME) of the US- and TS-based diets and the OMD and ME of the US and the TS, by derivation.

(a) DE was calculated by reference to the equation given by MAFF (1975) page 3:

$$DE = \frac{GE_{food} - GE_{faeces}}{DMI} \quad MJ/kg\ DM$$

(b) ME was then calculated from the definition given by McDonald, Edwards and Greenhalgh (1966):

$$ME = \frac{GE_{food} - (\text{Faecal E} + \text{Urinary E} + \text{Methane E})}{DMI} \quad MJ/kg\ DM$$

(c) Methane (CH_4) Energy losses were estimated from the equation derived by Blaxter and Clapperton (1965) where CH_4 energy loss (kJ gas/100 kJ GE of food eaten) = (3.67 + 0.062D) where D is the % ADC of GE. The result thus found was then related as a percentage of the GE of the food eaten.

(d) The ME value of extracted SBM was taken from standard tables (MAFF, 1975) as 12.3 MJ/kg DM.

(e) The ME of the US and TS could then be derived:

$$(ME_{diet} \times DMI_{diet}) = (ME_{SBM} \times DMI_{SBM}) + (ME_{straw} \times DMI_{straw})$$

where all factors are known except ME_{straw} which can then be calculated.

(d) Similarly, the OMD of the US and TS is calculated assuming from standard tables (MAFF, 1975) that the OMD of SBM is 0.835:

$$(OMD_{diet} \times OMI_{diet}) = (OMD_{SBM} \times OMI_{SBM}) + (OMD_{straw} \times OMI_{straw})$$