ALKALI TREATMENT OF ROUGHAGES
AND
ENERGY UTILIZATION OF TREATED ROUGHAGES FED TO SHEEP AND GOATS

NDELILIO A. URIO

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DECLARATION

I, NDELILIO ATHANAS URIO, DO HEREBY DECLARE TO THE SENATE OF THE UNIVERSITY OF DAR ES SALAAM, THAT THIS THESIS HAS NOT BEEN SUBMITTED FOR A DEGREE IN ANY OTHER UNIVERSITY

SIGNED ......Urio N.A..........................

DATE ......7th October, 1981..................

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TABLE OF CONTENTS

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LIST OF TABLES

page

page

****

LIST OF FIGURES

GLOSSARY OF ABBREVIATIONS AND SYMBOLS

ADF	acid detergent fibre
A.O.A.C.	Association of Official Agricultural Chemists
CF	crude fibre
CP	crude protein
d	day(s)
DE	digestible energy
DM	dry matter
EE	ether extract
ESOM	enzyme soluble organic matter
g	gramme(s)
GE	gross energy
IVDMD	*in vitro* dry matter digestibility
IVOMD	*in vitro* organic matter digestibility
kg	kilogramme(s)
l	litre(s)
ME	metabolizable energy
MJ	mega joule(s)
NDF	neutral detergent fibre
NFE	nitrogen free extract
NPN	non-protein nitrogen
OM	organic matter
$W^{0.75}$	liveweight in kilogramme to the power 0.75 (metabolic body weight)

Statistical abbreviations and symbols

NS	not significant
($P < 0.05$) *	significant at the 5% level of probability
($P < 0.01$)**	significant at the 1% level of probability
LSD	least significant difference

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SUMMARY

Two series of experiments were conducted; laboratory scale experiments, and production experiments. The laboratory scale experiments were carried out to develop simple methods of alkali-treatment, and to test the effectiveness of cheap alternative chemicals to sodium hydroxide. Production experiments were conducted to test the effectiveness of an apparently promising "dip" treatment method developed in the laboratory scale experiments.

The effectiveness of Na_2CO_3 and $Ca(OH)_2$ as roughage treating chemicals were tested in combination with NaOH in a 3 x 3 factorial experiment. The levels of the chemicals tested were 0, 3 and 6 g/100 g of roughage (DM). Wheat straw was used as a test roughage. Neither of the chemicals resulted in any improvement in the digestibility of the straw although $Ca(OH)_2$ showed a slight effect in increasing the enzyme soluble organic matter of wheat straw. Both chemicals showed a somewhat negative interaction with NaOH.

Maize stover and *Hyparrhenia* grass were also treated with increasing levels of Na_2CO_3 from 0 to 10 g/100 g of roughage DM. Maize stover did not show any response to Na_2CO_3 treatment except for its enzyme soluble organic matter which increased with increasing levels of Na_2CO_3. The enzyme soluble organic matter for the untreated maize stover was 29%, while that for maize stover treated with 10 g Na_2CO_3/ 100 g of roughage DM was 43.6%. *Hyparrhenia* grass responded comparatively better to Na_2CO_3 treatment than maize stover. Addition of herring meal to the roughages resulted in a

marked improvement in the digestibility of both roughages. This also improved the response of the roughages to Na_2CO_3 treatment. Maize stover showed a higher response to the addition of herring meal than *Hyparrhenia* grass.

The chemical composition of 4 samples of local Magadi soda was determined. All the samples had high sodium chloride contents, indicating a possibility of Magadi soda having a positive effect on voluntary feed intake. It was noted that some samples had rather high fluorine contents.

Studies were conducted on the effectiveness of a simple "dip" method which involved dipping straw in a 1.5% NaOH solution overnight, letting it drip, washing with minimum water, and letting it drip again. The lye solution was reused 15 times, the strength of the solution being restored after each treatment. The DM and Na content of the lye solution increased with increasing reuse of the solution. The DM content of the solution increased from 1.9% to 7.2%, while the Na content increased from 0.7 to 1.4%. Both the DM and Na contents of the solution tended to stabilize after the solution had been reused more than 10 times. The IVOMD and ESOM of the treated straw increased with increasing reuse of the solution. The *in vivo* DM and OM digestibility as well as DE of the straw was improved markedly by the dip method. The digestibility of OM of the untreated straw was 50% as opposed to 73% for the dip treated straw. The digestibility of DM and OM *in vivo* was not affected by the reuse of the solution although that of CF tended to decrease slightly after the solution had been reused more than 10 times.

In the production experiments a comparative slaughter technique was applied with sheep and goats. Three groups of goats were fed rations based on untreated maize cobs, "dip" treated maize cobs (NaOH-treatment), and *Chloris gayana* hay. The experimental feeding period was 100 days. The DM intake from these rations was the same in the three groups, but the dip NaOH treatment of maize cobs resulted in a higher DM digestibility (64.1% as opposed to 55.6%) higher metabolizable energy intake (4.19 MJ as opposed to 3.40 MJ/d) when compared to the group fed untreated maize cobs. The group fed dip treated maize cobs also had significant higher gains in liveweight, carcass weight, carcass fat, and carcass gross energy content. This group, however, did not differ significantly from the group fed *Chloris gayana* hay in these parameters. It was also observed that, the group fed dip treated maize cobs had a tendency to lay down intestinal fat.

Three groups of sheep were also fed on untreated maize stover, dip treated maize stover and ensiled (NaOH-treated) *Hyparrhenia* grass silage for 100 days. The level of concentrate in the DM intake was about 20%. Although dip treatment of maize stover increased its digestibility, this did not result in significant differences in performance between the group fed untreated maize stover in all the parameters studied. The groups fed maize stover (untreated or treated) had however significantly better performance in all parameters measured than the group fed NaOH-treated *Hyparrhenia* silage.

Correlations were determined between whole carcass fat % and carcass weight, and between carcass fat % and carcass specific gravity.

In goats, the correlation coefficient for carcass fat % on carcass weight was 0.84, while that between carcass fat % and carcass specific gravity was -0.97. These parameters (carcass weight, and carcass specific gravity) can therefore probably be used to estimate carcass fat % and consequently carcass energy content in goats.

The correlation coefficient between carcass fat% and carcass weight in sheep was only 0.52, while that between carcass fat % and carcass specific gravity was -0.79. In addition to these comparatively low relationships in sheep, it was noted that carcass specific gravity was rather sensitive and difficult to measure in fat carcasses, and liable to technical errors. It is thought that these relationships cannot therefore be applied universally to the heterogeneous sheep of East Africa.

INTRODUCTION

I. INTRODUCTION

Feed shortages in the dry season is one of the major constraints limiting increased livestock production in many tropical countries. Lack of feed conservation methods, overgrazing, and generally poor management are some of the factors responsbile for this state of affairs. Incidentally, various types of crop residues become available at the beginning of the dry season after the grain has been harvested. It has often been pointed out that, if properly utilized, these crops residues have an appreciable potential as a livestock feed. In East Africa, it is a common practice for livestock to be turned into crop fields to graze the stubbles of various cereal crops such as millet, maize, and sorghum. Increasing pressure on grazing land as well as the need to combat feed shortages during the dry season, has aroused tremendous interest on the utilization of these crop residues in recent years. Early research works in East Africa (French,1943, Rogerson, 1956) pointed out the potential of various local cereal straws as livestock feeds. Unfortunately, no serious attempts were made to develop methods of utilizing these feeds efficiently. In Europe, feed shortages after the second world war led to an increased use of cereal straws as animal feeds. Various methods were devised and developed to ensure efficient utilization of these straws as well as to improve their nutritive value. Major research works were carried out on both physical and chemical means of improving the nutritive value of straws.

The most successful methods were the chemical methods which involved treatment of straw with one form of alkali or another. Sodium hydroxide has been the most successful and the main chemical used for treatment of straw. According to Homb et al. (1976), Norway was the first country to use appreciable amounts of alkali-treated straw as a livestock feed. The traditional Beckmann method which was used extensively in Norway, has been discontinued mainly due to pollution hazards as well as for the fact that the method was extremely laborious.

The works by Lampila (1963) and Wilson and Pigden (1964) and the consequent development of the dry methods in Denmark and other countries has been a catalyst for the recent increased interest on the use of alkali treated roughages in several countries.

In Tanzania, as pointed out earlier, cereal crop residues are used to some varying degrees for feeding livestock during the dry season. In a few areas, a local salt known as "Magadi" is sprinkled on these residues before feeding. The main effect of "Magadi" is thought to be on improving the voluntary feed intake. This practice is particularly common with stall feeding of sheep and goats around Kilimanjaro and Arusha. In many of these places it is common to select a few goats and sheep and especially fatten them indoors. In East Africa, "ndafu", "sitima" and "olkinie" raised by the Wachagga, Wameru and Waarusha of Tanzania respectively, and the "thenges", the stall fed castrated goats raised by the Wakikuyu in Kenya, are examples of these specially fattened animals. These animals are prodigous yielders of carcass fat. In these communities usually the more fat an animal puts on, the higher the value of its carcass. Goat meat particularly, is also becoming quite a delicacy in urban communities in Tanzania. In almost all the areas where sheep and goats are raised, there is no standard feed used for feeding these animals. Feeds used include crop residues, such as maize stover, grass and leguminous weeds usually collected from the fields and roadsides.

This study was therefore carried with two main objectives:

1. To develop a simple method of alkali treatment of crop residues and other low quality roughages which could to some extent be easily adapted to local conditions
2. To study the utilization of such treated roughages in fattening sheep and goats

The experiments in this study were divided into two main parts, PART I and PART II. Part I series of experiments were mainly laboratory scale experiments conducted at the Agricultural University of Norway, Aas-NLH. The main objective of the experiments in Part I was to formulate and study the effectiveness of some of the methods which might suit small scale treatment of straw. Some of the chemicals that might be suitable for such treatments were also studied. Part II series were production experiments. Fattening experiments were conducted with sheep and goats with the objective of studying the utilization of roughages treated as to the one of the methods formulated in the laboratory scale experiments. A comparative slaughter procedure similar to the one applied by Garrett et al. (1959) and that by Lofgreen (1965), was used in estimating the energy ratained in the carcasses of the animals. The energy ratained in the dressed carcasses of the animals at the end of the experimental feeding period was determined by calculating the difference in the dressed carcass gross energy content between the initial slaughter group and the experimental animals. The production experiments were conducted at the faculty of Agriculture, Forestry and Veterinary Science of the University of Dar es Salaam, Morogoro, Tanzania.

LITERATURE
REVIEW

II. LITERATURE REVIEW

A. Historical note

Recorded literature indicate that probably the first attempts to improve the nutritive value of low quality roughages by chemical means took place in Germany towards the end of the last century. Pioneer work by Lehmann (1895) (citated by Homb et al., 1976) showed a marked increase in digestibility obtained by treating straw with sodium hydroxide (NaOH) solution. An increase of about 37 to 63% in dry matter digestibility was obtained when oat straw was boiled in a 2% solution. In later experiments, Lehmann tried other methods of treating straw; he varied both the strength of the NaOH solution and in addition he boiled the straw under pressure at 5-6 atmospheres for about 6-8 hours; and obtained digestibility coefficients ranging from 54 to 71% as opposed to 31-42% for the untreated straw. In the review paper by Homb et al. (1976), several works are cited which were undertaken in Germany around 1920's. Most of these attempted to modify Lehmann's method. Some chemicals other than NaOH were also tried. These included sodium carbonate (Na_2CO_3), calcium hydroxide ($Ca(OH)_2$), hydrochloric acid (HCl), ammonia (NH_3) and chlorine (Cl).

All of these chemicals were less effective compared to NaOH.

The most remarkable pioneer work in chemical treatment of straw is probably that by Beckmann in Germany (Beckmann 1919). Homb *et al.* (1976) review some of this early work in Germany. In this method, straw was treated at room temperature for about 3 days in 1.5 to 2% NaOH solution. A series of experiments on this method led to a general recommendation of the use of a 1.5% NaOH solution and treatment time reduced to 12 to 24 hours. In this method straw was soaked in a solution about 10 times its weight, and the straw subsequently washed with enormous amounts of water after treating. The digestibility of organic matter of the straw was in this way increased by more than 20% units compared to the untreated straw. Apart from Germany, the Beckmann method was also tried on a small scale in Switzerland and U.K.; but the method was particularly used to an appreciable extent in Norway and other Scandinavian countries. The use of the Beckmann method was discontinued because among other reasons, the method was associated with pollution problems, it required an enormous amount of water for washing resulting in both a bulky product and loss of soluble nutrients. The method was a batch process and the product could not be stored for a long time. The process as a whole was also very laborious. Despite these disadvantages, the Beckmann method has been the basis and a reference method upon which several methods have been proposed and developed.

The experiments of Wilson and Pigden (1964) acted to some extent as a catalyst for a renewed interest in alakli treatment of low quality roughages. Studies have mainly been geared towards overcoming the disadvantages of the Beckmann method. Different ways of manipulating the factors which affect the effectiveness of alkali treatment of roughages have resulted in the development of several methods of straw treatment. The methods differ in cost of treatment, effectiveness, and consequently they differ in suitability for different situations. The suitability and hence selection of any of the methods to a given location, very much depends on the manipulation of the different factors influencing the effectiveness of the treatment. These factors can be listed as:

1. The type of chemical used
2. The concentration of the chemical used
3. Time of treatment, temperature and pressure
4. Moisture content of the roughage, and the amount of solution used
5. The type of the roughage treated
6. The method of the treatment applied

A brief review of these factors follows:

B. Factors influencing the effectiveness of alkali treatment of low quality roughages

1. The Type of Chemical used

The concept of using chemical treatment as a means of improving the digestibility of various low quality roughages, was based on the ability of various chemicals to delignify various ligno-cellulose materials. Chemicals used in the paper industry have been particularly tested for their ability to remove lignin and increase the digestibility of several roughages. Among the different chemicals which have been used, sodium hydroxide (NaOH) has been proved to be the most effective. The literature reviewed by Homb et al. (1976), and Jackson (1977) indicate that a wide range of roughages are more digestible after treatment with sodium hydroxide. The improvement, however, tends to vary with the type of method of treatment. Homb et al. (1976) cite various works carried out in Germany in the 1920's involving the use of various chemicals. These included sodium hydroxide sodium carbonate (Na_2CO_3), calcium hydroxide ($Ca(OH)_2$), hydrochloric acid (HCl), copper oxide (CuO), chlorine (cl), and ammonia (NH_3). Sodium hydroxide was found to be superior to all these chemicals. Chandra and Jackson (1971), studied the effectiveness of sodium hydroxide, sodium sulfite, sodium sulphide, sodium carbonate, equal parts of sodium hydroxide and sodium carbonate, hydrogen peroxide, and bleaching powder, in removing lignin and increasing the in vitro digestibility of ground maize cobs. All the chemcals reduced the lignin content of the roughage. The resulting increase in in vitro dry matter digestibility was proportional to the degree of lignin breakdown with the exception of the bleaching powder reagent. Sodium hydroxide stood out as the most effective chemical.

Anderson and Ralston (1973), treated rye grass straw with NaOH, potassium hydroxide (KOH), ammonium hydroxide (NH_4OH), and sodium formate ($NaCHO_2$). Both NaOH and KOH increased the in vitro dry matter digestibility of the rye straw; with no difference between the two chemicals. Although sodium formate also increased in vitro dry matter digestibility of the straw, higher treatment levels were necessary to achieve the same effect as NaOH. Ammonium hydroxide treatment produced variable results but the crude protein content of the treated straw was increased consistently.

A number of investigations have been carried out on treatment of low quality roughages with calcium hydroxide ($Ca(OH)_2$). It is advocated that because calcium hydroxide is cheaper and less dangerous to handle than sodium hydroxide, it would be more suitable for use on the farms. Inconsistent results have, however, been obtained from various investigations. Jackson (1977) refers to studies by Abou-Raya (1964), where $Ca(OH)_2$ was found to be less effective than NaOH in increasing the digestibility of maize and sorghum stovers. Sundstøl et al. (1979), found no effect when 4% solid $Ca(OH)_2$ was added to straw having a moisture content of up to 51%. It is important however to note that calcium hydroxide is only sparingly soluble and reacts much slower than sodium hydroxide; consequently the method of application and treatment time is rather of significant importance. Owen (1978), for instance, cites the work of Gonzalez Santillana (1977), where calcium hydroxide (50 g/kg DM) was found ineffective in improving the digestibility (in vitro) of barley straw OM (49.0%) after 1 day of treatment, but after 90 days ensilage (43% DM silage) digestibility was increased to 60.7%. Comparable treatment with sodium hydroxide gave a digestibility of 65.9%. Increasing the amount of alkali to 100 g/kg DM increased digestibility to 64.5% with calcium hydroxide and 75.7% with sodium hydroxide. Gharib et al. (1975), observed the same increase in digestibility of poplar bark when treated with either NaOH or $Ca(OH)_2$ after the treated material had been stored for 150 days. Waller and Klopfenstein (1975) conducted growth trials with lambs fed on rations based on corn cobs treated with different combinations of NaOH and $Ca(OH)_2$. They obtained the highest daily gain as well as the lowest feed/gain from rations based on corn cobs treated with 3% NaOH and 1% $Ca(OH)_2$ in the treatment as opposed to 100 g/day when NaOH was used alone. Kategile et al. (1981), reported that both NaOH and $Ca(OH)_2$ treatments increased the in vitro DM and OM digestibility of maize stover. However, combinations of NaOH, and $Ca(OH)_2$ gave no consistent effects. The digestibility in actual fact tended to decrease at higher rates of $Ca(CH)_2$. In addition to the inconsistence of results obtained with calcium hydroxide, it should be noted that use of calcium hydroxide at high rates would also increase the need to supplement the diets with phosphorus (Owen, 1978).

Specific interest has been shown in recent years on the use of ammonia (NH_3) for treating straw. Ammonia is said to have a number of notable advantages over sodium hydroxide especially under farm conditions. These include, a reduction in environmental pollution, ease of application, addition of NPN to treated roughage, effectiveness in preservation as fungal growth inhibitor, the possibility of using urea where ammonia is not available, and absence of undesirable residue in the treated material. The chemical, however, suffers the disadvantage that it is slow in reacting, and like sodium hydroxide it is corrosive and needs careful handling. Both anhydrous and aqueous ammonia have been used successfully in treating low quality roughages. Ammonia can also be released from urea and other sources if the enzyme urease is available. Sundstøl et al. (1978) point out the fact that most low quality roughages contain 0.5 and 1.0 per cent nitrogen (N) of which the apparent digestibility is very low. Ammonia treatment can generally increase the N content of these low quality roughages by 0.8 to 1.0 percent units which is equivalent to an increase of 5 to 6 percent units in crude protein content. Although in this way the N content of the roughages is roughly doubled by ammonia treatment, the effect of the ammonia treatment on the digestibility of nitrogen in these roughages is not quite clear. Considerable variation can be noted from a number of digestibility experiments. This is probably due to the lack of consistency in manipulating the factors which affect ammonia treatment such as treatment time, moisture, and temperature. Generally, under optimum conditions, an increase of 10 to 15 percent units in organic matter digestibility can be achieved (Sundstøl *et al.*, 1978). Compared to other chemicals such as methods involving a "dry" treatment with sodium hydroxide, or ensiling with mixtures of sodium hydroxide and calcium hydroxide ammonia treatment appear to give a similar or slightly lower improvement in feeding value.

The hazardous nature of sodium hydroxide and ammonia (especially anhydrous ammonia) has stimulated research into safer alternatives. This is especially true for developing countries. Sodium carbonate which occurs in impure forms as mineral deposits in many tropical areas, has in this respect received some considerable attention in recent years. In East Africa, a local compound called "Magadi" has been used for many years as a livestock mineral supplement during the dry season. A few grammes of "Magadi" are sprinkled on banana peelings, maize stover, etc., in order to improve the voluntary feed intake as well as to supply some minerals to the animals. "Magadi" occurs naturally in a number of trona lakes and swamps in East Africa, e.g. Lake "Magadi" in Kenya and Lake Natron in Tanzania. According to some analyses done on the Lake Magadi product in Kenya (Magadi Soda Co., 1976), "Magadi" is composed mainly of sodium sesquicarbonate ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) with varying traces of sodium flouride. The liquor from the tronas at Lake Magadi was found to have the chemical composition as shown in table 1.

Table 1. Chemical composition of Magdi soda liquor

Name of the compound	Percentage by weight
Sodium Carbonate (Na_2CO_3)	14 - 18%
Sodium Chloride	9 - 12%
Sodium Bicarbonate	0.3%
Sodium Flouride	0.3%

Source: Magadi Soda Co. 1976, unpublished report

Some preliminary studies have been carried out in East Africa, to study the effectiveness of this compound in improving the feeding value of local quality roughages. Interest has particularly been centered on studying the effect of sodium carbonate (Na_2CO_3) which seems to form an appreciable percentage of the "Magadi" Compound. Massae (1977) in Tanzania, fed rations containing 67% ground maize cobs to sheep. Na_2CO_3 treatment significantly increased dry matter and organic matter digestibility of the maize cobs based diets. Urio (1977) obtained similar results in digestibility (*in vivo*) when either NaOH or Na_2CO_3 was used for treating maize stover. However, the differences between the NaOH and Na_2CO_3 might have been masked by the high rate of concentrate supplementation (38%); as in the *in vitro* studies, and in *ad libitum* feeding of the roughage, NaOH was clearly found to be superior to Na_2CO_3. The low effect of Na_2CO_3 compared to NaOH, however, cannot justify the discredit of the use of "Magadi". From the composition of "Magadi" as shown in table 1, it would appear that in addition to the slight improvement in digestibility the compound would have an obvious effect in improving intake of roughages due to its high sodium chloride (NaCl) content.

2. The Concentration of the Chemical used

With most chemicals used in the treatment of roughages there seems to be a linear positive correlation with the increase in the level of the chemical used. In the original Beckmann method where straw was soaked and washed it was observed that the digestibility of organic matter *in vivo* increased with increasing amounts of NaOH up to 12 percent as shown in table 2.

Table 2. Digestion coefficients of organic matter in straw after treatment with increasing amounts of NaOH (Fingerling *et al.*, 1923, cited by Homb *et al.*, 1976)

Treatment	Digestion coefficient
Untreated straw	45.7
2 kg NaOH/100 kg straw	46.3
4 " " "	50.2
6 " " "	61.1
8 " " "	66.1
10 " " "	66.2
12 " " "	71.2

From the above observations, 12 kg NaOH/100 kg of straw was recommended as the optimum level of alkali in the Beckmann method. It must be noted, however, that in the Beckmann method, the excess alkali was washed out. In closed systems and "dry" methods, such a high level of alkali cannot be used because of both economic reasons as well as the possible harmful effects on the animals health.

Results of Wilson and Pigden (1964), Ololade *et al.*, (1970), Anderson and Ralston (1973), Rexen *et al.* (1976) *interalia*, show an approximately linear increase in *in vitro* digestibility with increasing amounts of alkali up to 8 to 10 kg/100 kg of straw (see fig. 1 below).

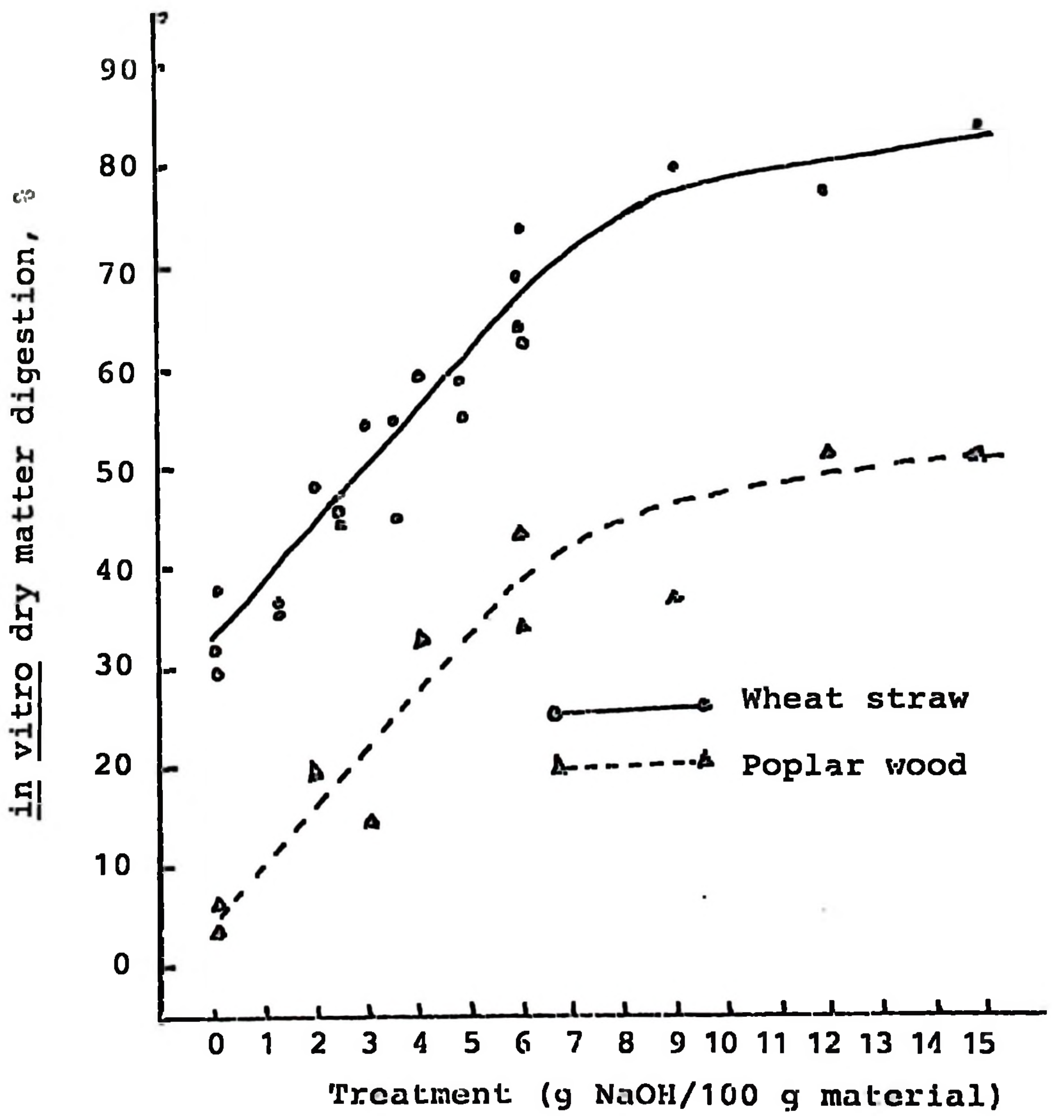

Figure 1. The effect of sodium hydroxide upon the percentage dry matter digestion *in vitro* with rumen microorganisms (Wilson and Pigden, 1964)

In an ensilage experiment, Wilkinson and Gonzalez Santillana (1978), reported the optimum level of alkali treatment of barley straw to be 7.5 g NaOH/100 g straw DM. This optimum level was also reported for maize cobs by Kategile and Frederiksen (1979).

Results from _in vivo_ digestibility studies have shown that the range in which the alkali level can be increased is much limited compared to the levels obtained in _in vitro_ studies. Thomsen _et al._ (1973) reported that in the dry methods, treatment with NaOH (at 4 to 6% of straw DM) resulted in digestibility of the same magnitude as that obtained when using the Beckmann method. At higher levels of NaOH application, _in vivo_ digestibility increased less than digestibility _in vitro_. More or less similar results are reported by Mowat and Ololade (1970), Singh and Jackson (1971), and Klopfenstein _et al._ (1972). According to Owen (1978), higher rates of sodium hydroxide tend to depress intake despite the marginal improvement in digestibility. Jayasuriya and Owen (1975) reported that the optimum amount of sodium hydroxide to maximize voluntary intake of treated straw was between 50 g and 70 g NaOH/kg DM. However, Jackson (1978) suggests that higher optimum levels of sodium hydroxide can be attained when treated straw is fed with large proportions of other ingredients, which have a diluting effect on high and presumably deleterious sodium content of treated straw. The limit on the use of higher rates of sodium hydroxide _in vivo_ seems to be related to some negative effects of the alkali on optimum conditions for microbial activity in the rumen. There also seems to be an adverse effect on increased rate of passage out of the rumen, due to an increased water consumption by animals consuming materials treated with high levels of sodium hydroxide. Berger et al. (1980) observed that the rate of rumen passage increased linearly when NaOH in the complete diets increased from 0 to 8% (DM basis). The increased rate of passage through the rumen was accompanied by a decreased rate of ruminal fiber digestion.

In the case of ammonia, the factors are so interrelated that it is difficult to discuss one in exclusive of the other. However, most experiments, according to Sundstøl et al. (1978), indicate that there is very little improvement in digestibility resulting from an increase of the ammonia level above 3-4 percent of dry matter. Waiss et al. (1972) using aqueous ammonia studied the effect of increasing amounts of ammonia, moisture, and treatment time on the enzyme solubility of cereal and grass straws. They concluded that the optimum level of ammonia was 3 percent. In Tanzania, Kiangi (1979) used three sources of ammonia for treating maize stover, wheat straw and rice straw. The in vitro dry matter and organic matter as well as the crude protein content of the roughages were increased markedly by increasing the level of ammonia from 0 to 2.5 g NH_3/100 g of roughage DM. Beyond this level, the increase in digestibility and crude protein content was only slight.

3. Time of Treatment, Temperature and Pressure

The factors of time, temperature and pressure are very much interrelated. Chemical reactions are very much affected by these factors and consequently it would be expected that chemical treatment of roughages will be influenced by these factors. In the review by Homb *et al.* (1976) it is pointed out that most of the early work in Germany involved boiling straw at different pressures and different times. Jackson (1978) refers to the work of Fingerling and Schmidt (1919) and that of Ferguson (1943) where studies were carried out to study the effect of varying the time of soaking on the digestibility of straw treated by the Beckmann method. As shown in table 3, the time of soaking greatly affected the organic matter digestibility.

Table 3. The effect of duration of soaking on the digestibility of Beckmann-treated straw (Fingerling and Schmidt 1919)

Duration of treatment		Organic matter digestibility %
Untreated straw		46
Treated straw:	1.5 hours	59
	3 "	63
	6 "	70
	12 "	71
	3 days	73

Source: Review by Jackson (1978)

In later experiments Ferguson found out that the soaking time of 20 hours which had been recommended from the results of Fingerling and Schmidt could be reduced to 7 hours without reducing the effectiveness of the treatment if treatment was carried out in summer instead of winter. The effect of environmental temperature was further studied by Ferguson, the clear effect of environmental temperature is seen in the results shown in table 4.

Table 4. The effect of environmental temperature on the digestibility of Beckmann-treated straw (Ferguson, 1943)

Temperature °C	Digestibility coefficients %	
	Crude fibre	NFE
0	69	50
7	73	49
30-40	74	56

Source: Review by Jackson (1978)

Ololade *et al.* (1970), studied the effect of temperature, duration of treatment and concentration of sodium hydroxide on the *in vitro* dry matter digestibility of barley straw. Their results as shown in table 5 indicated a marked influence on both the duration of treatment and temperature.

Table 5. Effect of temperature, duration of treatment and concentration of sodium hydroxide on *in vitro* dry matter digestibility of barley straw (Ololade *et al.*, 1970)

Temperature °C	Processing time	Sodium hydroxide concentration (% of dry matter) 0	2	4	6	8	12
	hours						
23	0	38	39	42	41	42	39
	24	38	44	54	63	48	68
	Minutes						
60	5	38	43	52	60	64	67
	15	36	45	54	62	67	68
	45	38	45	55	65	68	68
	90	38	45	56	65	68	68
80	5	36	45	56	66	73	73
	15	37	46	60	69	72	70
	45	37	49	63	70	73	76
	90	38	51	64	72	76	76
100	5	38	47	59	70	74	77
	15	37	46	60	70	74	75
	45	38	49	63	72	77	79
	90	38	51	65	73	78	80
130	5	37	48	63	74	78	80
	15	38	49	65	75	78	81
	45	40	51	66	74	79	82
	90	41	52	67	75	78	81

Although in the original Beckmann method, a long treatment time of more than 12 hours was recommended, recent results have shown that the beneficial effect of NaOH can be obtained within 30 minutes of treatment (Sundstøl 1981). However, under such circumstances, it is necessary to store the treated material for some time. This time has been referred to as time for "ripening" (Sundstøl, 1981). Sundstøl (1981) reports on some work done on different times of soaking and "ripening". As shown in table 6, the *in vitro* digestibility did not vary with time of soaking but was considerably higher after two days of ripening compared to 1 day of ripening.

Table 6. Amount of NaOH used, Na content, temperature, excess NaOH, and *in vitro* digestibility of straw soaked in a 1.5% NaOH solution for two or six hours (Sundstøl, 1981)

	Time of soaking, hrs		
	2	4	6
NaOH used g/kg straw DM	69	60	60
Na in the straw, g/100 g DM	2,47	2,89	2,51
Temperature of straw during ripening(°C)	12,1	14,2	14,1
Excess NaOH g/kg wet straw			
1 day of ripening	4,4	4,6	4,3
2 days " "	3,8	4,9	4,1
3 days " "	4,0	5,5	4,3
In vitro OM digestibility (untreated straw 35.8%)			
1 day of ripening	67.4	65.4	67.7
2 days " "	71.4	71.4	71.4
3 days " "	74.0	69.4	70.4

Although both boiling and application of pressure tend to increase the effectiveness of alkali treatment, under practical conditions these are seldom applied. The effect of high temperatures are, however, of some practical importance. As already pointed out and shown in table 4 chemical treatment at high ambient temperatures is very favourable.

Treatment of straw by the use of farm machines such as the Danish J.F. and Taarup, results in a considerable rise in temperature of the stacked material after treatment. This rise in temperature which results from chemical reactions between NaOH and straw facilitates treatment and at the same time ensures that the straw moisture content is reduced to a safe level for storage of the treated material.

In the case of treatment with ammonia as well as other slow reacting chemicals such as calcium hydroxide, the effect of temperature and treatment time is of some particular significance. Temperature and treatment time are particularly interrelated in ammoniation of straw. At low temperatures, the action of ammonia is very slow; and longer treatment times would be necessary for a similar effect at higher temperatures. Waagepetersen and Vestergaard Thomsen (1977) reported a positive effect of temperature up to 45°C with short treatment times of 3 to 7 days. Ammonia treatment under tropical conditions should therefore be expected to take shorter time. Kiangi (1979), in Tanzania, used three different sources of ammonia for treating maize stover, wheat straw, and rice straw. He observed that 15 days were adequate for effective treatment. As a general guide for treatment of straw with ammonia, Sundstøl et al. (1978) recommended the following treatment times for different ambient temperatures:

Temperature	Length of treatment time
Below 5°C	More than 8 weeks
5-15°C	4-8 weeks
15-30°C	1-4 weeks
Above 30°C	Less than 1 week

They however, pointed out that treatment time could probably be extended beyond the times shown above without any harmful effects.

4. Moisture content of the roughage and the amount of solution used

The improvement in digestibility of roughages through alkali treatment is thought to be brought about through:

a) Breakage of bonds between lignin and cellulose
b) Hydrolysis of hemicellulose to give a decrease in the content of neutral detergent fibre in the treated material, and
c) Swelling of cellulose fibres within the cell-wall matrix (Theander, 1981)

All these processes require water and therefore the level of moisture in the material to be treated or the amount of solution used is likely to have an influence on the effectiveness of the treatment. In the Beckmann method, large amounts of solution were used, and in fact the softness of the nodes of the treated straw was used as a simple hand test to determine the effectiveness of treatment. The importance of the amount of solution or moisture content of the roughage as such appears to be in ensuring an effective mixing of the alkali with the roughage. A minimum amount of water to ensure efficient soaking appears to be necessary, beyond which, large volumes of solutions have no effect. Jayasuriya and Owen (1975) observed that when very small amounts of solutions were used, the digestibility of straw decreased, but on the other hand very high volumes did not increase the digestibility of straw. Kategile and Frederiksen (1979) varied the amount of solution from 25 l to 200 l/100 kg DM. They also observed a slightly low digestibility at the low volumes of solution. In the "dry" method of straw treatment developed in Denmark, effective wetting can be achieved with as little as 15 l per 100 kg of straw (Rexen and Vestergaard Thomsen, 1976). Generally, in the treatment with NaOH, it appears that, it is the amount of solution used which is of importance, rather than the moisture content of straw. In the ammonia treatment on the other hand, the moisture content of the roughage has been shown to have a marked influence of the effectiveness of ammoniation. Waiss et al. (1972) reported an optimum moisture content of about 30% when rice straw was treated with 5 percent ammonia at ambient temperatures. Sundstøl et al. (1978) report on the effect of varying the moisture content of the roughage from 12.5 to 50 percent. It was observed that the in vitro organic matter digestibility increased with increasing moisture content. The level of moisture content in the roughage is particularly of importance when anhydrous ammonia is used. When very dry materials are treated, aqueous ammonia, for this reason becomes more efficient. Westgaard (1981) points out that with very dry materials in the tropics, it may be necessary to add water to the material prior to treatment. In Tanzania, Kiangi (1979) compared two levels of moisture content (20 and 40%) when treating maize stover, wheat straw and rice straw with three different sources of ammonia. He observed that the 20 percent moisture level was adequate for effective treatment. Too high moisture content is, however, undesirable as Sundstøl et al. (1978) point out that a high moisture content in the material may cause distribution problems when anhydrous ammonia is used for treatment.

5. The Type of Roughage treated

In the reviews by Jackson (1978) and Westgaard (1981), it is pointed out that differences exist in the digestibility and energy content of roughages both among and within species; and that these differences tend to persist even after alkali treatment. It is widely recognized that the extent of lignification in roughages is highly and negatively correlated to the digestibility of roughages. The studies by Mwakatundu and Owen (1974) showed a gradual reduction in digestibility as grasses matured due to the increase in the degree of lignification. They also observed that the late cut hay which had a low initial digestibility responded more to NaOH treatment than early cut hay. The difference existing between species in response to alkali treatment was also observed by Summers and Sherrod (1975) as shown in table 7.

Table 7. The effect of sodium hydroxide treatment on different species of roughages (Summers and Sherrod,1975)

Type of roughage	In vitro dry matter digestibility Control	NaOH-treated (5% at 50% moisture)
Peanut hulls	18.9	17.2
Cotton seed hulls	24.8	29.5
Corn cobs	48.4	54.9
Corn stover	60.9	71.1
Wheat straw	57.3	65.5
Prefrost sorghum stubble	56.9	65.2
Weathered sorghum stubble	55.0	63.7
Alfalfa	56.8	57.7
Forage sorghum hay	68.7	71.3
Alicia Bermuda grass	50.8	61.2

This difference between species of roughages in response to alkali treatment was also evident in the studies by Wilson and Pigden (1964) as shown in figure 1. El-Shazly (1981) points out that due to the high lignification in leguminous roughages, this class of roughages have a high response to alkali treatment compared to roughages of cereal origin. He refers to the work by Abou-Raya et al. (1963) where it was observed that the improvement in the nutritive value of leguminous roughages following an alkali treatment, was 73% while it was only 36% in roughage of cereal origin. Owen (1981), however points out that legumes are very irresponsive to treatment. This view is also supported by Sundstøl et al. (1978), who points out that legumes respond less to ammoniation than grass forages.

Pigden (1981) stresses that it is important to distinguish between low quality roughages and medium quality roughages. He classifies low quality roughages as those characterized by less than 35% DM digestibility, low nitrogen content, and low intake (even when properly supplemented). The status of forages with DM digestibility between 45 and 55% is according to Pigden (1981), not so clear. If appropriately supplemented, an acceptable level of animal production can be obtained from roughages in this range, and they become effectively medium quality products. Maize stover with 47-57% DM digestibility is a specific example which responds well to appropriate supplementation. This factor is therefore of some significance when deciding whether or not to apply chemical treatment to a given roughage.

Different roughages also respond differently to ammonia treatment as seen in the results of Waiss et al. (1972) (table 8). Similar results are also cited in the review paper by Sundstøl et al. (1978). In Tanzania, Kiangi (1979) observed the highest response in wheat straw when he treated maize stover, wheat straw and rice straw with ammonia.

Table 8. Influence of ammonia treatment at ambient temperature on enzyme solubility and N content of several straw types (Waiss et al., 1972)

Straw type	Enzyme solubility		N concent, %	
	Untreated	Treated	Untreated	Treated
Alfalfa	53	62	2.63	3.24
Barley	37	73	0.53	2.01
Bean	52	65	0.91	2.47
Fescue	37	62	0.79	1.50
Oat	33	63	0.43	1.77
Perennial grass	40	65	1.00	1.92
Rice	29	62	0.56	1.32
Wheat	37	62	0.86	2.14

6. The Physical form of the Roughage

From various experiments, the physical form of the roughage appears to have no influence on the effectiveness of a given alkali treatment method. Homb (1953) did not find any difference in OM digestibility (*in vivo*) in Beckmann treated straw, chopped or unchopped. Fernandez Carmona and Greenhalgh (1972), compared chopped and coarsely milled barley straw, soaked or sprayed with alkali. They reported that the physical form of the straw had no effect on the digestible energy content after treatment. Anderson and Ralston (1973) chopped rye grass straw at two different lengths (0.64 cm and 2.54 cm) and either soaked or sprayed the straw with different chemicals and they observed no difference in *in vitro* dry matter digestibility between the two lengths of chopping. Despite these observations it should be expected that the physical form of a given roughage will affect the easiness with which the alkali can effectively be mixed with the roughage. The digestibility of straw prior to treatment as pointed out by Jackson (1978), is affected by how it is harvested and subsequently handled. This indicates the effect of the physical form which is affected by methods of harvesting and handling. Generally, leaves are more digestible than stems. In materials like maize cobs, maize stover, or sorghum stover, the physical form of the material will definitely influence the effectiveness of the alkali treatment. Maize cobs for example , is a very hard material and in many cases it is necessary to either grind the material or soak it for a long time to get an effective alkali treatment. Thus whether or not the physical form of a roughage will influence the effectiveness of treatment, depends very much on the type of the roughage used.

7. Method of Treatment applied

Jackson (1978) classifies the different methods of chemical treatment broadly into:

Wet Methods (which involve soaking)

(i) Beckmann method

(ii) Various modifications of the Beckmann method e.g. Torgrimsby method

Dry Methods (which involve spraying the straw with minimum alkaline solutions)

(i) Farm scale treatment
(ii) Treatment with ammonia
(iii) Industrial processes

These different methods are affected to varying extent by the different factors already reviewed. The methods therefore differ both in their effectiveness and costs. All the different factors discussed have therefore to be taken into account when selecting a suitable method of treatment in a given situation.

The wet methods. (i) The Beckmann method

In the original Beckmann method, straw was soaked in a 1.5% NaOH solution for about 12 hours or more. A large amount of water was used for soaking the straw (more than 10 l/kg of straw). The straw was then washed and the water discarded. The disadvantages which led to the disuse of this method have already been mentioned. These disadvantages nothwithstanding, however, the Beckmann method resulted in a remarkable improvement of the nutritive value of straw. The digestibility of OM was raised by more than 20 percent units as already shown in table 2, and according to Sundstøl (1981), straw treated in this way was comparable to good quality grass silage or hay (in terms of energy value). The main reason for the effectiveness of the Beckmann method was the high ratio of alkali to straw which was employed (a ratio of 12 kg NaOH or more to 100 kg of straw). When straw is treated by the dry methods on the other hand, not more than about 5 kg NaOH/100 kg of straw can be used.

(ii) Modifications of the Beckmann method

Several attempts have been made to overcome some of the disadvantages of the Beckmann method. Homb et al. (1976) refer to the method of Torgrimsby (1971). In this method a so called "closed" system was developed. The system is referred as a "closed" one as no water or alkali is discarded. The straw is washed with water of equal amounts to that taken up by it after treatment. A detailed review of this method is given by Jackson (1978). The simplicity of this method and the fact that the method retains to a large extent the advantages of the Beckmann's method effectiveness of treatment; has given this method a strong credit for deserving further investigation and development. On simlar principles, another method was developed in Sweden by the Boliden Company (Jackson,1978). In this method known as the Boliden method, batches of medium density bales of straw are sprayed with a NaOH solution. The effluent is recirculated over a period of about 3½ hours, and the straw left for "ripening" for about 16 to 18 hours. The straw is then neutralized by spraying it with phosphoric acid, which is circulated for a period of about 1 hour. The straw is then ready for feeding after the excess acid has drained off. The use of phosphoric acid as a neutralizing acid was chosen particularly in order to eliminate any further need to otherwise supplement phosphates in the feed. Although this method seems attractively simple, its adaptation to farm situations may be hampered by its high cost.

Dry Methods. (i) Farm scale treatments

The so called "dry methods" were largely initiated by the work of Wilson and Pigden (1964). In these methods, the amount of solution used is minimized as much as possible. Wilson and Pigden (1964) used 30 ml of NaOH solution per 100 g of straw, but various modifications have been made on this. According to Jackson (1978), the amount of solution used varies from 0.1 to 3 l of chemical solution per kg DM of straw. Comparatively, the dry methods are not as effective as the wet methods. The dry methods generally increase the digestibility of organic matter by only 10 percent units when 4-5 kg of NaOH/100 kg of straw are used. The digestibility can however be increased by 15 percent units if in addition, heat is applied.

Based on the principles of the dry method, i.e. use of minimum volumes of solution without washing, various techniques and methods have been devised for treating straw both on a farm scale and industrial scale. Farm scale techniques have been based on the use of various chemicals including NaOH, $Ca(OH)_2$, and NH_3; and various techniques including ensilage after treatment have been tried. From various research papers, it is evident that considerable improvement can be achieved provided that optimum amounts of moisture, level of alkali and reaction time are properly manipulated. The farm scale treatments, however, suffer from one disadvantage in that with the exception of the ammonia treatment, the methods are not yet standardized. Farm machinery such as the JF and Taarup of Denmark and Farm hand, Wymondham, and Norfolk of the UK were developed for on farm treatment of straw by using the dry methods. These involve chopping and shredding conventional size baled straw, application of very low volumes of concentrated alkali solution (20-30% equivalent to 4-5 kg NaOH/100 kg straw DM) and blowing up the material into huge heaps. The heaps of treated material are left for sometime before feeding (usually a week or more). One danger of this method is the risk of fire due to the considerable heat liberated from the exothermic reaction between NaOH and straw. The cost of these machines is also prohibitively high and their use for on farm treatment of straw is limited to a few countries.

Simpler methods of dry treatment have been tried in several developing countries, notably in Bangladesh, Tanzania and Kenya (Urio 1977, Saadullah et al., 1981, Said, 1981, interalia). Most of these involve sprinkling straw with minimum amounts of alkali solutions, mixing, and feeding without washing. Ensiling of such material has also been tried in Bangladesh. In this case, thorough mixing becomes necessary in order to ensure a uniform distribution of the chemical over the roughage. Although such methods have the merits of being simple and easily adaptable to farm situations especially in developing countries, the degree of improvement in terms of digestibility can hardly exceed 10 percent units (Jackson, 1978). It seems possible, however, to achieve higher improvements by increasing treatment times, e.g. through ensilage or by increasing "ripening" time.

(ii) Treatment with Ammonia

One of the most promising methods developed for on farm treatment of straw has been the ammoniation method. Both anhydrous ammonia and aqueous ammonia have been successfully employed for treating various types of straws. Ammonia can also be released from urea by use of urease enzyme or by applying high temperature on urea as in the factory processing of straw in the German Democratic Republic (Jackson, 1978). In recent years, treatment of straw with ammonia has become extremely popular. In Norway for example, about 10% of the available straw was treated with ammonia in 1980 (Sundstøl, 1981). Some of the advantages of the ammoniation process which are responsible for its popularity include the fact that the method involves simple and flexible technology, capital costs are rather low, pollution problems are considerably reduced, and the method adds NPN to the treated material which can be utilized by the rumen microbes for protein synthesis. Various techniques of ammoniation have been devised and developed. These are well outlined by Sundstøl et al. (1978), Jackson (1978), and by Sundstøl (1981).

A disadvantage of ammoniation process is that compared to sodium hydroxide, ammonia is a slow reacting and a weaker base and thus the degree of improvement in digestibility resulting from ammoniation is lower than that obtained with NaOH. According to Jackson (1978) digestibility *in vitro* has been found to increase by a maximum of only 15 per cent units when about 3 kg NH_3/100 kg of straw are employed. In addition , the pollution problem is not altogether eliminated. Sundstøl (1981) points out that about 1/3 to 2/3 of the ammonia remains unreacted and this is released in the air when the stack is uncovered, and thus causing air pollution. However, recent work carried out at the Agricultural University of Norway (Borhami and Sundstøl, 1981) indicate that it is possible to capture almost 100% of the unreacted ammonia by spraying the straw with acids when opening the stacks. Another disadvantage is that ammonia, especially anhydrous ammonia is a hazardous chemical and requires special handling. Its irregular supply in many situations may also be a setback to this method. Although aqueous ammonia is less hazardous than anhydrous ammonia, it is also somewhat more bulky and difficult to transport.

Compared to other methods, ammonia treatment gives a similar or slightly lower improvement in feeding value than the dry methods employing sodium hydroxide and those involving ensiling after treatment with sodium hydroxide and calcium hydroxide. According to Sundstøl *et al.* (1978), when ammoniation of straw is performed under optimum conditions, an increase in organic matter digestibility of 10-15 percent units can generally be achieved.

(iii) Industrial processing

In developed countries, several firms have taken up the production of alkali-treated roughages on a commercial scale. A number of firms in the U.K. and in Denmark produce feeds with varying amounts of alkali-treated roughages. It is however, important to note that alkali-treated roughages are essentially incorporated as feed ingredients in the production of various compounded complete pelleted feeds. Certain factories, however produce pure treated straw pellets and sell them to feed compounding firms or even to individual farmers. Most plants utilize about 4-5 kg NaOH/100 kg of straw and according to Jackson (1978), this treatment increases *in vitro* digestibility by about 20 percent units, otherwise only 16 percent units of improvement have been reported in *in vivo* digestibility. In investigations carried out at the Biotechnical Institute at Kolding in Denmark, Rexen *et al.* (1975) reported that potentially an improvement of 30 percent units in *in vitro* digestibility can be attained by use of 7 kg NaOH/100 kg of straw. This higher rate of NaOH application is however, not feasible from both economical and the animals' health point of view. It must also be noted that industrial alkali processing is too capital and energy intensive and this excludes its feasibility in many countries especially the developing countries.

C. The Mechanism of improvement of nutritive value of low quality roughages after treatment with alkali

The cell wall constituents of most low quality roughages make up about 70 per cent or more of the plant material (Theander, 1981). The main components of the cell walls are often referred to as the lignocellulose component of the plant material. The cell walls also contain small amounts of pectin and protein and varying amounts of silica. It is well known that lignin and perhaps silica, are mostly responsible for the low digestibility of low quality roughages - by making the polysaccharides of these materials inaccessible to microbial digestion. Alkali treatment of straws and other low quality roughages somehow increases the accessibility of the polysaccharides of these materials to microbial digestion, and hence enhance both digestibility of the roughage as well as its voluntary intake. The mechanism by which alkali treatment brings about this improvement is not all that clear. It has been suggested that alkali treatment hydrolyses the inter-molecular ester linkages between uronic acid groups of hemicellulose and cellulose, makes cellulose swollen, and to some degree solubilises lignin, silica, and hemicellulose (Feist et al., 1970). Alkali treatment reduces the strength of inter-molecular hydrogen bonds which bind cellulose together, and this causes swelling of the cellulose. Swollen cellulose becomes more easily penetrated by rumen fluid and hence its digestibility increases. According to Fernandez Carmona and Greenhalgh (1972) the solubilised fraction as well as an increase in digestibility of the residual part of the treated material, accounts for the difference or rather increase in digestibility of treated material as opposed to the untreated material. It has been observed that NaOH treatment increases the rate of passage through the digestive tract (Hogan and Weston 1971, Berger et al. 1980). This increase in the rate of passage is thought to be brought about mainly through an increase in water intake by the animals consuming treated materials as well as through an increased content of soluble organic matter in the treated material. It is also thought that the increase in the rate of passage is partly responsible for the increase in feed intake of alkali treated roughages. Berger et al. (1979) however, point out that this increase in the rate of passage results in some of the potentially digestible materials passing through undigested. This is also supported by the results of Coombe et al. (1979). In later studies Berger et al. (1980) suggested that increased water intake may result in a dilution of the bacterial population in the rumen and result in an apparent reduction in digestibility. Generally, however, alkali treatment results in an overall greater increase in potentially digestible dry matter (Coombe et al., 1979).

It has generally been observed that the response *in vitro* following alkali treatment of roughages is often higher than response *in vivo* (Chandra and Jackson, 1971, Klopfenstein et al., 1972, Thomsen et al., 1973). Friis Kristensen (1981) points out that it is important to note that the *in vitro* methods measure solubility rather than digestibility. NaOH treatment renders parts of the cell wall constituents soluble in neutral detergents as well as in water. Phoenix *et al.* (1974) reported an increase in water solubility of dry matter in barley straw from 5-10% in untreated straw to 30-35% in straw treated with 8% NaOH solution. A great portion of these solubles may be lost when treated straw is washed. Homb (1948) reported that about 20% of the straw DM was lost when straw was treated and washed according to the Beckmann method. It is also important to note that a greater portion of the organic matter which is rendered soluble after alkali treatment is mainly hemicellulose, but some of the lignin may be dissolved as well. In the *in vitro* methods, these solubles are measured as digestible materials, while some of them are not digestible *in vivo*.

D. Utilization of Alkali-treated roughages as a livestock feed and factors affecting utilization

The objective of alkali treatment of low quality roughages is to ultimately increase digestible energy intake from them (Jackson, 1978). This can be achieved by either improving the digestibility of the roughage and/or by improving voluntary feed intake. The utilization of treated roughages will thus be influenced by the efficiency of the treatment method which is in turn influenced by a number of factors already reviewed. In addition, the utilization of the roughages will be influenced by intrinsic factors such as species and variety of the roughage, methods of harvesting and handling, method of feeding, i.e. diet composition and level of feeding etc. Most of the experiments conducted on chemical treatment of roughages have involved studying the effectiveness of the various treatment methods. These have to a large extent been *in vitro* digestibility studies and *in vivo* digestibility studies mostly with sheep. Comparatively few production experiments have been conducted to study the utilization of chemically treated roughages. Since the objective of roughage treatment is ultimately to improve its utilization by livestock, the need to carry out more studies on the utilization of treated roughages is of paramount importance. This need was well stressed by Jackson (1978) and Owen (1981) *interalia*.

Voluntary feed intake has often been regarded as one of the first measures of the nutritive value of a given feed (Raymond, 1969). Animals which consume more of a given feed are likely to give higher production from that feed than animals which consume less. Alkali treatment has been shown to improve the voluntary feed intake of various low quality roughages. The improvement in digestibility of Beckmann-treated straw was accompanied by an improvement in intake (15 to 16 kg/day, similar to good quality silage, Homb, 1948). The improvement in digestibility and intake results in better utilization of the treated materials and consequently higher production. Saxena *et al.* (1971) fed growing lambs Beckmann treated oat straw and observed marked improvement in daily feed intake, growth rate and feed efficiency (see table 9).

Table 9. Performance of lambs fed untreated or alkali treated oat straw (Treatment according to Beckmann method (Saxena et al., 1971)

	Untreated straw + soyabean meal	Treated straw + soyabean meal	Untreated straw + urea	Treated straw + urea
Daily feed intake g/day	870	1290	820	1110
Daily gain, g	62	177	53	125
Feed efficiency (kg DM/kg gain)	14.6	7.3	15.3	8.8

It should be noted from the above results that the amount of nitrogen in the diet affects the degree of improvement that occurs as a result of alkali treatment. Similar results were reported by Hasimoglu et al. (1969) (see table 10).

Table 10. The effect of nitrogen supplementation on performance of lambs fed on untreated or NaOH-treated wheat straw (After Hasimoglu et al., 1969)

	Untreated straw + soyabean meal	Untreated straw + urea	NaOH treated straw + soyabean meal	NaOH-treated straw + urea
Daily feed intake g/day	938	680	1196	988
Daily gain, g	107	0	213	126
Feed efficiency (kg DM/kg gain)	8.8	-	5.6	7.8

(Note: Wheat straw inclusion at 70% of the ration. Treatment of straw by 4% NaOH).

It should also be noted that the effect of nitrogen supplementation even from cheap NPN sources such as urea can be quite remarkable. Jackson (1978) refers to the work of Donefer et al. (1969), where the effect of urea supplementation (2.5%) was measured on the response of alkali treatment (8 kg NaOH/100 kg straw neutralized with acetic acid) of ground oat straw fed to sheep. Energy digestibility increased by 13.5 percent units when no urea was given as opposed to 18.3 percent units when urea was given. Kategile (1979) studied the effect of supplementing urea on NaOH-treated maize cobs based diets. He varied the amount of urea from 0 to 1.5%, and the digestibility of dry matter increased linearly from 38% to 64% as seen in table 11.

Table 11. The effect of urea supplementation on feed intake and digestion of diets based on NaOH-treated maize cobs (Kategile, 1979)

	Level of urea, %			
	0	0.5	1.0	1.5
Feed intake, g/day	332	284	320	352
DM (g/kg $W^{0.75}$)	26.2	19.2	23.3	26.0
Digestibility coefficients, %				
DM	38.3	50.2	56.3	64.3
OM	34.6	47.3	54.9	63.7
CWC	18.3	37.2	46.9	56.5

The effect of diet composition and level of feeding

It is generally recognized that the digestibility of roughages is lowered at higher levels of feeding (Blaxter et al., 1961). The amount of concentrates in the diet is also known to affect both the intake and digestibility of the roughage. These factors are well outlined in the review article by Jackson (1978). Generally, if the proportion of straw in the diet is small, the change in the feeding value of the total ration following alkali treatment of the roughage may be negligible and perhaps difficult to measure. The apparent difference between treated and untreated straw digestibility is reduced as the level of concentrate supplementation is increased and according to Jackson (1978), it may be reduced to zero when the level of concentrates is about 40-50 per cent. Kristensen (1981) reports on some work carried out in Denmark where young bulls (weight interval 220-440 kg) were fed pelleted rations containing 20 and 40% untreated and treated (5% NaOH) barley straw ad lib. As seen in table 12, the live weight and carcass gain did not respond to treatment at the low level (20%) of straw inclusion, but at 40% straw inclusion, the gain was significantly improved by treatment.

Table 12. Effects of different levels of untreated and NaOH-treated barley straw in pelleted rations for young bulls (Friis-Kristensen, 1981)

	Untreated straw		NaOH-treated straw	
% of straw in the diet	20	40	20	40
DM intake, kg/day	7.8	8.5	7.8	8.5
Live weight gain, g/day	1374	1209	1336	1322
Carcass gain, g/day	736	624	707	685

The improvement in digestibility and voluntary feed intake resulting from alkali treatment of cereal straws , according to Balch (1976), appear to be sufficient to allow treated straw to replace about 15 to 20% of the diet of dairy and beef animals in semi intensive systems. From a number of experiments carried out it appears, however, that the level of straw inclusion depends on the type of the straw used, and the method of treatment applied. Greenhalgh et al. (1976) fed dairy cows complete rations containing 50% concentrate and 50% either untreated or NaOH-treated barley straw. As seen in table 13, the alkali treatment increased feed intake, milk yield, and milk fat content.

Table 13. The effect of alkali treatment* of barley straw in complete rations for dairy cows (Greenhalgh et al., 1976)

	Untreated straw +50% concentr.	Treated straw +50% concentr.
DM intake, kg/day	10.8	13.4
Milk yield, kg/day	17.8	19.0
Milk fat, %	3.54	3.74
Milk total solid contents, %	12.27	12.82

*Straw treated by mixing 500 kg of barley straw with 250 kg of a 16% NaOH solution.

Similar results are reported by Friis Kristensen (1981) in Denmark. In this experiment, NaOH-treated (4% NaOH) barley straw was compared with untreated barley straw in rations for dairy cows. The NaOH treatment increased straw intake by 30% and again as seen in table 14, the milk yield and fat content were significantly increased by the alkali treatment.

Table 14. Daily feed intake, milk yield, and live weight change in dairy cows fed untreated and NaOH treated chopped barley straw (Friis Kristensen, 1981)

	Untreated barley straw	NaOH-treated barley straw
Feed intake	6.9	6.9
Concentrate, kg DM/day	3.8	3.8
Molasses, " "	5.7	7.4
Straw, " "		
Production		
Milk yield, kg/day	24.0	24.6
Milk fat %	3.34	3.64
4% FCM, kg/day	21.6	23.3
Weight change in the animal, g	136	414

Garmo (1981) reviewed a number of feeding experiments carried out in Norway, in which NaOH and NH_3-treated straw were used to replace silage in various proportion. No adverse effects on milk yield were reported.

In recent years, ammonia-treated straw has particularly become popular in Norway, and large amounts of straw are treated with ammonia and used both in dairy and beef cattle rations. Mo (1978) reported on some experiments carried out in Norway where NH_3-treated straw replaced high quality silage in dairy cows rations. As seen in table 15, about 3.5 kg (DM) of good quality silage could be replaced by NH_3-treated straw with no effect on milk yield.

Table 15. Replacement of grass silage by NH_3-treated barley straw to dairy cows (Mo, 1978)

	Experiment 1		Experiment 2	
Group	1	2	1	2
Feed intake				
Silage, kg DM	5.2	8.5	5.2	8.8
Straw, kg DM	3.2	-	2.7	-
Concentrates, kg	7.6	6.8	7.4	6.2
Production				
Milk yield, kg/day	21.4	21.8	20.3	20.4
Milk fat, %	3.64	3.61	3.69	3.77
4% FCM, kg	20.2	20.6	19.4	19.6

When properly supplemented, it appears that ammonia treated straw can even be used as the sole source of roughage in feeding beef cattle. Sundstøl and Matre (1980) fed ammonia treated straw to growing steers and obtained on average a growth rate of 400 g/day (see table 16). The straw was supplemented with a small amount of concentrate, mineral, and vitamins.

Table 16. Feed composition and growth rates of steers fed either untreated or ammonia-treated straw as the only roughage for 168 days (Sundstøl and Matre, 1980)

	Untreated straw	NH_3-treated straw
Number of steers	14	14
Amount of concentrate, kg/d	1.9	0.25
Straw (practically *ad lib.*) kg/d	6.0	10.0
Straw intake kg DM/100 kg body weight	1.3	2.1
Starting weight (kg)	375	375
Final weight (kg)	434	454
Weight gain, g/day	349	434

As pointed out by Owen (1981) very few production experiments have been conducted with sheep and hardly no experiment is reported in the literature where a production experiment has been conducted with goats utilizing alkali-treated roughages. Sheep have been utilized mostly in evaluating the effectiveness of the treatment methods through digestibility experiments. Nevertheless, the few production experiments conducted with sheep indicate that alkali treated roughages can be utilized efficiently by sheep and appreciable improvements in production can be attained. Kalinowski (1974, cited by Owen, 1981) fed NaOH-treated straw to weaned lambs and tried to minimize the amount of supplement in order to simulate typical tropical feeding conditions. As seen in table 17, lambs fed untreated straw with or without urea supplementation lost weight. Modest growth rates were obtained with sheep fed treated straw supplemented with urea, while higher growth rates were obtained with sheep fed treated straw and supplemented with soyabean meal. It is interesting to note from table 17, the high compensatory growth rates that were obtained following the feeding of the same animals with higher quality feeds. It is evident that the NaOH treated barley straw was still an inferior feed compared to good quality maize silage. However, when rations based on treated straw are properly formulated, comparatively high production response can be obtained. Again the level of straw inclusion appears to be of paramount significance. This is evident from the work of Garrett <u>et al.</u> (1979) who conducted comparative slaughter feeding experiments with sheep and cattle using diets containing 36 or 72% treated rice straw (as feed basis). The rice straw was treated with 4% NaOH or with ammonia. As seen in table 18, diets containing 72% treated rice straw were consumed in larger quantities and also with higher efficiency. Treated straw also had higher net energy values. On the other hand, when straw was fed at 36% level, there was no significant difference in digestion or animal performance between untreated straw and treated straw.

Table 17. Effect of NaOH treatment, neutralization and N supplementation on lamb growth (Kalinowski, 1974, cited by Owen, 1981)

	Treatments					
NaOH, g/kg DM	0	0	70	70	70	70
HCl, g/kg DM	0	0	26	26	26	0
Urea, g/day	0	20	0	20	0	20
Soyabean meal, g DM/day	-	-	-	-	97	-
Molasses, g DM/day	150	150	150	150	34	150
Minerals, vitamins, g/day	22	22	22	22	22	22
	Results					
Lamb performance						
Initial weight, kg	27.2	27.1	28.0	25.7	28.3	26.6
Final weight, kg	22.3	25.8	23.4	29.8	34.3	31.2
Gain/loss, g/day	-68.1	-18.1	-63.9	56.9	83.3	63.4
Daily DM intake						
Total, g	404	483	368	701	847	682
Straw, g	283	298	232	516	671	501
Straw, g/kg $W^{0.75}$	21.5	25.3	20.3	42.7	50.7	40.6
Post-experiment performance on supplemented maize silage						
DM intake, g/kg $W^{0.75}$	64.4	65.9	63.5	67.3	-	64.6
Live weight gain, g/day	202	185	215	144	-	177

Table 18. Growth response, feed intake and carcass characteristic of lambs fed 72% and 36% rice straw (Garrett _et al._, 1979)

Diet	Growth response and feed intake					Carcass characteristics		
	Initial weight, kg	Final weight kg	Daily gain, g	Daily feed intake, g	Feed gain	Warm carcass weight, kg	Dressing %	Carcass fat %
72% rice straw								
Control	25.9	31.5	89	186	20.9	18.8	40.9	25.1
NaOH soaked	25.4	34.0	137	197	14.4	20.5	52.0	24.8
NaOH pelleted	25.1	33.3	132	209	15.8	20.1	53.5	24.9
NH_3, 7%	25.5	33.8	131	214	16.3	20.4	50.4	26.1
NH_3, 4.7%	25.0	33.6	136	197	14.5	20.2	52.5	27.2
36% rice straw								
Control	25.9	37.5	184	187	10.2	22.9	53.1	31.2
NaOH soaked	26.5	38.8	196	191	9.7	23.8	56.0	28.0
NaOH pelleted	26.2	39.9	217	208	9.6	24.4	54.5	27.2
NH_3 7%	26.4	36.7	165	166	10.1	22.4	54.5	30.3
NH_3 4.7%	24.8	30.4	89	116	13.0	18.0	54.9	30.9
Alfalfa control	26.7	36.5	156	171	11	22.3	52.4	26.5

It has been suggested as pointed out earlier, that the digestibility of straw and in particular the response of alkali treatment can be reduced to zero when the proportion of concentrate in the diet is more than 40% (Jackson, 1977, Jackson 1978). However, this generalization does not always hold true, especially when it is possible to vary the form of feeding, source of roughage, concentrate etc. In the results of Greenhalgh et al. (1976) where complete rations containing 50% of either untreated or NaOH-treated barley straw, and 50% concentrates, were fed to fattening lambs, a clear effect of alkali treatment was observed in the production performance of the lambs. As seen in table 19, the alkali treatment had a marked improvement in digestibility and feed intake and empty body gain - even when the amount of concentrate fed was relatively high.

Table 19. Performance of lambs fattened on complete rations containing either 50% untreated or NaOH-treated barley straw (Greenhalgh et al., 1976)

Diet	Untreated barley straw	NaOH-treated barley straw	Concentrate alone
DM daily intake, g	560	848	910
Empty body gain, g/day	77	140	235
DM digestibility, %	62.0	71.3	-

In Kenya, Said (1981) fed NaOH treated maize stover and *Chloris gayana* hay to sheep and observed that NaOH-treated maize stover was utilized better than *Chloris gayana* even when intake in the latter was slightly higher (see table 20).

Table 20. Performance of sheep fed either NaOH-treated maize stover or Chloris gayana hay, plus concentrate (Said, 1981)

Diet	NaOH-treated maize stover	Untreated Chloris gayana hay
Number of sheep	12	12
Mean starting live weight, kg	23.0	24.0
Finishing live weight, kg	29.5	30.0
Daily gain (112 days), g	58	54
Concentrate intake, DM g/d	386	386
Offered roughage, g DM/day	309	371
Intake of the roughage, g DM/day	217	270

In another experiment in Kenya (Tubei and Said, 1981) even higher growth rates than those shown in table 20 were reported when NH_3-treated maize stover and NH_3-treated maize cobs were fed to sheep. Tubei and Said (1981) reported a daily gain of 79 g/day and 130 g/day for rations based on untreated maize cobs and NH_3-treated maize cobs respectively, and 62 g/day and 89 g/day for the untreated maize stover and NH_3-treated maize stover respectively. The level of concentrate supplementation was also about 50%.

Owen (1981) points out that, although the different methods of alkali treatment may improve the intake and metabolizable energy content of poor quality roughages by up to 50 per cent, most of the treated materials still remain low energy feedstuffs. Their metabolizable energy content being hardly more than 9.0 MJ/kg DM. Comparatively, high quality feeds such as maize silage has an ME content of about 10.8 MJ/kg DM, and concentrate such as maize grain has an

ME content of about 14.2 MJ/kg DM. It, however, should also be noted that unless treated with ammonia these materials remain low-protein feedstuffs with crude protein contents of less than 5%, and thus require nitrogen supplementation after treatment. In many production systems in developed countries, alkali treated roughages are mainly used to replace, in varying proportions, feeds such as silage and hay, which are otherwise expensive or in short supply. The feasibility and economics of using alkali treated roughages in different livestock production systems is influenced by many factors, and is therefore likely to differ from one country to another and from place to place.

It is important to note that a totally different situation exists in many developing countries as regards the role or the potential role of alkali treated roughages as livestock feeds. As pointed out earlier, the level of animal feeding in many developing countries especially during the dry season, is very low. Whereas the main role of alkali treated roughages in developed countries is likely to continue as being replacer feeds during short periods, their potential and role as better feeds, at least for maintaining animals during the dry season, is considerably larger in many developing countries. As stressed by Pigden (1981), it is also important to note that some of the roughages available in many of the developing countries need only proper supplementation of protein, minerals and vitamins to make them better feeds. Of particular significance in this case are roughages such as maize stover, which when properly supplemented with a protein source, can provide a feed of relatively high nutritive value. In many of the developing countries, the urgent need is a survey of the different roughages which can be upgraded through alkali treatment or proper supplementation and the feasibility of utilizing the different methods and chemicals so far developed. As stressed by Pigden (1981) it is important that before chemical or physical treatments of roughages (which are often likely to be too expensive) are considered in developing countries, many unprocessed roughages should be evaluated by feeding them, say to small ruminants. Supplementation, without or with simple physical processing may be the only requirement for effective utilization of many low quality roughages.

E. <u>The effect of feeding alkali-treated roughages on the animal's health</u>

The fact that most of the alkalis used for treating roughages are strong and corrosive bases, has often raised some concern on the possible harmful effects when alkali-treated roughages are used as animal feeds. In some quarters, this unfounded fear has even resulted in skepticism and resentment on the use of such feeds. It is, however true, that an appreciable amount of base remains in the treated roughage when straw is treated by the so called "dry" or spray methods. The unreacted alkali raises the pH of the roughage (usually above 10) and the sodium content of the roughage also rises at the rate of about 0.6 units (on DM basis) for each 1% (w/w) NaOH used for treating straw (Jackson, 1977). Although the animal body seems to have mechanisms of dealing with high sodium and high pH feeds (Pierce, 1957, 1959, 1960, 1962) feed intake is usually depressed by higher levels of alkali treatment and this indicates a physiological stress.

In the original Beckmann method, straw was washed with enormous amount of water and practically all excess base was washed away (unfortunately together with valuable solubles). The problem of extra base in the feed did not therefore arise. In Norway, where the Beckmann method was extensively used, Homb (1948) reported that in a survey carried out in 1945 in Norway, there was even an indication of a decline in the frequency of acetonemia as a result of inclusion of Beckmann treated straw in the ration of dairy cows. It was thought that inclusion of Beckmann treated straw in the ration resulted in an overall better balance of minerals. This view is partly supported by recent results of Arndt et al. (1980) who fed NaOH-treated cotton plant by-products and observed an increase in Na balance, but also a decrease of K, Cl and Mg balance.

In the "dry" methods, it appears that the safe level of alkali utilization lies between 3 g - 6 g NaOH/100 g straw DM when straw is the main or the only form of roughage fed. At this level of alkali utilization, animals seem to be capable of effectively handling the excess base in the treated material. Available evidence indicates that the extra sodium ingested from such materials is entirely excreted in the urine. Feeding NaOH-treated roughages therefore results in an increased water consumption, and urine excretion (Maeng et al., 1971, Singh and Jackson, 1971). Maeng et al. (1971) did not observe any increase in excretion of sodium in the faeces or milk - as a result of feeding alkali treated roughages.

Some attempts have been made to neutralize the excess alkali by using inorganic acids such as hydrochloric acid (organic acids cannot be utilized for this purpose because they are metabolized in the rumen). Stigsen (1975) compared treated straw (5% NaOH) neutralized with hydrochloric acid, with NaOH-treated unneutralized straw. Unneautralized straw gave a higher rumen pH than neutralized straw. The count of rumen cellulolytic bacteria was much increased by neutralization and the apparent digestibility of DM was increased by 4-5 percent units in neutralized compared to unneutralized straw. These observations are, however, not in agreement with those of Rexen et al. (1976) and Robb (1976) who observed no beneficial effects of neutralization. Owen (1978) nevertheless, suggests that there may be some beneficial effects of feeding alkali-treated roughages with low pH feedstuffs such as grass silage, or acidosis promoting diets containing high levels of concentrates.

The only experiment reported in the literature where alkali is reported to have caused apparent ill-effects is that by Arnason (1980) in Norway. In this experiment growing bulls were fed NaOH-treated straw (4-5 % NaOH) and for the first 12 weeks it was observed that feed intake of the treated straw was high and the growth rate of the bulls was also high. After 12 weeks on this feed, however, the animals started having diarrhoea and they drastically lost weight. Feed intake surprisingly, remained high. On examining the kidneys, it was observed that the weight of the kidneys of the bulls fed NaOH-treated straw was significanly greater than those of the control group. On the other hand Henriksen (1978, cited by Friis Kristensen, 1981) in Denmark, did not observe any significant difference in kidneys of bulls fed NaOH-treated straw compared to bulls fed untreated straw; nor did macroscopic and microscopic investigations on liver, and kidneys show any significant histological differences between the two groups.

F. Evaluation of feed utilization through measurements of carcass specific gravity and other carcass parameters

The greatest function of a feed is the production of energy for various body processes including energy storage (Maynard et al., 1979). Since all the organic nutrients can serve this purpose, energy value provides a common basis for expressing their nutritive value. For this reason, it is widely recognized that a measure of gain or loss of energy can provide a useful measure of the state of nutrition of the animals body as well as the relative value of different feeds. Measurement of energy brought about by the consumption of a given quantity of a feed by an animal can be achieved either through direct calorimetry, or through indirect calorimetry in which the kind of tissue gained is determined from carbon and nitrogen balances and energy retention calculated from the composition of the body weight gain. Lofgreen (1965) points out that these methods suffer from the main disadvantage in that they take relatively short time, the animals are kept in rather unnatural conditions, and that the methods involve expensive equipments. In attempts to overcome these difficulties, a number of workers have developed methods of using body weight gains and other carcass parameters as measures of energy retention (Brown et al., 1951, Kraybill et al., 1952, Kline et al., 1955, Reid et al., 1955, Barton and Kirton,1956, Kirton and Barton, 1958, Garrett et al., 1959, Meyer et al., 1960, Meyer,1962, Lofgreen, 1965). Some of these workers have, however, pointed out that body weight gain as a parameter of response is very succeptible to errors especially when applied in experiments with ruminants; as changes in ruminal fill which are reflected in the body weight can result in appreciable errors, particularly in experiments of short duration (Reid et al., 1955, Garrett et al., 1959, Meyer et al., 1960, Lofgreen et al., 1962). In addition the use of body weight changes assumes that irrespective of treatment, the weight gained or lost is of the same chemical composition. However, as noted by Reid et al. (1955) and by Garrett et al. (1959) the gains of growing animals vary in their content of water, protein and fat, and therefore the same increment in weight resulting from consumption of different rations do not necessarily reflect equivalent nutritive effects. In many experiments, body composition and the energy content of the various components have been used in estimating energy retention (Kraybill et al., 1952, Reid et al., 1955, Garrett et al., 1959, Meyer, 1962, Lofgreen et al., 1962). Alternatively, the net energy values of diets and feedstuffs for maintenance, growth and fattening may be determined by measuring the heats of combustion of representative samples of the whole empty bodies of animals at the beginning and those of different animals at the end of feeding period. Protein and fat contribute almost all of the energy value of the body (Reid et al., 1955). Carbohydrates generally constitute less than 0.5 per cent of the animal body and therefore according to Reid et al. (1955) this portion can be disregarded in considerations of the energy value of the body in experiments of long duration. Since the caloric values of protein and fat in the animal body are well established, the energy value may be derived alternatively from data on the protein and fat content of the whole body.

Various methods have been developed for determining or estimating body composition of animals. The specific gravity technique has been used by a number of workers (Rathbun and Pace, 1945, Brown et al., 1951, Kraybill et al. 1952, Whiteman et al., 1953, Barton and Kirton, 1956, Meyer, 1962). The specific gravity index has particularly been used in estimating body or carcass fat content. The concept of the use of specific gravity as a means of estimating body or carcass fat content is based on the fact that the density of carcass fat is considerably less than that of other carcass components, and hence the larger the proportion of fat, the lower will be the specific gravity. In using specific gravity as an index of fatness, it is also assumed that the fat-free portion of the body is constant in composition, and if this is true, then the density of this portion of the body which consists essentially of muscle and bone must also be relatively constant. For this reason, fat with a low density (about 0.92) as compared with that of muscle (about 1.06) and bone (about 1.50, Kraybill et al., 1952) can be regarded as cheifly responsible for deviations of the carcass specific gravity. Rathbun and Pace (1945) studied the relationship between total body fat and specific gravity in guinea pigs and reported a correlation coefficient of -0.97; while Kraybill et al. (1952), and Barton and Kirton (1956) reported correlation coefficients of -0.96 and -0.88 in cattle and ewes respectively. According to Kirton and Barton (1958), however, specific gravity is not a very accurate parameter of estimating carcass fat in thin carcasses. These workers reported that there was a tendency of overestimating the fat content of this carcasses when specific gravity was used as an index of estimating the fat content. The thin carcasses were apparently too light under water giving a wrong impression of high fat contents when their fat contents were estimated from specific gravity values. Meyer (1962) explains that this apparent low weight under water was due to air or gases trapped under the fascia of the thin carcasses. He suggested that this could be overcomed by chilling of the carcass 24 to 48 hours before weighing under water. It was also stressed that it was important to keep the carcass thoroughly chilled until just before underwater weighing; and to carry out the underwater weighing as rapidly as possible. This latter precaution was to minimize trapped gas or air expansion when under water.

From the relationship between carcass fat and carcass specific gravity, regression equations have been developed and these have been used to estimate carcass fat content from measurement of carcass specific gravity. Garrett et al. (1959) obtained a correlation coefficient of -0.90 between carcass specific gravity and carcass fat-percentage in sheep, with a standard error of estimate of 2.6. They obtained the following regression equation:

$$Y = 556.6 - 505.0\ X$$

where Y = Per cent carcass fat

X = Carcass specific gfavity

Meyer (1962), obtained the following relationship:

$$Y = 463.7 - 418.4\ X_1$$

where Y = Per cent carcass fat

X_1 = Carcass specific gravity

The correlation coefficient between specific gravity of the dressed carcass and carcass fat was -0.84, with a standard error of estimate of 2.64. When carcass weight was included in a multiple regression, an improved estimate was obtained, i.e.: $Y = 436.8 - 398.7\ X_1 + 0.1756\ X_2$

where Y = Per cent carcass fat

X_1 = Carcass specific gravity

X_2 = Carcass weight (in pounds)

MATERIALS AND METHODS

The multiple correlation coefficient was -0.96, with a standard error of estimate of 1.40. It was also noted that the fat content of the small thin carcasses were overestimated if only specific gravity was used. This observation has been noted by a number of workers as pointed out earlier, particularly where carcasses of low fat contents are involved. Some workers have advocated the use of carcass weight alone as a more reliable parameter. Barton and Kirton (1958) argued that carcass weight as an index of carcass fat content was not so subject to errors of measurements as was carcass specific gravity. Barton and Kirton (1956) in addition, pointed out that carcass composition in terms of chemical fat or dissectible fat tissue and muscular tissue can be predicted from carcass weight with reasonable accuracy. Meyer et al. (1960) argue that carcass weight as an index is easy to measure, and more precise than specific gravity, and in additon the dressed carcass is the main economic end product. On the other hand, carcass weight as an index of fat content, will not distinguish between treatment effects which alter the proportions of tissues in the carcass without affecting carcass weight. In other instances, carcass grade is often used as an indication of fatness (Creek et al.,1977, Kirton and Colmer-Rocher, 1978). These workers however, also point out that carcass grade depends on visual judgement and can result in great variation in fat content.

III. MATERIALS AND METHODS

A. Laboratory scale experiments

Experiment 1: Treatment of wheat straw with different levels of sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3) and calcium hydroxide $Ca(OH)_2$

The main objective in this experiment was to find out the possibility of replacing the amount of NaOH used for treating straw by the cheaper chemicals, $NaCO_3$ and $Ca(OH)_2$, either by using a combination of the chemicals or by using the weaker chemicals exclusively. The aim of using combinations of chemicals was also to see if there was any positive interaction arising from such combinations. The experiment was divided into experiment 1a and 1b. In experiment 1a, NaOH and Na_2CO_3 were used in a 3 x 3 factorial experiment. The three levels of each chemical tested were 0, 3 and 6 g of chemical/100 g DM of roughage. In experiment 1b, $Ca(OH)_2$ was used in similar combinations with NaOH. Solutions containing combinations of the chemicals were made separately. In the case of $Ca(OH)_2$, a slurry of $Ca(OH)_2$ was used due to the low solubility of the chemical. Duplicate samples of 250 g of wheat straw were weighed separately into 20 l plastic pails. To each plastic pail, 250 ml of the respective treating solution were added. This gave a 1:1 ratio (w/v) of straw to treating solution. This ratio was adapted from previous experiences which ensured that all the solution was taken up by the straw, and at the same time ensured as much as possible an even distribution of the alkali on the roughage. The strength of the solutions were made to give the corresponding amounts of chemical per 100 g (DM) of straw. Corresponding amount of tap water was added to the control batches. The straw in each plastic pail was then thoroughly mixed by hand and left in the plastic pail overnight, after which it was dried in a forced air oven dryer at 80°C. After drying, the straw was ground through a 0.8 mm sieve and the following analyses were carried out:

Neutral detergent fibre (NDF)

Acid detergent fibre (ADF)

Lignin content ($KMnO_4$-lignin)

Silica content

In vitro dry matter and organic matter digestibility (IVDMD and IVOMD)

Enzyme soluble organic matter (ESOM)

NDF, ADF, $KMnO_4$-lignin and silica contents were determined using the procedure described by Goering and Van Soest (1970). IVDMD and IVOMD were carried out using the method of Tilley and Terry (1963), while ESOM was determined using the procedure described by Rexen (1977).

As replications per treatment (9 treatments) were limited to the duplicate samples of the treated straw, no analysis of variance was carried out for the data. The means for the two duplicates of each treatment were determined and these are presented as two way tables in the results and discussion chapter. The mean values although not sufficient for carrying out an analysis of variance, were nevertheless considered sufficient to show the trend of the effects of the treatments and this was the main aim of the laboratory scale experiments.

Experiment 2: Treatment of maize stover and Hyparrhenia grass with varying levels of sodium carbonate (Na_2CO_3)

Maize stover and Hyparrhenia grass were both treated with varying levels of Na_2CO_3 i.e. from 0 to 10 g Na_2CO_3/ 100 g (DM) of the roughage. Maize stover was collected from the university farm at Morogoro, after the grain had been harvested. Hyparrhenia grass was cut from natural stands within the University farm. The same ratio of 1:1 (w/v) of roughage : solution was used as in experiment 1. Duplicate samples of 250 g the roughages were treated with solutions containing the different levels of the chemicals, and then thoroughly mixed by hand. After mixing, the roughages were left to stand overnight, and then sundried. All samples were ground in a laboratory mill through a 0.8 mm sieve and chemical analyses carried out as for experiment 1 except that no silica determinations were carried out. In addition, IVDMD and IVOMD were run on duplicate samples of both roughages for all the different levels of treatment, with a 10% herring meal added to the samples. The 10% herring meal was added directly to the *in vitro* centrifuge tubes after the samples had been weighed. The aim of adding the herring meal was to find out the influence of protein supplementation on affecting the digestibility of the Na_2CO_3

treated roughages. The significance of availability of nitrogen has been shown to have a marked influence on the response of poor quality roughages to alkali treatment. Roughage treatments were carried out at the Faculty of Agriculture, Forestry and Veterinary Science, Morogoro, Tanzania; while the chemical analyses were carried out at the Department of Animal Nutrition of the Agricultural University of Norway, Aas-NLH. Linear regression and correlation analyses were carried out to study the effect of increasing the level of Na_2CO_3 on the different parameters. A t test was applied to find out the effect of adding herring meal to both Hyparrhenia and maize stover on IVDMD and IVOMD. Correlation and linear regression analysis were carried out with an ABC 80 computer.

Determination of chemical composition of local Magadi samples

Samples of Magadi soda were collected from four different places in Tanzania; these were:

1. Ilongero (Singinda region)
2. Lake Manyara
3. Ngarenanyuki (Arumeru district)
4. King'ori (" ")

All the samples except the one from Ngarenanyuki were purchased from local markets. In Ngarenanyuki, Magadi samples were obtained from dried up deposits of Magadi soda along Ngarenanyuki river. There were great differences in both texture and colour of the different Magadi samples. Magadi sample from Ilongero consisted of big white crystals and looked and tested quite like common salt. Lake Manyara samples consisted of hard lumps of greyish salt; while those from Ngarenanyuki and Kingori consisted of whitish grey powdered salt.

The samples were crushed in a laboratory motor to obtain a somewhat homogenous mixture and then sent to the Analytical Chemistry Laboratory at the Agricultural University of Norway (Aas-NLH) where the following analyses were carried out:

Total phosphorus	(P)
Sodium	(Na)
Calcium	(Ca)
Chlorine	(Cl)
Water soluble fluorine	(F)
Carbon	(C)

Experiment 3: "Dip and Drip" method of alkali treatment of straw

The objective of this experiment was to study the effect of continous reuse of the treating solution on the chemical composition of the treated straw, the nutritive value of the treated straw, and the chemical composition of the lye solution. The method simply involved dipping straw in a 1.5% NaOH solution, lifting it up from the solution, letting it drip, washing, and letting it drip again, and hence the name dip and drip method.

Barley straw was treated in a 1.5% NaOH solution by soaking bales of straw in the solution overnight. Three plastic basins of about 400 litres capacity were used. These were filled with 250 l of a 1.5% NaOH solution. Three bales of barley straw were weighed separately and each soaked in one of the basins. The ratio of straw : solution was about 1 : 25 (w/v). After soaking overnight in the solution they were lifted up and the solution allowed to drip back into the basins by resting the bales on wooden bars placed across the basins. The bales were left to drip for about 2 to 3 hours and then rinsed with tap water using a garden can. Earlier experience had shown that the straw absorbed an amount of solution equivalent to about three times its weight, and therefore an amount of water approximately three times the weight of each bale of straw was used for rinsing. After rinsing, the bales were again left to drip for about 2 to 3 hours. Samples of the straw were taken and the following determinations were carried out: Dry matter (DM), ash, sodium content, in vitro dry matter and organic matter digestibility (IVDMD and IVOMD) and enzyme soluble organic matter (ESOM). The solution in each basin was then made up to the 250 l mark by adding water. Samples of the solutions were then taken for DM, ash, and Na content determinations. Titrations were carried out to determine the concentration of the NaOH solutions after straw treatment. The strength of the NaOH solutions were then restored to their original 1.5% by adding more NaOH to the solution; the amount of NaOH being based on the titrations. This procedure was repeated 15 times, i.e. the lye solutions were used 15 times before being discarded. After each treatment, titration was carried out and NaOH added to the solutions to maintain the 1.5% NaOH strength in the solutions. Straws from the 1st, 5th, 10th and 15th day of treatment (i.e. after 1st, 5th, 10th and 15th time of reuse of the lye solution) were in addition used in digestibility studies with sheep. Two sheep were used for each treatment. The treated straws were used as the only roughages and were fed at about 3 kg of treated straw/sheep/day. In addition, each sheep was offered 50 g of herring meal, 10 g salt, and 10 g of dicalcium phosphate/day. Chemical analyses of the straw on these days were also carried out. Correlation and linear regression analyses were carried out to study the trend in changes of the different parameters in the lye solution and the treated straw, as the treating solution was reused several times. A two way analysis of variance was carried out to test the effect of the 5 different periods of reusing the lye solution, on the digestibility (in vivo) of the treated straw. An ABC 80 computer was used for statistical analyses and the results verified with a TI programmable 57 Texas instruments hand calculator.

B. Production experiments

Two experiments were conducted to study the utilization of alkali treated roughages by two different species of ruminants i.e. sheep and goats. The utilization of these roughages was measured in the form of energy retained in the carcass of these animals as well as by other carcass parameters. A comparative slaughter procedure similar to the one applied by Garrett et al. (1959) and that by Lofgreen (1965) was used in estimating the energy retained in the carcasses of the experimental animals. The main objective of the production experiments was to practically test and utilize information from the laboratory scale experiments by evaluating roughages treated as to one of the methods developed in the laboratory scale experiments.

Experiment 4: Energy utilization of alkali-treated roughages fed to goats

Twenty four local Tanzanian castrated male goats were used in the actual design of the experiment, but in addition, five animals were slaughtered together with the initial slaughter group in order to increase the accuracy of using some carcass parameters in estimating the carcass fat content; in particular the use of carcass specific gravity as a measure of carcass fat content. The animals were approximately 1 year old at the beginning of the experiment, with an average liveweight of about 15 kg. Four groups of six animals each, were matched for liveweight and general body conformation. One group was selected at random as the initial slaughter group. The average carcass composition of this group was assumed to be a fair representative of the remaining three groups. The remaining three groups of animals were then assigned randomly to one of the three experimental diets. The experimental diets were based on the following roughages:

Untreated maize cobs

NaOH-treated maize cobs

Chloris gayana hay

The NaOH treated maize cobs were treated by the dip and drip method described in experiment 3. The cobs were placed in a locally made rectangular weld-mesh basket, and then soaked in a 1.5% NaOH solution for 48 hours. The solution was contained in a 400 l plastic basin. Heavy stones were placed on top of the maize cobs (covered with a sheet of weldmesh wire) to make them sink and well soaked. After soaking for 48 hours, the cobs were then lifted from the solution, allowed to drip and then washed as described in experiment 3. After completely dripping, the cobs were ground on a tractor mounted cormal harmmer mill through a 8 mm sieve and then air dried. The black lye solution was titrated and the solution strength reinforced after each treatment. The lye solution was reused 2 or 3 times only, as enough feed was made per treatment to last several days. A somewhat undesirable smell was also detected if the solution was allowed to stand for several days. The untreated maize cobs were soaked in water for 48 hours and similarly ground and air dried before feeding.

Loose *Chloris gayana* hay was made from established pasture plots of *Chloris gayana* at Magadu on the University farm, Morogoro. The hay was made from late bloom cut grass of newly established pastures. At this late bloom stage, the grass was nevertheless considered of higher feeding quality than most of the grasses available in the grazing fields during the dry season.

All the roughages were fed *ad libitum* at 80% acceptance level. In addition to the *ad libitum* feeding of the roughages, each animal was fed 200 g/day of a concentrate feed (89% DM) composed of:

50% sunflower meal

28% maize bran

17% molasses

5% bone meal

The concentrate was in addition enriched with vitamins A and D. The animals were confined to digestibility crates and fed individually. Water was offered *ad lib.* Concentrate was fed separately in two portions, one in the morning and one in the evening. All the concentrate was eaten up, but the roughage refusals were removed each morning and weighed. During the 7th week, a total collection of faeces and urine was carried out to study the *in vivo* digestibility of the rations. All the animals were dewormed at the beginning of the experiment using recommended drugs. A preliminary period of 3 weeks was followed by an experimental feeding period of 100 days. During this preliminary period, the groups fed on maize cobs were also offered 100 g (DM) of hay to train them to eat the maize cobs diets. This was removed gradually during the second week of the preliminary period. The group fed on untreated maize cobs showed some reluctance in eating the material in the first week, but thereafter the material was well accepted.

The initial slaughter group was slaughtered at the beginning of the experiment. No feed or water was offered to the animals 12 hours prior to slaughter. After slaughter each carcass was dressed i.e. intestines and other offals were removed. The head and bones of the extremities including the metarcarpals and metatarsus were removed. Kidneys were also removed but perienal fat was left intact. The following parameters were recorded on live animals and on the dressed carcass:

Initial live weight

Live weight gain (weekly weighings)

Live weight at slaughter

Dressed carcass weight

Dressing percentage

The carcasses were then wrapped separately in plastic sheets and stored under low temperature in a temperature controlled Electrolux deep freezer and allowed to stay there for 48 hours before underwater weights of the carcasses were determined. The underwater weights were determined as follows: A 400 l rectangular hard plastic basin was filled with water and the carcasses weighed while submerged in the water. The carcasses were suspended by means of a sisal twine and weighed to the nearest gram while submerged in water. The carcass specific gravity (S.G.) was determined by the water displacement method and the procedure followed was similar to that described by Meyer (1962). The specific gravity of each carcass was calculated from the equation:

$$S.G. = \frac{\text{weight of dressed warm carcass in air}}{\text{weight of carcass in air - weight of carcass under water}}$$

The weight of the carcass immediately after slaughter was used as the base weight in air while the carcass weight under water was taken after chilling for 48 hours. The carcasses were then divided down the middle of the back using a meat band saw. The right hand side of each carcass was used for chemical analyses while the left side was sold for consumption. The right hand side halves of the carcasses were then deep frozen for 12 hours, and then sliced into small pieces. This additional freezing was necessary to ease grinding as well as for obtaining a uniform mince especially in fat carcasses. The sliced pieces were ground in a two-horsepower Globe meat grinder through a 4-76 mm ($\frac{3}{16}$") plate. An attempt to grind the offals resulted in a very heterogenous sample due to the difficulty in grinding the more fibrous muscles in the offals into a uniform mince. The analyses were then limited to the dressed half carcasses as such . The ground sample was mixed thoroughly by hand, and the whole amount put through the grinder again. After another thorough mixing, a sample of approximately 700 g was taken for analysis. Prior to chemical analysis, the minced samples were freeze dried in an FTS- Multi-Dry Freeze Dryer.

The following analyses were carried out:

- Moisture content of the minced samples
- Crude protein (C.P.) %
- Ether extract (E.E.) %
- Ash content %
- Gross energy content (G.E.) %

The C.P. content was determined by the Kjeldahl method as outlined by A.O.A.C. (1965). Ether extract and ash contents were determined as outlined by A.O.A.C. (1960), while the gross energy content was determined by using an adiabatic Gallenkamp oxygen bomb calorimeter. Total feed intake was recorded in terms of average dry matter intake per day and DM intake/kg $W^{0.75}$/day, and the energy intake in terms of gross energy (G.E.), digestible energy (D.E.) and metabolizable energy /ME). ME values were obtained by multiplying DE values by a factor of 0.82. Energy values in kcal were converted into joule units by multiplying units calories x 4.184. The G.E. content of each carcass was calculated from its percentage fat (i.e. % E.E.) and percentage protein, and these were compared with the G.E. contents obtained by means of a bomb calorimeter. The energy value of fat was assumed to be 39.137 MJ/kg (9354 kcal/kg), while that of protein was assumed to be 23.30 MJ/kg (5570 kcal/kg, Garrett <u>et al.</u>, 1959). Gains in terms of carcass weight, carcass fat, carcass protein and carcass gross energy content were obtained by difference between the contents of the initial slaughter group and that of the experimental animals at slaughter.

A two way analysis of variance was carried out to compare parameters between the initial slaughter group and the experimental groups as well as within the experimental groups themselves. An LSD test was used for testing the differences between means. Linear regression and correlation analysis were carried out between carcass weight and carcass fat %. A t test was used to compare G.E. contents determined by a bomb calorimeter and G.E. contents estimated from fat and protein percentages. All statistical analyses were again carried out using an ABC 80 computer and the results verified with a TI programmable 57 Texas instruments hand calculator.

Experiment 5. Energy utilization of alkali-treated roughages fed to sheep

Essentially the layout of this experiment was similar to that of experiment 4, except that different species of animals and different roughages were used.

Twenty six Black Headed Persian uncastrated male sheep weighing approximately 30 kg and aged between 1½ to 2 years, were used in the experiment. Four groups of six animals each were matched for live weight, age, and general body conformation. One group was selected at random to represent the initial slaughter group. Additional two animals were added to this initial slaughter group for the same reason as explained in experiment 4 i.e. to increase the accuracy of measuring correlation between carcass specific gravity and carcass fat content. The animals in the remaining three groups were then each assigned randomly to the three experimental diets. The experimental diets were based on the following roughages:

Untreated maize stover

NaOH-treated maize stover

NaOH-treated <u>Hyparrhenia</u> silage

Prior to treatment and feeding, maize stover was chopped by hand using a "panga" (a huge hand knife) into 4 to 6 cm pieces long. NaOH treatment was carried out by soaking maize stover in a 1% NaOH solution overnight. The stover was packed in locally made round weld-mesh baskets and then dipped in ordinary round oil drums (about 200 l), containing the 1% NaOH solution. Heavy stones were placed on the stover to make them sink into the solution, and then the stover was allowed to soak in the solution overnight. It was then lifted up and the excess solution allowed to drip back into the drums. The stover was then washed and again allowed to drip as in experiment 4. After this the stover was ready for feeding. The weaker 1% NaOH solution was used because sheep refused to eat materials treated with stronger solutions than this. Apparently it was not possible to wash all the excess NaOH from the stover using a garden can. The stem of the maize stover is made up of extrememly porous material and this tends to absorb a lot of solution. After each treatment, titrations were carried out and strenght of the lye solution restored by adding NaOH as for experiment 3. The lye solution was used 7 times and then discarded. Fresh solutions were made each week.

The *Hyparrhenia* silage was made from natural pastures of almost pure stands of *Hyparrhenia* at the University farm Morogoro (Magadu Unit). The silage was made and treated by using a specially modified Taarup flail forage harvester (Kategile, 1981). The mature stand was cut at the beginning of the dry season when the grass was about 2 meters high and with a moisture content of about 50%. The forage harvester was modified to enable it to cut the grass and treat it with a NaOH solution simultaneously. A sodium hydroxide solution of 8% (w/v) strenght was pumped from a 440 l boom sprayer tank fitted with six nozzles. The flowrate of this solution was adjusted in order to pump out 25 litres of solution/ 100 kg of the cut forage. At this rate of flow, the moisture content of the grass was raised by 10% and the NaOH treatment rate was 4 kg NaOH/100 kg DM of roughage. The silage was preserved in an earth trench silo. The design, and modification of the forage harvester was carried out by the Institute of Agricultural Engineering of the Agricultural University of Norway, Aas-NLH.

In addition to the *ad libitum* feeding of the roughages described above, each animal was fed 200 grams of the same concentrate used in experiment 4. The animals were housed in individual pens and fed individually. Water was offered *ad lib*. All the animals were dewormed at the beginning of the experiment. A preliminary period of 3 weeks was followed by an experimental period of 100 days. One sheep died during the first two weeks of the preliminary period and was replaced by another similar sheep. Post mortem examination revealed urinary calculi as being the cause of the death of the animal. Since the sheep had been on the NaOH-treated maize stover diet for 2 weeks only, it was difficult to establish whether the alkali-treated roughage was the cause of the urinary caliculi and hence the death of the animal as such.

All carcass analysis and parameter measurements were handled as for experiment 4. Statistical analysis were also handled as for experiment 4.

RESULTS AND DISCUSSION

IV. RESULTS AND DISCUSSION

Experiment 1a. Treatment of wheat straw with different levels of NaOH/Na_2CO_3

The solubilization of the cell wall constituents of roughages by alkaline chemicals as well as the ability of these chemicals to delignify roughages, is thought to be chiefly responsible for the increase in digestibility when poor quality roughages are treated with alkaline chemicals such as NaOH. The results of experiment 1a shown in tables 21 and 22, indicate that NaOH was very effective in making the cell wall constituents (NDF) more soluble. The chemical also slightly made lignin more soluble when it was applied at the rate of 6 g/100 g of straw (DM). On the other hand, sodium carbonate (Na_2CO_3) apparently had no effect on these components. Neither of the chemical had any clear effect on the silica content of the straw. The implication of the results of table 21 and 22 are evident in tables 23 and 24. The increase in IVDMD, IVOMD and ESOM with increasing levels of NaOH was very clear. As would be expected from the results shown in tables 21 and 22, the results shown in tables 23 and 24 indicate that Na_2CO_3 had no effect in improving the digestibility of wheat straw. It is also clear from these tables that there was no interaction between NaOH and Na_2CO_3, and infact there appears to be a clear negative interaction between the chemicals on IVDMD, IVOMD and ESOM. The poor effect of Na_2CO_3 on improving the digestibility of low quality roughages was reported by Chandra and

Jackson (1971). Urio (1977) however, observed that in rations containing 60% treated maize stover, Na_2CO_3 was as good as NaOH in improving the digestibility of the rations in vivo. The results shown in tables 21 - 24 support the results reported by Chandra and Jackson (1971). It is however not clear why there was an apparent negative interaction between NaOH and Na_2CO_3. It is perhaps important to note that the method of treatment applied was a semi-dry one (1:1 ratio of straw : solution w/v). With weak chemicals such as Na_2CO_3, this might not be the appropriate method. Even with stronger chemicals such as NaOH, there is a clear difference when wet methods are applied as opposed to semi-dry or dry methods. It would therefore appear that, when semi-dry or dry methods are used the already inferior effect of weaker chemicals is eliminated altogether. Other factors such as the type of the roughage may also be of significance. It should also be remembered that both in vitro digestion and the ESOM method are measures of solubility brought about by enzymes. The application of higher levels of NaOH and Na_2CO_3 may have undesirable effects on the optimal conditions for the action of the enzymes and hence the apparently observed negative interaction.

Table 21. The effect of treatment of wheat straw with different levels of NaOH/Na_2CO_3 on NDF and ADF contents (% of DM)

NaOH g/100 g straw DM		Na_2CO_3, g/100 g straw DM 0	3	6
0	NDF	81.7	80.6	78.0
	ADF	52.4	51.8	49.4
3	NDF	76.1	77.1	73.1
	ADF	51.2	50.0	47.6
6	NDF	67.5	68.1	68.0
	ADF	48.5	48.3	47.4

Table 22. The effect of treatment of wheat straw with different levels of NaOH/Na_2CO_3 on lignin and silica contents (% of DM)

NaOH g/100 g straw DM		Na_2CO_3, g/100 g straw DM 0	3	6
0	Lignin	9.0	10.0	7.9
	Silica	1.9	1.4	0.9
3	Lignin	9.3	9.8	7.5
	Silica	1.9	2.0	0.8
6	Lignin	8.2	8.3	7.4
	Silica	1.5	1.5	0.6

Table 23. The effect of treatment of wheat straw with different levels of $NaOH/Na_2CO_3$ on IVDMD and IVOMD

NaOH g/100 g straw DM		Na_2CO_3, g/100 g straw DM		
		0	3	6
0	IVDMD	49.4	50.3	49.3
	IVOMD	47.9	47.5	43.3
3	IVDMD	55.4	51.4	51.2
	IVOMD	52.7	46.6	43.4
6	IVDMD	57.4	49.2	47.2
	IVOMD	52.5	40.8	34.8

Table 24. The effect of treatment of wheat straw with different levels of $NaOH/Na_2CO_3$ on ESOM

NaOH g/100 g straw DM	Na_2CO_3, g/100 g straw DM		
	0	3	6
0	21.0	21.9	23.0
3	31.3	24.4	22.4
6	38.5	31.5	19.1

Experiment 1b: Treatment of wheat straw with different levels of NaOH/$Ca(OH)_2$

The results shown in tables 25-27, indicate a similar trend as reported in experiment 1a. Table 28, however, indicates a clear effect of $Ca(OH)_2$ on ESOM. The ESOM method (Rexen, 1977) has been reported to be more sensitive in evaluating the effect of alkali-treatment of low quality roughages. The results in tables 27 and 28 seem to confirm this. Although again an apparent negative interaction in IVDMD and IVOMD (table 27) was observed, with ESOM, there was only an apparent negative interaction when $Ca(OH)_2$ levels were combined with the highest level of NaOH (i.e. the 6% NaOH level). It is known that $Ca(OH)_2$ is a weaker base than NaOH. It is evident that $Ca(OH)_2$ had a slight effect on solubilizing the organic matter of wheat straw but that this effect was so low that it could not be detected by the *in vitro* digestion technique but was markedly shown up when the ESOM method was used. Table 25 also shows that $Ca(OH)_2$ was effective in solubilizing the cell wall constituents (NDF). There was a decrease of about 10 percent units when the level of $Ca(OH)_2$ was increased from 0 to 6 g/100 g (DM) of the straw. Due to the fact that $Ca(OH)_2$ is only sparingly soluble, it would be expected that the method of treatment would again have a significant effect on the response to treatment. The semi-dry and dry method does not appear suitable when weaker chemicals are used. This view appears in line with the results of Sundstøl *et al.* (1979) who reported no effect on improvement when 4% solid $Ca(OH)_2$ was added to straw having a moisture content of up to 50%. With weaker and sparingly soluble chemicals such as $Ca(OH)_2$, the time of reaction would appear to have some notable effects. With overnight soaking as was done in this experiment, the sparingly soluble $Ca(OH)_2$ appears to have no effect. With similar treating time, Kategile et al. (1981) reported the same trend of results as reported here. The importance of the length of treating time with $Ca(OH)_2$ was clearly demonstrated by results of Wilkinson and Gonzalez-Santillana (1978) where the IVOMD was 49% after 1 day of treatment and 60.7% after 90 days of ensiling. Due to the impressive effects of NaOH, there appears to be a weakness of trying to apply the same conditions used in treatments with NaOH, even when utilizing weaker chemicals such as $Ca(OH)_2$ and Na_2CO_3. Although both $Ca(OH)_2$ and Na_2CO_3 are weaker and less effective than NaOH in improving the digestibility of straw, they are cheaper and easier to handle. As suggested by Sundstøl (1981), shorter treatment times followed by longer periods of "ripening" may give more promising results. This may be specially true for chemicals such as $Ca(OH)_2$ and Na_2CO_3. The results shown in table 28 in particular suggest that given a longer time of "ripening" and perhaps by modifying the method of treatment slightly, $Ca(OH)_2$ could have showed more positive results.

Table 25. The effect of treatment of wheat straw with different levels of NaOH/$Ca(OH)_2$ on NDF and ADF contents (% of DM)

NaOH g/100 g straw DM		$Ca(OH)_2$, g/100 g straw DM		
		0	3	6
0	NDF	81.5	74.9	70.4
	ADF	51.8	49.9	48.3
3	NDF	75.6	71.6	67.3
	ADF	48.8	49.7	48.0
6	NDF	69.2	62.4	62.7
	ADF	48.7	45.0	45.0

Table 26. The effect of treatment of wheat straw with different levels of NaOH/$Ca(OH)_2$ on lignin and silica contents (% of DM)

NaOH g/100 g straw DM		$Ca(OH)_2$, g/100 g straw DM		
		0	3	6
0	Lignin	9.8	9.2	9.0
	Silica	0.7	0.8	1.0
3	Lignin	9.7	8.6	9.0
	Silica	0.4	0.8	0.6
6	Lignin	9.1	6.8	8.1
	Silica	0.9	0.2	0.4

Table 27. The effect of treatment of wheat straw with different levels of NaOH/$Ca(OH)_2$ on IVDMD and IVOMD

NaOH g/100 g straw DM		$Ca(OH)_2$, g/100 g straw DM 0	3	6
0	IVDMD	50.8	47.1	47.2
	IVOMD	48.8	42.4	39.5
3	IVDMD	58.0	52.8	44.5
	IVOMD	54.7	47.2	33.6
6	IVDMD	58.0	47.8	45.7
	IVOMD	52.6	37.9	32.0

Table 28. The effect of treatment of wheat straw with different levels of NaOH/$Ca(OH)_2$ on ESOM

NaOH g/100 g straw DM	$Ca(OH)_2$, g/100 g straw DM 0	3	6
0	21.5	25.8	30.5
3	33.7	32.8	34.3
6	38.8	33.3	32.7

Experiment 2: Treatment of maize stover and Hyparrhenia grass with increasing levels of Na_2CO_3

The results of experiment 1a showed Na_2CO_3 to be a weak chemical and hence to have no effect on the improvement of digestibility of straw. One way of overcoming this disadvantage is to increase the concentration of the chemical per given amount of roughage. This alternative was tried and tables 29 and 30 show the results obtained.

With Hyparrhenia grass (table 29), increasing the level of Na_2CO_3 resulted in a decrease in the cell wall constituents (NDF) from 84% for the control sample to about 76% when 10 g Na_2CO_3/100 g (DM) of roughage were used for treatment. The changes in Lignin, ADF, IVDMD and IVOMD, although statistically significant,were very inconsistent. There was a marked and consistent increase however, in ESOM, with increasing levels of Na_2CO_3 ($P < 0.01$). At 9 g Na_2CO_3/100 g (DM) of roughage level of treatment, there was an increase of about 13 percent units in ESOM as compared to the control sample.

In the case of maize stover (table 30) significant and consistent changes were observed only in NDF and ESOM values. Increasing the level of Na_2CO_3 up to 10 g/100 g (DM) of the roughage resulted in a decrease of about 7 percent units in NDF contents, while there was in increase of about 11 percent units in ESOM values. No significant changes occured in ADF, lignin, and IVOMD with increasing levels of Na_2CO_3. The changes in IVDMD (table 30) although statistically significant, were very inconsistent.

The response obtained with increasing levels of Na_2CO_3 was higher with Hyparrhenia grass than with maize stover. The response measured in terms of IVOMD in Hyparrhenia grass, though inconsistent was statistically significant ($P < 0.05$) while with maize stover there was no significant change in IVOMD with increasing levels of Na_2CO_3. The results in tables 29 and 30 indicate that Na_2CO_3 was apparently not very effective in improving the digestibility of Hyparrhenia grass and maize stover. The trends shown in NDF and ESOM values in both the roughages, however, indicate that there was some effect which again could not be detected through the in vitro digestion techniques. The enzyme solubility method was in this case more sensitive in detecting the effect of Na_2CO_3. On the other hand, the poor response indicates that the method of treatment applied was either ineffective or perhaps inappropriate. Modifying the method of treatment by for instance increasing the time of ripening could result in better response.

Table 29. The effect of treatment of Hyparrhenia grass with increasing levels of Na_2CO_3 on NDF, ADF, lignin, ESOM, IVDMD and IVOMD (% of DM)

Level of Na_2CO_3 g/100 g roughage DM	NDF	ADF	Lignin	ESOM	IVDMD	IVOMD
0 (control)	84.0	62.9	9.3	13.7	42.1	37.1
1	83.9	64.2	9.9	15.5	39.6	36.1
2	83.2	64.1	10.1	15.8	41.7	38.3
3	82.3	63.6	9.6	18.1	42.0	38.5
4	82.7	65.3	9.8	20.9	43.4	39.6
5	79.4	63.6	9.5	21.6	43.3	39.0
6	79.6	62.9	8.3	23.5	44.1	39.4
7	80.8	64.6	8.3	25.5	44.9	39.6
8	76.2	60.2	7.9	24.9	46.6	41.5
9	77.1	58.9	7.9	26.6	48.6	43.1
10	75.9	58.1	8.0	20.8	45.4	38.5

Table 30. The effect of treatment of maize stover with increasing levels of Na_2CO_3 on NDF, ADF, lignin, ESOM, IVDMD and IVOMD (% of DM)

Level of Na_2CO_3 g/100 g roughage DM	NDF	ADF	Lignin	ESOM	IVDMD	IVOMD
0 (control)	82.1	49.4	7.9	29.0	44.1	40.5
1	79.7	51.5	7.7	28.8	43.0	38.6
2	78.2	51.3	8.5	32.4	44.9	39.8
3	78.4	52.5	8.4	35.7	44.5	38.6
4	77.6	52.7	8.6	36.1	43.7	37.3
5	76.8	51.6	8.4	36.2	44.9	39.7
6	77.5	52.0	8.0	36.0	45.4	38.8
7	76.9	53.1	8.3	38.4	44.2	38.8
8	74.5	51.3	8.1	40.5	45.6	37.8
9	73.5	49.7	6.6	41.4	46.3	38.5
10	73.4	49.0	6.6	43.6	46.5	38.9

As pointed out in the literature review, the response of low quality roughages to alkali treatment is very much influenced by the nitrogen contents of the roughages. Both maize stover and Hyparrhenia grass were extremely poor in crude protein contents (see table 36). Supplementation of these roughages with protein source would therefore be expected to improve the response of these roughages to alkali treatment, perhaps even with weaker chemicals such as Na_2CO_3. This seems to have been the case when these roughages were supplemented with a 10% herring meal (tables 31 and 32).

In the case of Hyparrhenia grass, addition of herring meal improved both the *in vitro* digestibility of the untreated material, and increased its response to Na_2CO_3 treatment. The correlation coefficient between the level of Na_2CO_3 used and IVOMD in Hyparrhenia grass was 0.733 ($P < 0.05$) when no herring meal was added, but when herring meal was added, the correlation coefficient was 0.905 ($P < 0.01$). This indicates an improvement in response to increasing levels of Na_2CO_3.

With maize stover, the addition of herring meal also resulted in a marked increase in IVOMD as well as improvement in response to increasing levels of Na_2CO_3. An interesting observation to note in this case is that the addition of herring meal to maize stover as such (untreated), resulted in a marked increase in IVOMD. With addition of herring meal to untreated sample, there was an increase of 10% units in IVOMD. This could only otherwise happen on the assumption that IVOMD of the added herring meal was 100%. This explanation cannot however hold, as an increase of about 15 % units in IVOMD was obtained by adding herring meal to maize stover samples. This spectacular response although also observed with Hyparrhenia grass, was not of the same magnitude (see fig. 2). With Hyparrhenia grass there was an increase of about 7 percent units in IVOMD at each level of Na_2CO_3 treatment, when herring meal was added. These results underline the importance of nitrogen supplementation to low quality roughages, and also show how nitrogen supplementation can influence the response of such roughages to alkali treatment. These observations are in line with those of Hasimoglu *et al.* (1969), Saxena *et al.* (1971) and Kategile (1979). In addition, these results show that different roughages respond differently to both alkali treatment and nitrogen supplementation. In this case *Hyparrhenia* grass responded to Na_2CO_3 treatment when measured in terms of improvement in IVOMD, while maize stover did not respond to Na_2CO_3 treatment. On the other hand, maize stover showed higher response to nitrogen supplementation (herring meal) than *Hyparrhenia* grass, and the herring meal supplementation improved its response to Na_2CO_3 which otherwise had been unobserved.

Table 31. The effect of adding 10% herring meal to *Hyparrhenia* grass treated with increasing levels of Na_2CO_3, on IVDMD and IVOMD

Level of $NaCO_3$ g/100 g roughage DM	IVDMD (No herring meal)	IVDMD (10% herring meal added)	IVOMD (No herring meal)	IVOMD (10% herring meal added)
0	42.1	44.7	37.1	41.5
1	39.6	44.4	36.1	40.9
2	41.7	46.1	38.3	42.4
3	42.0	48.2	38.5	45.2
4	43.4	49.3	39.6	46.4
5	43.3	49.5	39.0	46.3
6	44.1	51.3	39.4	48.3
7	44.9	52.0	39.6	48.6
8	46.6	53.4	41.5	50.0
9	48.6	53.9	43.1	50.0
10	45.4	52.6	38.5	47.5

Table 32. The effect of adding 10% herring meal to maize stover treated with increasing levels of Na_2CO_3 on IVDMD and IVOMD

Level of Na_2CO_3 g/100 g roughage DM	IVDMD (No herring meal)	IVDMD (10% herring meal added)	IVOMD (No herring meal)	IVOMD (10% herring meal added)
0	44.1	52.7	40.5	50.0
1	43.0	52.8	38.6	49.7
2	44.9	54.6	39.8	52.8
3	44.5	56.1	38.6	52.4
4	43.7	56.4	37.3	54.0
5	44.9	57.7	39.7	54.9
6	45.4	58.4	38.8	53.1
7	44.2	58.2	38.8	56.3
8	45.6	58.9	37.8	54.8
9	46.3	59.9	38.5	56.8
10	46.5	57.7	38.9	52.4

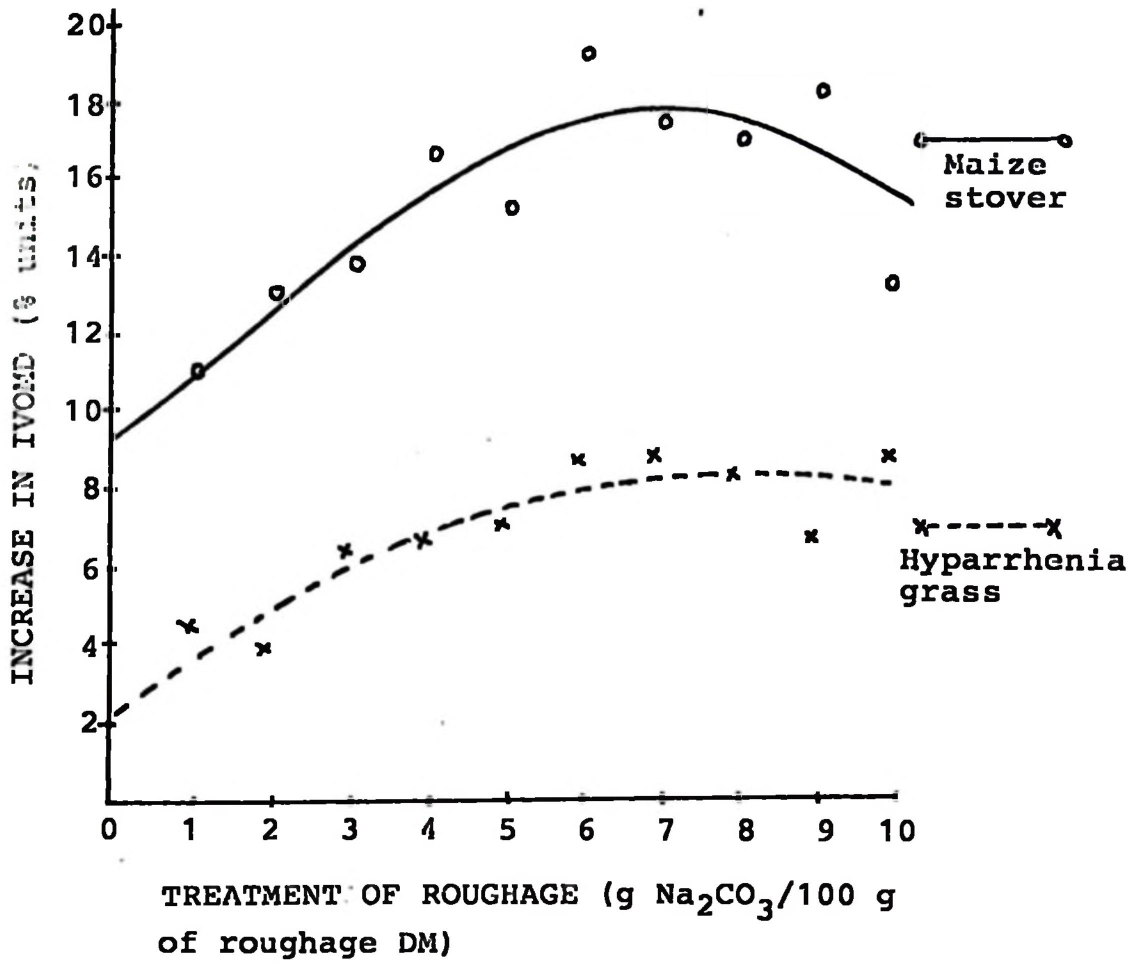

Fig. 2. The effect of adding 10% herring meal to Hyparrhenia grass and maize stover treated with different levels of Na_2CO_3

A note on the chemical composition of local Magadi Soda

Table 33. Chemical composition of samples of local Magadi soda

Places where Samples were collected	pH	P	Na	Ca	Cl	F (watersoluble Fluorine)	C
	Chemical composition, g/100 g of sample						
Lake Manyara	9.8	0.23	30.4	0.77	8.8	0.060 (600 ppm)	7.2
Ngarenanyuki (Arumeru)	9.9	0.13	17.9	0.93	13.1	0.206 (2060 ppm)	4.5
Kingori (Arumeru)	9.9	0.14	32.0	0.84	11.1	0.524 (5240 ppm)	6.0
Ilongero (Singida)	10.1	0.02	36.0	0.001	42.3	0.017 (170 ppm)	1.5

In Tanzania, there is no commercial production of Magadi soda although vast quantities of this compound are found in Lake Natron and Lake Eyasi. The mineral deposits in Lake Natron are likely to have the same composition as those at Lake Magadi in Kenya as the two lakes are a few kilometers apart and both situated within the Rift Valley The name Magadi as used in East Africa refers to a compound with a wide range in composition. The samples collected in the four places in Tanzania for instance differed not only in chemical composition as shown in table 33, but were also different in texture and colour. The only somewhat standardized product in East Africa, is that produced commercially by the Magadi soda company at Lake Magadi in Kenya.

Apart from being used as an animal salt, Magadi has other various domestic uses in many places in East Africa. In a number of places, the salt is used in cooking in order to soften seeds with hard coats such as unmilled maize, beans and other types of legumes, and even as a table salt. The latter use is common in Singida, and as seen in table 33, the sample from Ilongero was fairly rich in sodium chloride.

As pointed out earlier various forms of Magadi soda are traditionally fed with various types of roughages to ruminants. In this way the main effect of Magadi is thought to be in improving palatability of roughages; as well as in providing the animal with minerals. From the composition shown in table 33, it would appear that the high content of sodium chloride would have a definite effect to this end. Magadi is also known to have appreciable contents of Na_2CO_3 as seen in table 1; and this has been the main cause of interest in using Na_2CO_3 for treating straw. The alkalinity of the samples shown in table 33 in terms of high pH values, also suggests that Magadi could probably have some effect in treating low quality roughages with Magadi as such. The non availability of this product on a commercial basis in recent years has been the major set-back to this end.

It is also perhaps important to note the high fluorine contents of the samples in table 33.

The problem of fluorosis in cattle in the Ngarenanyuki area was noted some years back by Walker and Milne (1955). Ngarenanyuki, as well as other parts of East Africa, and Western Kilimanjaro are also noted for fluorosis in humans. Fluorosis in humans is also noted in some parts of Singida, although the samples from Ilongero had the lowest fluorine contents. If such minerals are to be used extensively the possibility of fluorosis problem has to be taken into consideration. Samples from Ngarenanyuki and Kingori appear to have rather high fluorine contents. The maximum permissible amount of fluorine by the EEC Animal feed Committee for sheep is for example 2000 ppm in compounded feeds (AGRA - EUROPE, 1971).

If Magadi soda was to be used extensively for animal feeding, a more detailed analysis of the chemical composition of the compound and standardization, appears to be necessary. In areas where Magadi soda is used traditionally for feeding livestock, eg. Ngarenanyuki, and Ilongero, the local people claim that the salt improves animal performance. It was indeed noted during the time of collection of the Magadi samples that animals in these areas seemed to thrive well, of course the serious problem of overstocking notwithstanding.

Experiment 3: "Dip and Drip" method of alkali treatment of straw

Results in table 34 show the effect of reusing sodium hydroxide solution for treating straw several times, on the chemical composition of both the lye solution and that of the treated straw. One of the reasons of conducting this experiment was that earlier observations had shown that if a NaOH solution was used continously, its effectiveness for treating straw was reduced as the solution became more and more saturated with organic and inorganic compounds. In table 34, it is seen that the dry matter (DM) content of the solution increased up to a maximum of about 7.2%. This increase in the dry matter of the solution was brought about by soluble organic matter from the straw into the solution which increased as more straw was treated. From this table it is also seen that as more solubles from the straw went into the solution, the organic matter (OM) proportion of the solution DM increased while the ash proportion decreased. that of After 15 times of reusing the solution, its DM content consisted of roughly 50% ash and 50% organic matter.

The sodium content of the solution also increased and reached a maximum of about 1.4% after 15 times of reusing the solution. It is also seen that there was a tendency for both the dry matter and the sodium content of the solution to stabilize as the solution was used several times (see figures 3 and 4). The implication of the stabilization of the sodium content of the solution is that with increasing reuse of the solution less and less NaOH will be needed for restrengthening the solution.

There was no consistent change in the sodium content of the treated straw although a slight increase was noted. The *in vitro* organic matter digestibility (IVOMD) and the enzyme soluble organic matter (ESOM) increased with increasing re-use of the solution. This increase is probably due to the fact that more solubles went into the solution at the beginning than later. In other words, as the solution became more saturated and its dry matter stabilized (figure 3) the straw "lost" less and less organic matter into the solution.

Table 34. The effect of reusing a 1.5% NaOH solution several times on the chemical composition of the lye solution and on the composition and digestibility of treated straw (Expt 3)

	Effect on lye solution			Effect on straw		
No of times of solution reuse	DM %	Ash % of DM	Na % of DM	Na % of DM	IVOMD	ESOM
1	1.9	96.4	0.7	3.2	54.6	39.6
2	2.8	74.5	0.9	2.9	56.5	40.2
3	3.1	69.9	1.0	2.5	60.7	42.4
4	3.7	65.2	1.0	2.7	57.0	41.1
5	3.9	66.1	1.0	2.5	58.4	42.4
6	4.2	66.1	1.0	2.6	60.7	45.1
7	4.9	59.3	1.0	3.4	56.4	44.7
8	5.6	53.7	1.1	3.8	57.9	47.4
9	6.1	53.6	1.3	3.5	58.8	46.2
10	6.4	51.9	1.2	3.4	64.4	49.8
11	6.8	52.0	1.4	3.7	60.1	49.5
12	7.3	50.9	1.4	3.5	59.5	49.0
13	7.1	52.3	1.4	3.6	61.8	50.6
14	7.2	52.6	1.5	3.4	61.6	51.9
15	7.3	52.3	1.4			

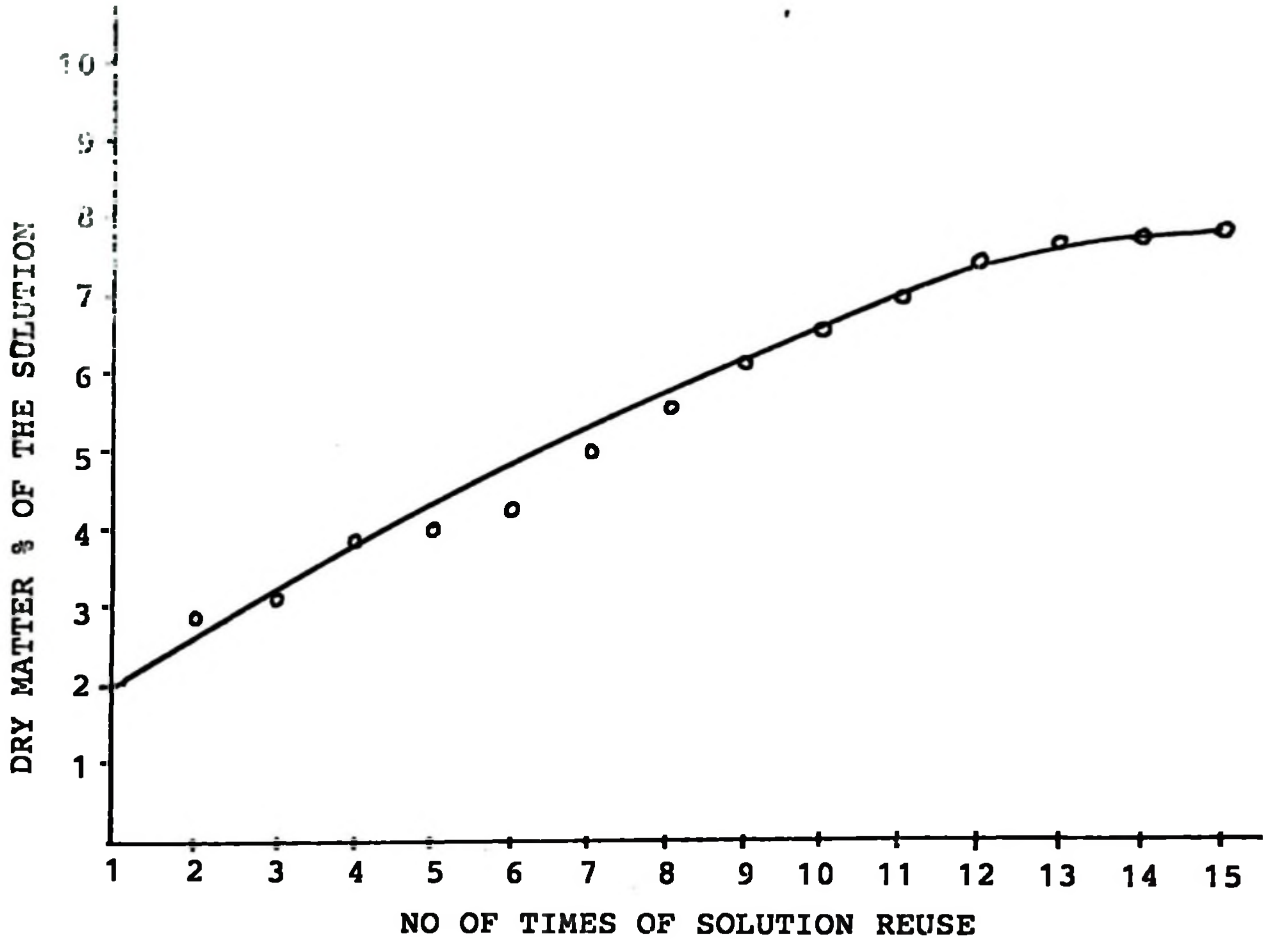

Figure 3. The effect of reusing a NaOH solution several times for treating straw on the dry matter content of the solution

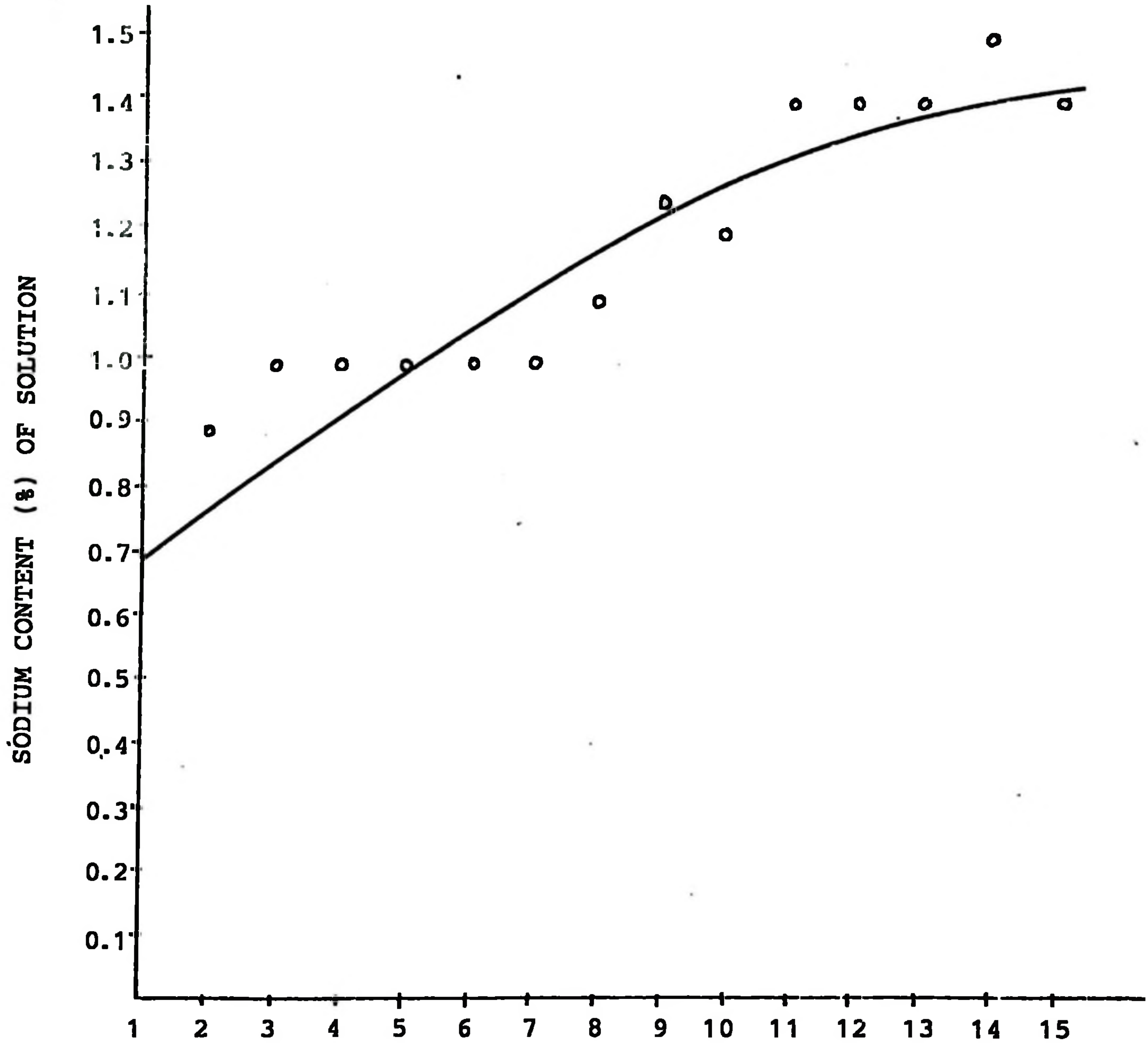

Figure 4. The effect of reusing a NaOH solution several times for treating straw on its sodium content

The results of the in vivo digestibility studies of the straw after 1, 5, 10 and 15 times of reusing the solution are shown in table 35. The straw dry matter and organic matter as well as digestible energy (DE) did not change with increasing reuse of the solution. There was a slight decrease in digestibility of dry matter and organic matter after the solution had been reused 15 times compared to fresh solution, but this difference was not statistically significant. The digestibility of crude fibre (CF), however, decreased significantly after the solution had been reused more than 10 times. This is probably an indication of a slight decrease in the effectiveness of the solution. As pointed above, this slight decrease in the strength of the solution did not result in a significant decrease in the digestibility of dry matter and organic matter.

Table 35. The effect of reusing a 1.5% NaOH solution several times on the digestibility (in vivo) of dip treated barley straw

No of times of solution reuse	digestion coefficients %			
	DM	OM	CF	DE
untreated straw	47.1^a	50.0^a	62.4^a	45.6^a
1	72.0^b	73.2^b	83.9^c	66.9^b
5	72.6^b	73.4^b	86.6^d	67.3^b
10	72.1^b	73.1^b	87.2^d	66.2^b
15	70.9^b	71.3^b	76.1^b	66.5^b

Means within a column with different superscripts are statistically different ($P < 0.05$).

The results of this study indicate that the "dip" treatment of straw is very effective in improving the digestibility of straw, and that the lye solution can be reused up to 15 times without any decrease in the effectiveness of the solution. According to Sundstøl (1981) this method can be modified by having shorter treatment times and longer ripening times (see appendix A). In this way the solution can probably be reused several times and the amount of sodium in the straw reduced. This alternative also seems to have a promising potential with weaker chemicals such as Magadi soda. It must be noted that although the dip method is simple and cheap, it does not eliminate the pollution problem altogether, as eventually the lye solution will have to be discarded. The method however reduces pollution drastically as comparatively small amounts of solution have to be discarded after being reused several times.

One major disadvantage of the dip method is the high sodium content of the straw (3% equivalent to about 5-6% NaOH). As pointed out in the literature review, the long effects of feeding roughages with high sodium content are not very clear. On the other hand, according to Tasker (1971) sodium especially in animals fed high proportions of forages and roughages can have some beneficial effects in balancing the potassium : sodium (K : Na) ratio as roughages and forages in general contain relatively higher K levels and low Na levels. Again this view is to a large extent speculative.

Experiment 4: Energy utilization of alkali-treated roughages fed to goats

The chemical composition of feedstuffs used in the production experiments is given in table 36. Liveweight changes and carcass composition of the experimental groups compared to the initial slaughter group are given in table 37. Feed intakes in terms of total dry matter intake, digestible energy intake, and metabolizable energy intake are given in table 38. Gains in live weight, carcass weight, carcass fat, carcass protein and carcass gross energy (GE) content are also given in table 38. These gains were obtained by difference between parameters in the initial slaughter group and the experimental animals.

The total dry matter intakes and gross energy intakes were not different between the three basal roughages. The *in vivo* dry matter digestibilities of the rations were, however, different. NaOH treatment increased the dry matter digestibility of the maize cobs based diet from 55.6 to 64.1%. The *Chloris gayana* hay had the highest dry matter digestibility among the three roughages (70.2%). A similar trend was observed when *in vitro* digestion studies were carried out on the roughages alone (table 36).

The difference in the *in vivo* digestibility of the diets also resulted in difference in digestible and metabolizable energy intake (table 38). While the metabolizable energy intake for the group fed NaOH-treated maize cobs was significantly higher than that of the group fed untreated maize cobs, it was not significantly different from that of the group fed Chloris gayana hay.

The observations noted in the metabolizable energy intake are also reflected in live weight at slaughter and the dressed warm carcass weight. While the group fed NaOH-treated maize cobs showed clear superiority to the group fed untreated maize cobs, it again did not differ significantly from that of the group fed on Chloris gayana hay.

There was no change in carcass dressing % between the initial slaughter group and the experimental animals. There was, however, a marked increase in the carcass fat % of the experimental groups compared to the initial slaughter group. This increase was of about 10% units of carcass fat in all the experimental groups. The differences shown in the carcass fat (as kg of fat) are rather reflections of the differences in the dressed carcass weights.

The carcass protein % was the same in all the three experimental groups which had all significantly lower percentage protein (about 2% units) compared to the initial slaughter group. The trend in the ash content was similar to that shown in the protein %. The slightly lower ash content of the experimental animals being a reflection that the animals had put on more flesh which then resulted in a low bone/flesh ratio.

The carcass gross energy (GE) content of the group fed NaOH-treated maize cobs was higher than that of the group fed untreated maize cobs but again not statistically different from that of the group fed Chloris gayana hay.

The carcass energy concentration measured in terms of GE/kg of dressed carcass was highest for the group fed on NaOH-treated maize cobs. The group fed *Chloris gayana* hay and that fed on untreated maize cobs were not significantly different in this respect.

It should also be noted that there was no significant difference ($P < 0.01$) between the GE energy determined by means of a bomb calorimeter and that estimated from fat % and protein %. The energy values referred to in this study however, are those obtained by means of the bomb calorimeter.

Feed efficiency expressed as kg feed/kg liveweight gain as well as kg feed/kg carcass gain (table 38) show a clear effect of NaOH treatment of maize cobs. This improvement in feed efficiency is a result of the improvement in the digestibility of the roughage, and the consequent improvement in digestible energy and metabolizable energy intakes. In this respect the group fed NaOH-treated maize cobs was slightly superior to the group fed *Chloris gayana* hay, although the difference was not statistically significant.

From tables 37 and 38, it is clear that the NaOH treatment of maize cobs resulted in improvement of the following parameters; metabolizable energy intake, feed efficiency, live weight at slaughter, dressed carcass weight, and carcass gross energy content as well as carcass gross energy/kg of carcass. The group fed NaOH-treated maize cobs while being clearly superior to the group fed untreated maize cobs in all these parameters, was however not significantly superior to the group fed on *Chloris gayana* hay.

The higher carcass gross energy content of the group fed NaOH treated maize cobs compared to the group fed untreated maize cobs, is an overall reflection of the effect of NaOH treatment on improving the nutritive value of maize cobs. It has also been speculated by some workers (notably Tasker, 1971) that sodium as such, together with potassium are essential components of enzymes and that its ions play an important role in active transport of glucose and amino acids. Whether the sodium provided through alkali treatment play any significant role to this effect, is a matter of speculation.

It was observed that some of the animals in the group fed NaOH-treated maize cobs had deposited a considerable amount of fat around the intestines. The initial slaughter group had negligible amount of intestinal fat, and therefore in addition to the reasons given in the materials and methods section , this parameter was not included in the study. However, it was recorded that some of the animals in this group had laid down up to 600 g of dissectible intestinal fat, although there was nevertheless great variation in this respect. In assessing the total fat laid down by animals on different feeds, it would appear that a measure of dissectible fat from the whole body, instead of the carcass alone, would be more appropriate.

It should be noted that although the group fed on untreated maize cobs did not perform as well as the others, it nevertheless did achieve appreciable gains. Part of this good performance can probably be attributed to the concentrate supplementation of the roughage which eventually was about 40% of the ration. In planning the experiment it had been expected that the proportion of concentrate in the overall dry matter intake would have been lower than recorded here. The roughages were offered ad libitum, and since the whole amount of concentrate offered was taken up (178 g DM), the average roughage dry matter of the roughage ended up making about 60% of the total dry matter intake. The performance of the group fed the untreated maize cobs, as well as that fed NaOH treated maize cobs, must be considered under the background that during the dry seasons most livestock invariably lose weight, not due to the consumption of poor quality roughages as such, but rather due to an acute shortage of feeds. Any improvement in the roughages which result in the roughages being able to sustain maintenance requirements of the animals and somehow halt the usual dry season losses in weight is thus viewed as an appreciable improvement of the nutritive value of the roughages under most tropical conditions. It is known that some of the low quality roughages can be improved remarkably by simply supplementing them with a protein source (Pigden, 1981). This seems to have been the case with the maize cobs used in this experiment.

When the factor of economics is considered, NaOH-treatment can certainly not be advocated under Tanzanian conditions, and presumably in most developing countries. The price of a 340 kg drum of solid caustic soda in Tanzania for example was about 300 Tz.shs. in 1976. The same drum costed 1700 Tz.shs. in 1980. At such high prices, NaOH-treatment of roughages certainly cannot be advocated. The more rational alternative would be to feed the maize cobs untreated, and supplement it with a protein rich concentrate. The ingredients used for the concentrate feed are all locally available at reasonably cheap prices. The possibility of utilizing NPN sources such as urea also exists. The only limitation is the cost of grinding maize cobs which is necessary for sheep and goats. With cattle, however, it is possible to feed whole maize cobs, if the cobs are soaked for 48 hours or more. The possibility of utilizing Magadi in such treatments also exists. It may be possible also to obtain an appreciable improvement with Magadi by modifying the dip and drip method as suggested by Sundstøl (1981, see appendix A). It may also be possible to design a special grinding machine for maize cobs to minimize tear and wear of the hammers and the screens. This has been successfully done in Peru (personal observation) and feedlots based on untreated maize cobs and maize stover, supplemented with a rich protein source were doing impressively well in that country. There seems to be a great potential in this respect in Tanzania as well.

The relationship between carcass fat % and carcass weight, and between carcass fat % and carcass specific gravity in goats

Comparative slaughter experiments are rather expensive and hence it has quite often been desirable to obtain estimates of body composition of the animal without rendering the carcass unfit for human consumption The various parameters which have been used to meet this goal were outlined in the literature review.

In this study correlations were determined between carcass weight and carcass fat %, as well as between carcass specific gravity and carcass fat %.

The correlation coefficient between carcass weight and carcass fat % was 0.84, and the following regression equation for predicting carcass fat % from carcass weight was obtained:

$$y = 1.67\,x - 4.27$$

where y = carcass fat %

x = carcass wight in kg

The correlation coefficient between carcass fat % and carcass specific gravity was -0.97, and the following regression equation for predicting carcass fat % from specific gravity measurements was obtained.

$$y = 459.3 - 423.2\,x$$

where y = carcass fat %

x = carcass specific gravity

These relationships compare well to those obtained by Barton and Kirton (1958) and those by Meyer (1962) with sheep. These relationships suggest that both carcass weight and carcass specific gravity can be used for estimating carcass fat % with an appreciable degree of accuracy. In this way, both carcass weight and carcass specific gravity can be utilized in estimating carcass fat % and consequently carcass energy content. It should be noted, however, that although the specific gravity had a stronger relationship with carcass fat % (r = -0.97) than carcass weight (r = 0.84), carcass specific gravity, as pointed out by Whiteman et al. (1953) and others, and as observed in this study, is a rather sensitive parameter to measure. The technique is therefore liable to technical experimental errors. The technique is also time consuming and comparatively costly. In many siatuations, it would appear that carcass weight would suffice as a measurement. As pointed out by Barton and Kirton (1958) and by Meyer (1960), carcass weight is the main economic product, and for comparative evaluation purposes, this parameter may be sufficient. From the observations noted in this study, however, particularly for the tendency of goats fed NaOH-treated maize cobs to lay down intestinal fat, it would appear that these two parameters (carcass weight and carcass specific gravity) may not give an accurate evaluation. In this case evaluation through the differences in the amount of dissectible fat as well as in the dressed carcass weight may be more appropriate and probably more accurate.

Table 36. Chemical composition and *in vitro* digestibility of the feedstuffs used in the feeding experiments with sheep and goats

Feedstuff	DM % as fed	OM % of DM	Ash % of DM	CP % of DM	IVDMD	IVOMD	G.E. MJ/kg DM
Untreated maize stover	90.6	93.6	6.0	2.4	43.2	47.0	16.32
NaOH-treated maize stover	88.9	92.4	7.4	2.3	49.8	55.9	16.32
Untreated maize cobs	87.0	95.3	3.9	2.2	44.5	46.2	17.29
NaOH-treated maize cobs	88.1	93.8	5.3	1.9	52.0	51.3	17.29
Hyparrhenia silage	62.0	88.6	10.1	2.8	49.2	48.5	15.21
Chloris gayana hay	87.7	90.3	9.1	3.4	54.6	56.2	16.42
Maize bran	92.1	96.6	3.5	11.4	72.2	70.3	18.29
Sunflower meal	84.1	91.4	8.6	25.4	55.4	56.5	20.38
Concentrate feed	94.8	92.3	7.5	16.4	71.2	73.6	17.86

Table 37. Live weight and carcass composition of goats fed rations based on different roughages (experimental feeding period, 100 days)

	Initial slaughter group	Basal roughage: Untreated maize cobs	Basal roughage: NaOH-treated maize cobs	Basal roughage: Chloris gayana hay
No of animals	6	6	6	6
Initial live weight, kg	15.3	15.2	15.8	15.5
Live weight at slaughter, kg	15.3^{a}	18.5^{b}	20.9^{c}	19.9^{bc}
<u>Composition of warm dressed carcass:</u>				
Warm carcass weight, kg	6.6^{a}	8.4^{b}	9.7^{c}	9.3^{bc}
Dressing percentage	43.3	45.5	46.4	46.6
Fat (% E.E.)	11.3^{a}	20.8^{b}	21.5^{b}	21.4^{b}
Fat, kg	0.75^{a}	1.75^{b}	2.09^{c}	1.99^{bc}
Protein, %	23.0^{b}	21.0^{a}	20.7^{a}	20.9^{a}
Protein, kg	1.52^{a}	1.76^{b}	2.01^{c}	1.94^{bc}
Ash, %	5.0^{b}	4.0^{a}	3.6^{a}	3.8^{a}
GE content, MJ	63.21^{a}	108.37^{b}	128.14^{c}	120.87^{c}
GE MJ/kg of warm dressed carcass	9.57^{a}	12.90^{b}	13.21^{c}	12.99^{bc}

Means within a row having no superscript or having at least one common superscript are not statistically different ($P < 0.05$).

Table 38. Total feed intake and energy gains in goats fed rations based on different roughages (experimental feeding period, 100 days)

	Basal roughage		
	Untreated maize cobs	NaOH-treated maize cobs	Chloris gayana hay
Feed intake			
DM intake, g/d	406.2	432	413.5
DM intake, g/kg $W^{0.75}$/d	45.6	44.4	44.0
GE intake, MJ/d	7.12	7.55	7.08
DM digestibility (*in vivo*) of the ration	55.6^{a}	64.1^{b}	70.2^{c}
DE intake, MJ/d	4.15^{a}	5.11^{b}	5.04^{b}
ME intake, MJ/d	3.40^{a}	4.19^{b}	4.13^{b}
Gains and feed efficiency			
Live weight gain, g/d	33.2^{a}	51.0^{b}	43.3^{b}
kg feed/kg live weight gain	13.0^{b}	9.3^{a}	9.9^{a}
Dressed carcass weight gain,kg	1.8^{a}	3.1^{b}	2.7^{b}
kg feed/kg carcass gain	22.5^{b}	13.9^{a}	15.3^{a}
Carcass fat gain, kg	1.0^{a}	1.34^{b}	1.24^{b}
Carcass protein gain, kg	0.25^{a}	0.49^{b}	0.43^{b}
Total gain in carcass GE content, MJ	45.15^{a}	64.92^{b}	57.66^{b}

Means within a row having no superscript or having at least one superscript in common, are not statistically different ($P < 0.05$).

Experiment 5: Energy utilization of alkali-treated roughages fed to sheep

Table 39 gives the carcass composition of the initial slaughter group and that of the experimental groups. The table also shows the initial live weight at the commencement of the experiment and the final weights at slaughter.

Feed intakes i.e. dry matter (DM) intake, digestible energy (DE) intake and metabolizable energy intake are shown in table 40. Gains in terms of live weight gain, carcass weight gain and carcass fat gain as well as gross energy gain are also given in table 40. In addition the table also shows the feed efficiencies of the experimental groups in terms of kg feed/kg live weight gain and kg feed/kg carcass weight gain.

The dry matter intake was the same for the groups fed untreated and NaOH-treated maize stover, while the intake of the group fed NaOH-treated *Hyparrhenia* silage was significantly lower. The proportion of concentrate in the overall dry matter intake was about 20% for the maize stover groups and about 25% for the group fed *Hyparrhenia* silage. It should be noted that concentrate was restricted (178 g DM/d) while the roughages were offered *ad lib.*

The *in vivo* dry matter digestibility of the rations based on the roughages was highest with the NaOH-treated maize stover, followed by the untreated maize stover and lowest for the NaOH-treated *Hyparrhenia* silage. In the *in vitro* dry matter and organic matter digestibility carried out on the roughages as such, the NaOH-treated *Hyparrhenia* silage had a slightly higher digestibility than the un-treated maize stover (table 36).

The digestible energy intake was the same for the groups fed untreated maize stover or NaOH-treated maize stover, but lower in the group fed *Hyparrhenia* silage. It should be noted that although the NaOH treatment increased the digestibility of the maize stover, and thus the group fed this roughage would be expected to have a higher digestible energy intake than the one fed untreated maize stover, the dry matter intake in the group fed untreated maize stover was slightly higher, and this resulted in the two groups eventually having the same digestible energy intake. It will also be remembered that the sheep refused to eat the maize stover treated with a 1.5% NaOH solution, until the strength of the solution was reduced to 1.0%. It has now been realized that the best alternative would probably have been to minimize treating time, and increasing the time of ripening as outlined in appendix A. It was thought that the slightly lower intake in the NaOH-treated maize stover compared to the untreated maize stover, was due to the high content of NaOH remaining in the spongy stems of stover. Too high sodium content has been reported to have a negative effect on intake (Meyer and Weir, 1954, Meyer *et al.*, 1955, Nelson *et al.*, 1955, Delvin and Roberts, 1963). The sodium content of the maize stover was not measured in this study, but it is likely that it was higher than that of the barley straw treated with a similar method in experiment 3 (The sodium content of the barley straw in this case was about 3%).

The metabolizable energy (ME) intake showed the same trend as digestible energy intake.

Live weight gain and feed efficiencies expressed as kg feed/kg live weight gain, and kg feed/kg carcass gain was the same for the three experimental groups. Apparently there was considerable variation within the groups. The gains in dressed carcass weight were the same for the groups fed untreated and NaOH treated maize stover. The group fed Hyparrhenia silage had significantly lower gains in this respect.

The gains in gross carcass energy content was higher with the group fed NaOH-treated maize stover, although due to a great variation within the groups, this gain was not significantly different from that observed with the group fed untreated maize stover. Both the groups fed on maize stover, however, gained significantly more gross carcass energy than the group fed on Hyparrhenia silage.

The tendency for the group fed NaOH-treated maize stover to put on more fat was again observed in sheep, but unlike in the case with goats, this difference was not significant. In sheep, there was no tendency of fat being deposited around the intestines as was the case with goats. Most of the fat in sheep was deposited around the tail (note fat tailed sheep used) as well as uniformly within the dressed carcass.

It was also noted that although there was an increase in carcass fat % in all the groups over the initial slaughter group, this increase was not of the same magnitude as was observed with goats. The reason for this is probably because the goats were in relatively poor condition at the beginning of the experiment and therefore responded more to feeding. The sheep on the other hand, were in a much better body condition at the beginning of the experiment, and thus although differences were observed, these were not as spectacular as those observed with goats.

It is also interesting to note that all the experimental groups gained in live weight, carcass weight, carcass fat and carcass gross energy content. Again although these gains may not appear that much impressive, they should be viewed against the background of massive losses in live weight common in the dry seasons in many tropical areas.

As pointed out earlier, the treatment of maize stover and *Hyparrhenia* silage with NaOH in Tanzania is no longer economically feasible. Due to the limit in the number of animals no group was fed untreated *Hyparrhenia* silage but the nutritive value of such silage is known to be very low. On the other hand, supplementation of the untreated maize stover with a concentrate as such, resulted in considerably impressive results. This confirms the observations noted in experiment 2 where maize stover responded very positively to nitrogen supplementation. The possibility of treating maize stover with Magadi also exists and perhaps by using the modified dip and drip method (appendix A) even better results than those observed in this study could be obtained.

The relationship between carcass fat % and carcass weight, and carcass specific gravity in sheep

The correlation coefficient between carcass weight and carcass fat % in sheep was only 0.52, The following regression equation for predicting carcass fat % from carcass weight was obtained:

$$y = 20.46 + 0.48\ x$$

where y = carcass fat %

x = carcass weight in kg

The correlation coefficient between carcass fat % and carcass specific gravity was -0.79, and the following regression equation was obtained for predicting carcass fat % from carcass specific gravity measurements:

$$y = 380.6 - 339\ x$$

where y = carcass fat %

x = carcass specific gravity

The correlation coefficient values indicate a rather poor relationship between the carcass weight and carcass fat % in the group of animals studied. This was probably caused by differences in ability or tendency to deposit fat around the tail. The Blackhead persian (Bhp) sheep at Morogoro have been crossbred with some other breeds of sheep, and this may have resulted in some genetical differences in fat deposition

Some of the smaller animals appeared more efficient in depositing more fat than some seemingly larger animals. This differential ability to deposit fat may then have affected the relationship between the carcass weight and the amount of fat the animal had deposited on. In such circumstances, it can only be concluded that carcass fat % cannot be predicted accurately from carcass weight. The comparatively lower correlation coefficient observed between the carcass fat % and carcass specific gravity, compared to that obtained with goats, was probably due to technical errors. In the case of sheep carcasses, it was particularly difficult to take measurements of carcass under water, due to a tendency of some of the fat carcasses to float on water.

The equations recorded here cannot probably be applied to sheep generally. The heterogenous nature of the sheep found in East Africa for example may further complicate this exercise. It is therefore thought that a measure of dissectible fat as such, is likely to be more accurate in evaluating the amount of fat deposited by sheep on different treatments where complete analysis of the carcass is not feasible or desirable.

Table 39, Live weight and carcass composition of sheep fed rations based on different roughages (experimental feeding period, 100 days)

	Initial slaughter group	Basal roughage: Untreated maize stover	Basal roughage: NaOH-treated maize-stover	Basal roughage: NaOH-treated Hyparrhenia silage
No of animals	6	6	6	6
Initial live weight, kg	31.1	30.3	31.1	30.4
Live weight at slaughter, kg	31.1[a]	38.5[b]	38.5[b]	37.4[b]
Composition of warm dressed carcass:				
Warm carcass weight, kg	14.4[a]	17.9[b]	17.9[b]	16.9[b]
Dressing percentage	46.4	46.7	46.2	45.2
fat (% E.E.)	26.5[a]	28.9[b]	30.6[b]	28.9[b]
fat, kg	3.8[a]	5.4[b]	5.5[b]	4.9[b]
protein, %	14.1[b]	12.0[a]	12.2[a]	13.4[b]
protein, kg	2.03[a]	2.15[b]	2.18[b]	2.26[c]
ash %	5.3[b]	4.5[a]	4.0[a]	4.0[a]
GE content, MJ	194.82[a]	253.85[b]	260.68[b]	238.68[b]
GE MJ/kg of dressed carcass	13.53[a]	14.18[b]	14.56[b]	14.1[b]

Mean within a row having no superscript or having at least one superscript in common, are not statistically different ($P < 0.05$).

Table 40. Total feed intake and energy gains in sheep fed rations based on different roughages (experimental feeding period, 100 days)

	Basal roughage		
	Untreated maize stover	NaOH-treated maize stover	NaOH-treated Hyparrhenia silage
<u>Feed intake</u>			
DM intake, g/d	944^{b}	929^{b}	716^{a}
DM intake, g/kg $W^{0.75}$/d	61.1^{b}	60.3^{b}	47.4^{a}
GE intake, MJ/d	15.68^{b}	15.44^{b}	11.36^{a}
DM digestibility (*in vivo*) of the ration	56.5^{b}	59.3^{c}	51.1^{a}
DE intake, MJ/d	9.23^{b}	9.43^{b}	6.15^{a}
ME intake, MJ/d	7.57^{b}	7.74^{b}	5.04^{a}
<u>Gains and feed efficiency</u>			
Live weight gain, g/d	80.7	74.0	70.0
kg feed/kg live weight gain	11.7	13.1	10.8
Dressed carcass weight gain, kg	3.5^{b}	3.5^{b}	2.5^{a}
kg feed/kg carcass gain	26.97	26.54	28.64
Carcass fat gain, kg	1.6^{b}	1.7^{b}	1.1^{a}
Total gain in carcass GE, MJ	59.1^{b}	65.86^{b}	43.8^{a}

Means within a row having no superscript or having at least one superscript in common, are not statistically different ($P < 0.05$).

CONCLUSION

V. CONCLUSION

The results of the laboratory scale experiments indicate that the use of weak chemicals such as sodium carbonate and calcium hydroxide for treating low quality roughages probably require longer time of reaction. It was also observed that both Na_2CO_3 and $Ca(OH)_2$ which are weak chemicals give poor or no effects at all when very low ratios of solution/straw (1:1, v/w) are used with short reacting time. There is neither any beneficial effect of combining either of these chemicals with sodium hydroxide when semi-dry methods are used with short reacting time; there is in effect a tendency for a negative interaction when such combinations are used. The cause of this apparent negative interaction is not clear.

The laboratory scale experiments also confirm the fact that difference exists between roughages in the degree of response to alkali treatment; even with weak chemicals such as Na_2CO_3. In this study for example, <u>Hyparrhenia</u> grass responded to treatment with high levels of Na_2CO_3 (> 4 g Na_2CO_3/100 kg DM of roughage) while maize stover did not. Nitrogen supplementation seems to have a clear and important effect in improving the digestibility of low quality roughages. In this study, both <u>Hyparrhenia</u> grass and maize stover responded sharply to a protein source supplementation; maize stover in particular seems to respond better to nitrogen supplementation than to Na_2CO_3 treatment. There seems to be a possibility of improving the effectiveness of Na_2CO_3 and perhaps that of Magadi soda, by using the dip method and by manipulating the factors of time of treatment and ripening.

The chemical composition of local Magadi soda, shows the possibility of at least improving voluntary feed intake through the high salt content of this compound. No general recommendations on the use of the compound can however be suggested in the absence of a standardized commercial product. High contents of certain chemicals at toxic levels such as fluorine have also to be taken into consideration.

The production experiments with goats and sheep show that the otherwise mass weight losses in livestock experienced during the dry season can be overcomed by proper utilization of crop residues and other dry season grasses. The nutritive value of these crop residues can be improved by alkali treatment or by simply supplementing them with the limiting nutrients, notably nitrogen. The practice of fattening sheep and goats on a more or less "scavenging" level in East Africa, can greatly be improved by proper utilization of crop residues, which are in most places abundant.

The dip method seems to be simple and effective in treating roughages, which were in this case well utilized by sheep and goats.

Animals fed alkali-treated roughages seem to put on more fat than those fed an untreated roughage. In this study, goats fed alkali treated roughage had a tendency to deposit more fat around the intestines although this observation needs further investigation.

The use of NaOH for treating roughages either through the dip method, use of the modified forage harvester, or by other methods, is no longer economically feasible in Tanzania. Possibility however exists of using chemicals such as Na_2CO_3, NH_3 and Magadi soda. By using the modified dip method with Magadi soda or Na_2CO_3 per se, better results may be obtained.

The relationship obtained between carcass weight and carcass fat %, as well as between carcass specific gravity and carcass fat % in goats indicate that these parameters can be used for estimating carcass fat % and consequently its energy content without otherwise resorting to complete chemical analysis of the carcass. These parameters, however, did not give promising results with sheep. The heterogenous nature of the East African sheep, with their apparent different efficiencies in fat deposition may probably limit the use of such equations. The sensitivity of carcass specific gravity measurements may also result in considerable technical errors. Other methods of evaluating fat deposition such as determination of dissectible fat, may result in more accurate results.

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VI. REFERENCES

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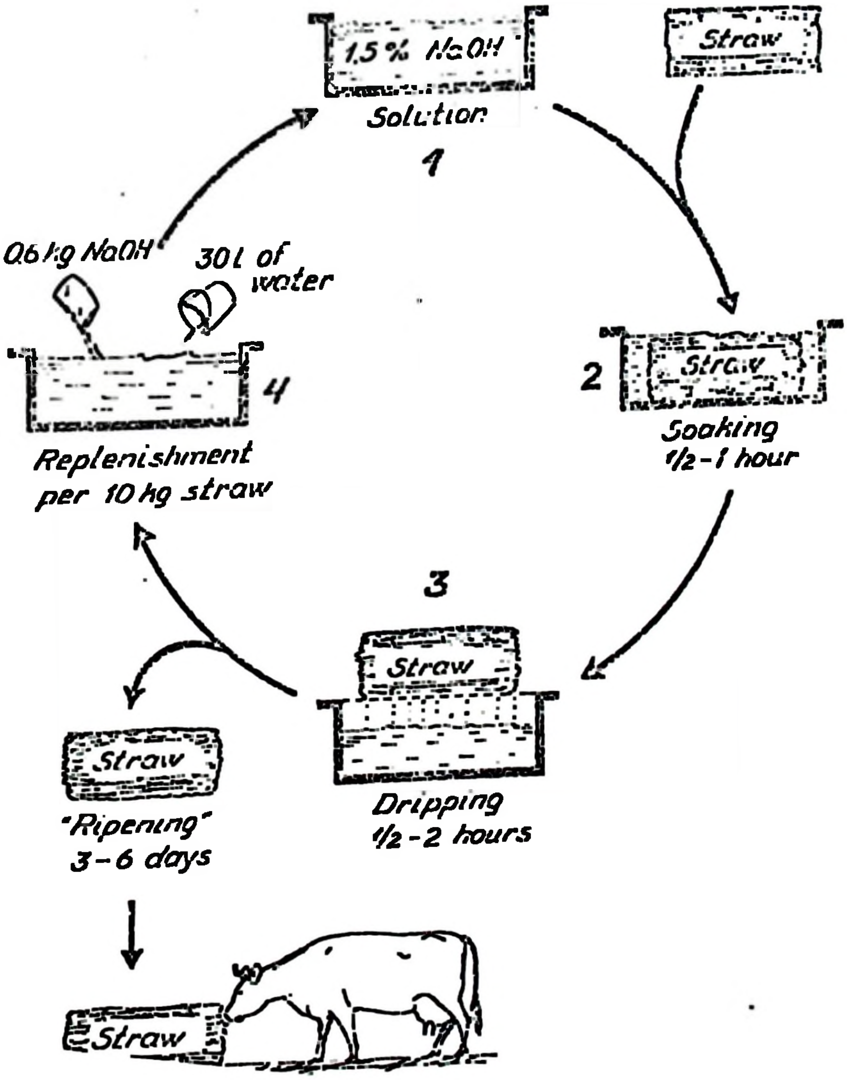
APPENDIX A

DIAGRAMATIC OUTLINE OF DIP TREATMENT OF STRAW (AFTER SUNDSTØL, 1981)



Appendix B1

ANOVA table for dry matter digestibility in Experiment 3

Source	DF	SS	MS	F
Treatment	4	991.12	247.78	229.43 **
Replication	1	0.96		
Error	4	4.32	1.08	
Total	9	996.40		

Appendix B2

ANOVA table for organic matter digestibility in Experiment 3

Source	DF	SS	MS	F
Treatment	4	834.80	208.70	193.69 **
Replication	1	0.25		
Error	4	4.31	1.08	
Total	9	839.36		

Appendix B3

ANOVA table for crude fibre digestibility in Experiment 3

Source	DF	SS	MS	F
Treatment	4	869.39	217.34	539.99 **
Replication	1	0.02		
Error	4	1.61	0.40	
Total	9	871.02		

Appendix B4

ANOVA table for digestible energy in Experiment 3

Source	DF	SS	MS	F
Treatment	4	713.73	178.43	109.64 **
Replication	1	1.60		
Error	4	6.51	1.63	
Total	9	721.84		

Appendix B5

ANOVA table for live weight at slaughter in Experiment 4

Source	DF	SS	MS	F
Treatment	3	106.33	35.44	9.65 **
Replication	5	34.64		
Error	15	55.07	3.67	
Total	23	196.04		

Appendix B6

ANOVA table for warm carcass weight in Experiment 4

Source	DF	SS	MS	F
Treatment	3	32.52	10.84	12.00 **
Replication	5	3.70		
Error	15	13.55	0.90	
Total	23	49.77		

Appendix B7

ANOVA table for dressing percentage in Experiment 4

Source	DF	SS	MS	F
Treatment	3	40.70	13.56	1.45 NS
Replication	5	57.69		
Error	15	140.40	9.36	
Total	23	238.79		

Appendix B8

ANOVA table for carcass fat percentage in Experiment 4

Source	DF	SS	MS	F
Treatment	3	451.04	150.34	381.59 **
Replication	5	0.89		
Error	15	5.91	0.39	
Total	23	457.84		

Appendix B9

ANOVA table for carcass protein percentage in Experiment 4

Source	DF	SS	MS	F
Treatment	3	21.54	7.18	17.60 **
Replication	5	5.02		
Error	15	6.12	0.41	
Total	23	32.68		

Appendix B10

ANOVA table for carcass ash percentage in Experiment 4

Source	DF	SS	MS	F
Treatment	3	7.50	2.50	18.29 **
Replication	5	3.62	0.72	
Error	15	2.05	0.13	
Total	23	13.17		

Appendix B11

ANOVA table for carcass gross energy content in Experiment 4

Source	DF	SS	MS	F
Treatment	3	1526.75	508.91	27.29 **
Replication	5	61.91		
Error	15	279.69		
Total	23	1868.35	18.64	

Appendix B12

ANOVA table for dry matter intake g per day in Experiment 4

Source	DF	SS	MS	F
Treatment	2	21.27	10.63	1.22 NS
Replication	5	68.82		
Error	10	87.02	8.70	
Total	17	172.11		

Appendix B13

ANOVA table for dry matter intake g per kg $W^{0.75}$ per day in Experiment 4

Source	DF	SS	MS	F
Treatment	2	8.92	4.46	0.77 NS
Replication	5	21.91		
Error	10	57.73	5.77	
Total	17	88.56		

Appendix B14

ANOVA table for gross energy intake MJ/d in Experiment 4

Source	DF	SS	MS	F
Treatment	2	82.86	41.43	1.53 NS
Replication	5	178.14		
Error	10	271.52	27.15	
Total	17	532.52		

Appendix B15

ANOVA table for dry matter digestibility in Experiment 4

Source	DF	SS	MS	F
Treatment	2	658.94	329.47	68.43 **
Replication	5	3.37		
Error	10	48.15	4.81	
Total	17	710.46		

Appendix B16

ANOVA table for digestible energy intake MJ/d in Experiment 4

Source	DF	SS	MS	F
Treatment	2	340.71	170.35	9.49 **
Replication	5	116.75		
Error	10	179.58	17.96	
Total	17	637.04		

Appendix B17

ANOVA table for metabolizable energy intake MJ/d in Experiment 4

Source	DF	SS	MS	F
Treatment	2	229.66	114.83	9.49 **
Replication	5	79.04		
Error	10	121.00	12.10	
Total	17	429.70		

Appendix B18

ANOVA table for live weight gain g/d in Experiment 4

Source	DF	SS	MS	F
Treatment	2	9.60	4.80	3.75 NS
Replication	5	14.76		
Error	10	12.80	1.28	
Total	17	37.16		

Appendix B19

ANOVA table for feed efficiency kg feed/kg gain in Experiment 4

Source	DF	SS	MS	F
Treatment	2	47.78	23.89	4.86 *
Replication	5	38.90		
Error	10	49.21	4.92	
Total	17	135.89		

Appendix B20

ANOVA table for live weight at slaughter in Experiment 5

Source	DF	SS	MS	F
Treatment	3	227.65	75.88	18.90 **
Replication	5	461.28		
Error	15	60.23	4.01	
Total	23	749.16		

Appendix B21

ANOVA table for warm carcass weight in Experiment 5

Source	DF	SS	MS	F
Treatment	3	48.90	16.30	6.65 **
Replication	5	130.14		
Error	15	36.79	2.45	
Total	23	215.83		

Appendix B22

ANOVA table for dresssing percentage in Experiment 5

Source	DF	SS	MS	F
Treatment	3	8.11	2.70	0.24 NS
Replication	5	35.69		
Error	15	168.12	11.21	
Total	23	211.92		

Appendix B23

ANOVA table for carcass fat percentage in Experiment 5

Source	DF	SS	MS	F
Treatment	3	56.56	18.85	5.85 **
Replication	5	14.91		
Error	15	48.31	3.22	
Total	23	119.78		

Appendix B24

ANOVA table for carcass protein percentage in Experiment 5

Source	DF	SS	MS	F
Treatment	3	15.05	5.01	9.26 **
Replication	5	3.54		
Error	15	8.13	0.54	
Total	23	26.72		

Appendix B25

ANOVA table for carcass ash percentage in Experiment 5

Source	DF	SS	MS	F
Treatment	3	5.24	1.74	6.79 **
Replication	5	2.58		
Error	15	3.86	0.25	
Total	23	11.68		

Appendix B26

ANOVA table for carcass gross energy content in Experiment 5

Source	DF	SS	MS	F
Treatment	3	1576.15	525.38	8.26 **
Replication	5	2935.10		
Error	15	954.10	63.61	
Total	23	5465.34		

Appendix B27

ANOVA table for dry matter intake g per day in Experiment 5

Source	DF	SS	MS	F
Treatment	2	19.50	9.75	84.21 **
Replication	5	10.25		
Error	10	1.16	0.11	
Total	17	30.91		

Appendix B28

ANOVA table for dry matter intake g per kg $W^{0.75}$ per day in Experiment 5

Source	DF	SS	MS	F
Treatment	2	71.21	35.60	136.88 **
Replication	5	1.31		
Error	10	2.60	0.26	
Total	17	75.12		

Appendix B29

ANOVA table for gross energy intake MJ/d in Experiment 5

Source	DF	SS	MS	F
Treatment	2	70.64	35.32	112.07 **
Replication	5	26.31		
Error	10	3.15	0.32	
Total	17	100.10		

Appendix B30

ANOVA table for dry matter digestibility in Experiment 5

Source	DF	SS	MS	F
Treatment	2	210.86	105.43	174.84 **
Replication	5	5.65		
Error	10	6.03	0.60	
Total	17	222.54		

Appendix B31

ANOVA table for digestible energy intake MJ/d in Experiment 5

Source	DF	SS	MS	F
Treatment	2	4076.26	2038.13	161.49 **
Replication	5	974.97		
Error	10	126.21	12.62	
Total	17	5177.44		

Appendix B32

ANOVA table for metabolizable energy intake MJ/d in Experiment 5

Source	DF	SS	MS	F
Treatment	2	2741.72	1370.86	162.69 **
Replication	5	654.56		
Error	10	84.26	8.42	
Total	17	3480.54		

Appendix B33

ANOVA table for live weight gain g/d in Experiment 5

Source	DF	SS	MS	F
Treatment	2	3.49	1.74	0.58 NS
Replication	5	10.07		
Error	10	29.96	2.99	
Total	17	43.52		

Appendix B34

ANOVA table for feed efficiency kg feed/kg gain in Experiment 5

Source	DF	SS	MS	F
Treatment	2	16.99	8.49	1.24 NS
Replication	5	45.66		
Error	10	68.56	6.85	
Total	17	131.21		