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DIGESTIBILITY OF CHEMICALLY TREATED CROP RESIDUES
USING THE NYLON BAG TECHNIQUE

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DIGESTIBILITY OF CHEMICALLY TREATED CROP RESIDUES USING THE NYLON BAG TECHNIQUE

By

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ABSTRACT

DIGESTIBILITY OF CHEMICALLY TREATED CROP RESIDUES USING THE NYLON BAG TECHNIQUE

By

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Three crop residues, wheat straw, corn cobs, and corn stover, were subjected to the following chemical treatments: (1) control--the untreated material; (2) 4% H_2O_2; (3) alkaline hydrogen peroxide (AHP), (4) 4% NH_4OH followed by 4% H_2O_2; (5) 4% NH_4OH, and (6) 4% NaOH. Two mature holstein cows maintained on an alfalfa hay diet plus trace mineralized salt were used to incubate samples for 8, 24, and 72 hours. Two nylon bags per treatment were removed from each cow after each incubation period. Two sets of incubations were carried out and dry matter, cellulose, ADF, and permanganate lignin were determined. NDF was determined on a separate set of samples.

Treatment did not alter the cellulose, ADF or lignin content of wheat straw. The cellulose content of corn stover was significantly increased by NH_4OH-H_2O_2 ($P < 0.01$) and NaOH ($P < 0.05$). The same treatments increased ADF content ($P < 0.05$). NH_4OH significantly increased both the ADF ($P < 0.05$) and cellulose ($P < 0.01$) content of corn cobs while NH_4OH increased the cellulose ($P < 0.01$) content only. The level of lignin in the corn residues was not altered by chemical treatment.

Treatments 3 to 6 significantly increased ($P < 0.01$) the in situ digestibility of wheat straw DM, ADF, NDF, and cellulose. Corn stover DMD was significantly enhanced by treatments AHP, NH_4OH-H_2O_2, NaOH ($P < 0.01$) and NH_4OH ($P < 0.05$). These treatments also increased ($P < 0.01$) the corn stover ADF and cellulose digestion. NDF disappearance was increased by treatments 3, 4, 5 ($P < 0.05$) and 6 ($P < 0.01$). Corn cob DM and NDF digestion was significantly increased ($P < 0.01$) by treatments 3 to 6. The ADF disappearance was increased by treatments 3, 6 ($P < 0.01$) and 5 ($P < 0.05$). These treatments also increased ($P < 0.01$) cellulose disappearance. Treatment 2 was not effective in increasing disappearance and did not alter the composition of the crop residues.

Rates of disappearance were calculated for incubation periods 0-24 hours and 24-72 hours. Rates for the 0-24 hour period were higher than for the second period.

To my husband Chad

and our children Tapiwanashe David and Tariro Nadine

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CHAPTER ONE

INTRODUCTION

Feeding animals adequately, while being important the world over, is of much concern in developing countries where adequate feeding of the human population is, at most times, a problem. Crop residues, the plant materials remaining after crops are harvested, are an important source of animal feed especially in those areas where feed production is unable to meet animal nutrient requirements, especially during the dry season.

Crop residues are of poor nutritive value and this limits their usefulness to the animal. Crude protein content is often too low to meet the nutrient requirements of the animal and supplementation is necessary. The residues are high in fiber, which contains an appreciable amount of lignin. The energy in the fibrous material is in a complex association between cellulose, hemicellulose, and lignin. This, as well as crystallinity of the cellulose, prevents the hydrolysis of the cellulose by microbial cellulase enzymes in the rumen.

Although the degree of lignification differs among plant parts, the lignification is greatest by harvest time since it increases as the plant matures. To increase the nutritive value of crop residues as a ruminant feed, methods must be developed to increase the digestibility thus increasing the energy availability. Research which has been done to meet this goal has involved the use of various physical and chemical methods alone and in various combinations.

Treatment of crop residues requires that it be gathered in some central place for treatment. In Zimbabwe, as in many other countries, animals are mostly let out into the fields to graze the residues. Few farmers bring the residues to a central place for feeding. However this can be done without much extra cost since this work occurs at a time when there is not a great competition for labour between different jobs on the farm.

The objective of this investigation was to determine the improvement in the digestibility of some crop residues as a result of chemical treatment with hydrogen peroxide, ammonium hydroxide and sodium hydroxide (NaOH).

Using ammonium hydroxide could provide a source of NPN to enhance feed utilization and meet the animal's needs. Hydrogen peroxide is very mild and could therefore be handled by small scale farmers, thus avoiding the use of NaOH which is very caustic and expensive.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Limitations of Crop Residues and Similar Roughages

The use of cereal straws and other crop residues is limited because of their low nutritive value. This poor quality is characterized by low digestibility of the fiber, which makes up a large proportion of the material. The material is highly lignified and this is the main cause of low digestibility because the potentially digestible material is shielded by the lignin. The composition of residues depends on species, variety, time of planting, time of harvest, cultural practices, growing conditions as well as location (Jackson 1977, Klopfenstein 1981, Owen 1979). In a review, Jackson (1977) compiled results of chemical analyses of roughages. The results show that cell walls account for 60-80% of the DM. Cottonseed hulls, sawdust and bark contain more than 90%. Lignin content ranges from 7-13% except for sawdust and bark which exceed 20%. Paddy straw and hulls have a high silica content (13% and 22% respectively vs 0-6% for most residues) which is a major cause of poor digestibility. Cellulose, a potential energy source for the ruminant is the major component of the cell wall fraction, ranging from 30% to 59%. It is evident that if a way of overcoming digestion inhibition by lignin and silica is available, these roughages can provide a good energy source for animal feeding.

2.2 Physical Treatment

Physical treatment basically disrupts the relationship between structural components making carbohydrates more accessible to digestion.

2.2.1 Particle size reduction

Grinding of roughages increases intake in ruminants (Nangole 1983, Greenhalgh and Wainman 1972 cited by Walker 1984). The increase is accounted for by increased density of the feed as well as a decrease in the amount of chewing time required for the feed (Walker 1984). The increase in intake due to chopping and grinding is more evident in sheep and young cattle and less so in older cattle.

Fine ball milling, which disrupts the celllulose-lignin linkages has been found to increase in vitro digestion of cellulose (Dehority and Johnson 1961). Walker (1984) also quotes an increase in in vitro DMD from the work of Pigden aand Heaney (1969). However in vivo digestibility tends to decrease because of increased passage rate of small particles, which pass through the digestive tract before maximum utilization can be made. Reduction of particle size by milling does not appear to be very practical.

Work to compare roughages ground to pass through different size sieves has produced variable results. In some cases there was no difference as far as animal performance is concerned as measured by intake, digestibility and weight gain. In others, feed efficiency and weight gain were increased (Shirley 1986).

While cubed barley straw increased dry matter intake in cows, it was insufficient to maintain butterfat levels when it comprised less than 35% of the diet. Chopped straw produced higher butterfat levels and was sufficient at 20%.

Pelletting can increase intake by as much as 60-115% (Walker 1984) although Hacket et al. (1975) say that an increase is not always guaranteed. According to the work of Heaney et al. 1963 (Walker 1984) pelletting may decrease digestibility.

Reducing particle size of low quality roughages has the advantages of producing a product that is more dense and uniform which is easier to handle and mix into diets. The main disadvantages are reduction in milk fat levels and increased susceptibility to health problems like appetite loss and bloat (Owens 1978, Walker 1984). Because the metabolizable energy (ME) content is not affected by particle size reduction the amount of ground low quality roughage material that can be fed to high producing animals like dairy cows is limited (Owens 1978).

Owens (1978) and Walker (1984) point out that assessing the effects of grinding and milling from the work of many researchers is made difficult by a lack of uniformity in the description of particle size. They stress that defining of the modulus of fineness (MF) or modulus of uniformity (MU) rather than simple sieve size is a better approach.

2.2.2 Steam pressure treatment

High pressure steam is hydrolytic, in that it breaks chemical bonds making treated roughages more digestible than the original. This is due mainly to increased solubility of residue components. Treatment with steam pressure results in dry matter losses of 1-20% and also losses in hemicellulose as well as the production of some phenolic derivatives and acetic acid (Walker 1984, Oji and Mowat 1978).

Steam pressure was used alone or in combination with chemicals as early as 1967 (Klopfenstein et al. 1967). The effectiveness of the treatment depends on the pressure (Klopfenstein and Bolsen 1971, Klopfenstein and Koers 1973, Hart et al. 1981), duration of treatment (Hart et al. 1981, Garret et al. 1981) and the material under treatment (Klopfenstein et al. 1967) as well as temperature (Ragnekar et al. 1982). Chemicals may enhance the effect of steam. When Klopfenstein et al. (1967) treated alfafa stems, wheat straw, prairie hay and corn cobs with Hydrogen Peroxide (HP), hydrochloric acid and water, they found a reduction in cell wall constituents for all treatments. Klopfenstein and Bolsen (1971) found an increase in in vitro DMD with increasing pressure up to 21kg/cm^2 for corn cobs and wheat straw. Above this, treatment appeared to decrease it. For milo stubble in the same experiment, an increase in pressure above 7kg/cm^2 did not result in increased DMD. When in vitro and in vivo digestibilities were compared (Klopfenstein and Koers 1973) the values were the same at 17.5kg/cm^2. At 28kg/cm^2 the in vivo DMD was lower. Walker (1984) reports that Phoenix et al. (1974) also found lower in vitro digestibility of treated barley straw at high pressures. Addition of sodium metabisulfite helped to increase in vivo digestibility and feed efficiency. When lambs received corn cobs as a large proportion of their diet an increase in daily gain (up to 200%) and feed efficiency (35-50%) was obtained when compared with lambs fed untreated cobs at the same level (Klopfenstein et al. 1974). Oji and Mowat (1979) found increases in dry matter intake and digestibilities of organic matter, gross energy, cell contents and cellulose as a result of steam treatment.

The effect of treatment duration is illustrated by the work of Garret et al. (1981). They found that rice straw treated for 90 seconds at 28.1kg/cm^2 resulted in poorer sheep performance than the untreated residue, indicating heat damage. When treatment time was only 20 seconds there was no difference between the treated and the original straw as measured by intake, gain and feed efficiency.

2.2.3 Radiation

The work of Lawton et al. 1951 (cited by Walker 1984) showed that cellulose length was shortened by radiation, making more carbohydrates available for digestion. Arthur (1971) says the effect of radiation is molecular depolymerisation and the formation of acid groups, reducing groups and radicals. Lignin is rather resistant to radiation because of aromatic rings.

Pritchard et al. (1962) found no significant difference in in vitro DMD of wheat straw at radiation dosages of less than 10Mrad, but found a significant increase when the dosage was increased to 100 and 1000Mrad. Maximum volatile fatty acid production was obtained at

250Mrad, while at higher levels of radiation acid production decreased. Yu et al. (1975) also found that cell wall digestion by rumen microorganisms decreased with dosages greater than 100Mrad. Although it has not been proved, the decrease is assumed to be due to toxins that are produced by high radiation doses. At 100Mrad about 50% of ADF and 30% of NDF was solubilized (Yu et al. 1975).

MacManus et al. (1972) found that irradiating dry rice straw increased in sacco digestibility more than the wet residue. They also found that irradiating increases passage rate of the straw.

Irradiating at dosage levels of 25-75Mrad makes straw more susceptible to microbial attack in the rumen. However, the increased passage rate will offset this benefit. In addition, for most crop residues there are cheaper means of treatment to increase nutritive value. Irradiation is therefore likely to be used only in extraordinary circumstances.

While physical treatment of residues may itself be beneficial in improving them as feed, a combination of physical treatments, especially particle size reduction and chemical treatment, is likely to bring more benefit.

2.3 Chemical Treatment of Roughages

Chemical treatment of roughages to improve nutritive value is recorded as having been attempted and reported towards the end of the last century by Lehmann in 1895 (Sundstol and Coxworth 1984). More work has been done since the beginning of the 20th century to assess the effect of different chemicals on composition, structure and improvements in nutritive quality and ruminant animal performance. Alkali chemical treatment is believed to result in the breaking of bonds between lignin and cell wall carbohydrates, and some solubilisation of hemicellulose, lignin, protein and silica (Graham and Aman 1984, Frape 1984).

2.3.1 Hydrogen Peroxide (HP)

The hypothesized effect of hydrogen peroxide (HP) on plant material is via oxidation and hydrolysis of organic compounds in lignocellulosic materials (Wei and Cheng 1985, Forney et al. 1982).

Forney et al. (1982) found an increase in hydrogen peroxide specific activity at the same time that lignolytic activity occurs in cultures of white rot fungi. Lignolytic activity by a culture of <u>Phanerochaete chrysosporium</u> was depressed when .OH radical scavengers were present (Forney et al. 1982), clearly demonstrating the involvement of this radical which has been proposed as the key in the lignolysis involving hydrogen peroxide.

Treatment of roughages with hydrogen peroxide alone reduced dry matter disappearance (DMD) when alfafa stems and corn cobs were tested (Jones and Klopfenstein 1967). In a different experiment hydrogen peroxide reduced both the lignin and cell wall contents of alfafa stems, wheat straw, prairie hay and corn cobs (Klopfenstein et al. 1967). In addition to lignin, HP solubilises hemicellulose, the greatest solubilisation occurring when the reaction takes place at pH>11.5 (Wei and Cheng 1985, Gould 1985, Gould 1984). Cellulose was not solubilised by HP, in fact, cellulose content of the residue increased with treatment (Gould 1984, Gould and Freer 1984).

Recent work on crop residue modification by hydrogen peroxide involves its use in alkaline solutions. Gould (1984, 1985) demonstrated lignin and hemicellulose solubilisation by alkaline hydrogen peroxide (AHP) resulting in efficient hydrolysis of cellulose by <u>Trichoderma resii</u> cellulase.

It has been suggested that reduction in the crystallinity of cellulose is an important factor in increasing its susceptibility to degradation by enzymes and microorganisms (Gould 1985a, Kerley et al. 1985, 1986). Wei and Cheng (1985) reported reduced cellulose crystallinity when wheat straw was treated at 60^{o}C with AHP. When maximum delignification is attained, the residue particles disintegrate into small fibers which have a higher water holding capacity than the original material (Gould and Freer 1984, Gould 1985a, Wei and Cheng 1985). The increased water holding capacity is interpreted as indicating that crystallinity is reduced (Gould 1985a). Puri (1984) did not find evidence to support that crystallinity affected enzymatic saccharification of cellulose because he found no changes in the crystallinity of cellulose with treatment. He found a reduction in the degree of polymerisation for samples that underwent alkaline explosion, carbon dioxide explosion and ozone treatment processes and he suggested that reduced molecular weight and the degree of polymerisation might affect cellulose hydrolysis. Besides increased saccharification, the increased accessibility of cellulose to microorganisms and enzymes has also been demonstrated by Wei and Cheng (1985), who found a higher cellulase adsorption rate and greater accessibility to cadoxen (a cellulose solvent) and by Kerley et al. (1985), who found that AHP treated wheat straw particles were heavily colonised by bacteria, whereas some portions of untreated wheat straw had no bacteria. This demonstrates that AHP is instrumental in removing a barrier that prevents bacterial attachment.

Effectiveness of AHP treatment is particularly dependent on pH. Temperature and HP concentration also have an effect. The pH affects both lignin and hemicellulose solubilisation. AHP treatment of residues at pH 10 led to a large decrease in hemicellulose content of the residue with complete solubilisation at pH 13 (Gould 1984a). Maintaining pH at 11.5 resulted in the greatest cellulose saccharification (93%), a decrease in hemicellulose solubilisation and also a reduction of treatment time from 18 to 6 hours (Gould 1985). When the reaction was carried on for 24 hours with no pH control, the cellulose saccharification was 87% and the hemicellulose recovered was only 1/3 of that obtained in the 6 hour reaction with pH control. Kerley et al. (1986) found that diets containing wheat straw treated with AHP had more ADF and less ADL than diets with non-treated straw. At pH 6.8 Gould (1984) found that only 10-15% of the lignin was solubilised when wheat straw was treated with AHP. The amount increased significantly at pH 10.0 with a maximum of up to 60%. Enzymatic conversion of cellulose to glucose was maximal at pH 11.5 with no further significant increase above this.

Gould (1984) found that about 50% of the lignin was solubilised at 25^{o}C (pH 11.5). Increasing the temperature from 32^{o}C to 60^{o}C resulted in an increase in both the rate and extent of substrate weight loss during the first hour of delignification as well as greater lignin solubilisation (Wei and Cheng 1985). Gould (1984), however, found that dry weight loss and cellulose digestiblities for treatment temperatures of 5, 25 and 60^{o}C were not significantly different. Treatment at room temperature is therefore more practical since energy input is very low.

HP concentration below 1% resulted in low delignification rates (Gould 1984) and increases above 1% did not result in higher delignification after 24 hours of reaction. The optimum ratio of HP to substrate is .25:1 (Gould 1984, Wei and Cheng 1985). A greater ratio resulted in no less delignification and cellulase activity (Gould 1985a). Using wheat straw dietary levels of 37% and 72% Kerley et. al. (1984b) found no difference in intake between the diets containing treated and untreated straw. In another experiment using 33% and 70% levels, sheep on the 70% untreated straw had significantly lower intakes while the other 3 groups were similar. Similar results were found by Kerley et. al. (1986). When 36% and 72% levels of wheat straw were used, lambs eating treated wheat straw diets consumed 122 +/- 35.8 g/day and 335 +/- 35.8g/day digestible matter respectively, more than those fed the same levels of untreated straw (Kerley et. al. 1985). They also found that the lambs on the 72% untreated wheat straw diet lost 106 g/day and those fed the same levels of treated straw gained 235 g/day.

When roughages were treated under 28kg/cm^2 pressure with water and HP solution, in vitro DMD increases were the same for wheat straw while with corn cobs the increase for the 4% HP was greater than for water alone (Klopfenstein et al. 1967). Jones and Klopfenstein (1967) found a significant increase in the digestibility of corn cobs and alfafa stems treated with a mixture of HP and sodium peroxide and this was similar to that due to sodium peroxide alone. HP alone however decreased DMD. Fahey Jr. et al. (1984) found significantly higher DMD for straw treated with HP 12 hours after NaOH treatment than when the two chemicals were added together. AHP treatment of straw resulted in significant increases (sometimes doubling) in the in situ digestibilities of corn cobs, cornstover, wheat straw, as well as NDF, ADF, and cellulose in sheep. In addition an increase in the rate of digestion has been reported (Kerley et al. 1984).

Kerley et al. (1984a, 1985) also found an increase in the ME and DE content of diets containing AHP treated wheat straw when compared to diets containing untreated straw. Increases in the digestibilities of dietary NDF, ADF and cellulose have also been found (Kerley et. al. 1985, 1986). AHP treatment also increases fluid dilution rate.

The effectiveness of HP also depends on the fibrous material in question. Corn cobs, stalks and husks, wheat straw and hay are very susceptible to cellulase hydrolysis after treatment while others like soybean stover, kenaf and oak shavings are more resistant.

2.3.2 Ammonia

Ammonia is probably easier to obtain than other chemicals used for treating forages to improve nutritive value. Because it is used as a fertiliser it is easily accessible to farmers. The source of the ammonia can be a chemical like urea which is convenient to handle.

Ammonia also has the advantage of being a source of nitrogen, a nutrient that is necessary for rumen bacteria metabolism but which is found in insufficient quantities in the diets of the animals which depend on low quality roughages for survival. After treatment, some of the nitrogen is retained in the material, thus increasing the protein content of the diet.

2.3.2.1 Methods of Treatment

Different methods of roughage treatment with ammonia have been described in detail by Sundstol and Coxworth (1984). A brief description of each method is given below.

a) Anhydrous Ammonia

When using anhydrous ammonia, the most concentrated form of this compound, it is important that the treatment occurs in a sealed, air tight system to reduce loss of the gas. Because it is a gas, rapid penetration of the treatment material occurrs. The major drawback, especially when considering on farm treatment in developing countries, is that ammonia is potentially dangerous and requires careful handling and appropriate equipment.

The Stack Method

The stack method used in countries like Norway, Denmark and Bulgaria involves injecting ammonia into stacks or large bales of the roughage covered with plastic to prevent loss of the gas (Nicholson et al. 1977, Sundstol et al. 1978, Sundstol and Coxworth 1984). Bulgarian workers found an improvement in organic matter digestibility (OMD) of maize stover in sheep (from 61.8% to 73.8%) that was similar to that obtained by treating the stover with sodium hydroxide (Sundstol and Coxworth 1984).

Hot Chamber Ammonia Treatment

Hot ammoniated air can be used to treat roughages effectively in 24 hours or less. These ammoniation chambers or ovens are used in some European countries. However this is an expensive method.

Ammonia Freeze - Expansion Process (AFEX)

A method which is believed to have some potential for roughage treatment with ammonia is AFEX, which was developed for ethanol production. In this method, the pressure of ammonia vapour is raised in a sealed container. A sudden release of the high pressure (12kg/cm^2) results in the reduction of the ammonia temperature below zero. As liquefied ammonia trapped in the cells expands to vapour, it causes the rupture of cell walls, resulting in improved cellulase activity when the enzyme is added to the treated material.

b) Aqueous Ammonia

Aqueous ammonia is convenient in dry climates. In this form the chemical is also easier to handle, store and transport than the anhydrous gas.

The Stack Method

Aqueous ammonia can be injected into a covered stack of material using a pump. Treatment can also be effected by allowing the solution to flow through the stack, allowing ammonia to penetrate all the material in the sealed stack as it evaporates.

Pelletting

Mixing chopped straw with aqueous ammonia before pelletting has produced positive results in both sheep and dairy cows (Bergner and Mainenburg 1974 cited by Sundstol and Coxworth 1984).

c) Other Sources of Ammonia

Urea

Urea is easy to handle and does not pose a health hazard like anhydrous ammonia or sodium hydroxide. Dolberg et al. (1981) found significant improvement when rice straw was ensiled after spraying with a urea solution. Positive results have also been reported by other researchers (Dias-da-Silva and Sundstol 1986, Wanapat et al. 1985, 1986). Dias-da-Silva and Sundstol (1986) found stack treatment with urea to be less effective than ensiling.

While it may be necessary to add urease to help ammonia production when treating some residues with urea, Oji and Mowat (1977) found that urea was completely decomposed by day 20, confirming that this is a good source of ammonia. It has been reported that at least a third of nitrogen added as urea can be lost by evaporation at feeding time (Verma and Jackson 1981). Urea can also be used industrially when residues are pelletted.

Urine

Treatment with animal urine can produce a palatable, more digestible product (Sundstol 1985, Wanapat et al. 1985, 1986). The main problem is the collection of the urine. Human urine may be a possibilty but the problems of handling and pathogenic contamination have to be dealt with first.

While urea and urine are usually not as effective as anhydrous or aqueous ammonia, they are probably more readily available and more economical in developing countries.

2.3.2.2 Effects of Ammonia Treatment on Usefulness of Low Quality Roughages

a) Digestibility

Treatment of low quality roughages with ammonia has been found to increase in situ DMD (Dryden and Kempton 1984, Graham and Aman 1984, Dryden and Leng 1986), in vitro DMD (Solaiman et al. 1979, Waiss et al. 1972) and in vivo DMD (Birkelo et al. 1985, Borhami et al. 1982, Brown et al. 1987, Dolberg et al. 1981, Jackson 1977, Nicholson et. al. 1977, Oji et al. 1977, Waiss et al. 1972) when compared with untreated material. Increases of 10 - 15 percentage units in DMD have been obtained in experiments with sheep (Sundstol et al. 1978). In Norway the average increase in OMD is 8 - 12 percentage units (Sundstol 1984). Borhami et al. (1982) found that spraying treated straw with acetic acid and formic acid to fix ammonia increased the apparent DM digestibility and the nitrogen digestibilities beyond what ammonia alone could achieve.

Morrison and Brice (1984), using rumen simulation technique, found that treatment of barley straw with ammonia resulted in a greater rate of digestion. The rates for cellulose and hemicellulose digestion were not affected. Dryden and Kempton (1984) who reported an increase in in vivo OMD, did not find any difference in the rate of digestion due to ammonia treatment of barley straw.

The digestibility of treated material is also dependent on other components of the diet. Cellulose digestion decreases when high levels of fermentable carbohydrates are fed, probably due to a decrease in the numbers of cellulolytic bacteria (Williams 1984).

b) Intake

Rounds et al. (1976) and Waller (1976) found that 4% ammonium hydroxide treatment of corn cobs resulted in decreased DM intake. Similar observations have also been made with treated straw. The intake problem, which is due to ammonia odor can be overcome by feeding the treated material in combination with a low pH feed such as silage (Waller 1976) or by aeration of the material before feeding (Sundstol 1984). When the odor problem is overcome, intake of treated material is greater than that of the untreated. This has also been demonstrated by a number of workers including Birkelo et al. 1985, Dryden and Kempton 1984, Mira et al. 1983 and Moore et al. 1985.

Because ammonia treated straw is comparable in nutritive value to low or medium quality hay, one cannot feed it in large amounts to animals that are expected to achieve high level production such as high producing dairy cows. Sundstol et al. (1978) recommended no more than 4-5kg of long straw per cow per day even though slightly higher amounts have been succesfully used in Finland and Denmark. Sundstol (1984) reports intakes averaging 4-6kg per day for intensively managed beef animals and up to 7kg for heifers that do not require much gain. For good quality straw intakes can be as high as 11kg per day for yearling steers (Sundstol 1984).

c) Weight Gain

Ammoniated wheat straw fed alone has been found to be inadequate to meet the maintance requirements of beef cows (Sundstol et al. 1978). However other work shows that animals fed ammoniated straw or corn residues gain more weight than those fed the roughages untreated (Mira et al. 1983, Sundstol 1984, Sundstol and Coxworth 1984). In Norway weight gains of 1 to 1.2kg/day are achieved when treated straw is supplemented with concentrate (Sundstol 1984). Verma and Jackson (1981) found higher milk yields in cattle and buffalo fed ammonia treated straw when compared with those fed the straw untreated. Calves from these cows achieved greater weight gains. Sundstol and Coxworth (1984) cite an experiment in which steers fed ammonia treated corn cobs gained 720g/day while those fed untreated cobs gained 390g/day. For more efficient use of treated material, it may be advisable to restrict intake. Verma and Jackson (1981) report the work of Khan and Davis who did not find differences in weight gain and feed efficiency between growing cattle fed the straw ad libitum and those that had the straw intake restricted.

d) Energy

Wanapat et al. (1985) found in a series of experiments conducted with sheep, that the metabolizable energy of wheat straw was increased by treatment. Birkelo et al. (1985) found an increase from 45.2% to 50% in metabolizability of the gross energy intake. Nicholson et al. (1977) found an increase of 8 percent in the gross energy digestibility when wheat straw was treated with 5% ammonia. Increases in energy digestibilities have been reported for other roughages such as corn stover (Oji et al. 1977). It has been reported that energy level of treated straw can be increased by as much as 70-80% above that of untreated straw (Sundstol et al 1978).

e) Preservative Effect

Ammonia treatment helps prevent molding in preserved wet forages such as corn silage. Its fungicidal effects have been demonstrated in straws treated with aqueous ammonia (Waiss et al. 1972, Oji et al 1977, Sundstol and Coxworth 1984). Grotheer et al. (1986) found a linear decrease in fungal counts in dry hay as the level of ammonia increased. Ammonia treatment has been shown to prevent the germination of weed seeds (wild oats) in Norway (Sundstol and Coxworth 1984, Sundstol et al. 1978). This might also apply to other weeds common to different parts of the world.

f) Protein Value

One of the main advantages of ammoniation is the increased nitrogen content of the material which is, in fact, an increase in the crude protein content. The proportion of the added nitrogen that is retained has a wide range--from about 1/3 (Mira et al. 1983, Solaiman et al. 1979) to over 99% (Moore et al. 1985) depending on the method of treatment. The crude protein in these treated materials is roughly double that of untreated material. In two experiments with barley straw Mira et al (1983) obtained CP increases from 43 and 26.8 to 92.3 and 76.2g/kg DM respectively. Some of this retained nitrogen is associated with ADF.

Some studies have been carried out to determine what happens in the rumen. A Danish experiment cited by Sundstol and Coxworth (1984) showed that microbial synthesis in cows fed ammoniated straw was similar to that obtained in cows on a conventional ration with no NPN. Reddy and Reddy (1986) found an increase in protozoal nitrogen in buffalo fed ammoniated cotton straw as the only source of roughage. They also found that both ammoniation and pelletting resulted in an increase in VFA.

The extent to which the nitrogen from ammonia treatment is used by the animal is affected by a number of factors such as the rate at which nitrogen is released in the rumen, the amount of nitrogen in the diet, the amount and degradability of dietary protein and the amount of energy available in the rumen. It has been suggested that in some cases it may be beneficial to add some source of energy to make better use of the added NPN (Herrera-Saldana et al. 1982). The reduced digestibility of nitrogen in some ammoniated forages may be related to this. With insufficient energy toprovide carbon skeletons for bacteria the nitrogen available in the rumen is wasted.

g) Changes in Fiber Components

Ammoniation of grass hays and straws results in a decrease in NDF and hemicellulose (Moore et al 1985, Solaiman et al. 1979, Van Soest et al. 1984). Van Soest et al.(1984) also found an increase in ADF. Grotheer et al. (1986) reported no change in cellulose content when bermuda grass hay was ammoniated. While these workers and Moore et al. 1985 found no effect on lignin, Van Soest et al. (1984) suggested that some lignin is solubilised by ammoniation. Sundstol and Coxworth (1984) cite the work of Muller and Bergner (1975) which showed that some lignin in oat straw was solubilised. Hargreaves et al. (1984) also found a decrease in lignin, cellulose and hemicellulose due to ammoniation of corn stalklage. Together with improved dry and organic matter digestibilities, increases in ADF, NDF, cellulose and hemicellulose digestibilities have been reported both in vivo and in vitro (Chestnut et al. 1985, Aines 1985, Moore et al. 1985, Solaiman et al. 1979)

2.3.2.3 <u>Factors Impacting the Effectiveness of Ammonia Treatment</u>

a) Level of Ammonia

Moore et al. (1985) found that NDF digestibility increased linearly with increasing ammonia levels up to 36gNH_3/kg DM. Other fibre components also showed similar responses. They also found an increasing solubilisation of hemicellulose with increases in ammonia levels. Sundstol et al. (1978) found a significant increase in in vitro digestibility when ammonia was increased from 1 to 2.5%, a slight increase up to 4% and no beneficial effect above 4%. Similar results were also observed by Waiss et al. 1972 and Oji et al. 1977. Indeed a negative effect has been reported when such increased levels were tested (Kernan and Spur 1978 cited by Sundstol and Coxworth 1984). Sundstol and Coxworth (1984) suggest that where ammonia is expensive the optimum level might be between 2.5 and 3.5%.

b) Temperature

Most ammonia treatment is carried out either at room temperature or at the ambient temperature when this takes place out of doors. This represents a wide range of temperatures. Temperature increases will lead to an increase in the rate of the reaction, thus reducing the time required for treatment. For example, treatment at 90-95C requires only 12 to 24 hours to be effective (Sundstol 1984, Sundstol and Coxworth 1984). Treatment at lower temperatures, characterized by slow reactions, needs longer time to be effective in increasing digestibility and total nitrogen. Thus effectiveness of treatment at any particular temperature is dependent on its duration.

Van Soest et al. (1984) found that cold and hot ammonia treatment were similar in the cleavage of lignin groups but found that the hot treatment resulted in higher ADIN.

c) Pressure

High pressure treatment is usually associated with high temperature. The responses therefore follow those of temperature.

d) Duration of Treatment

Low temperatures require longer treatment time and vice versa. The time required for treatment is at least 8 weeks for temperatures below 5^{o}C, 1-4 weeks for 15-30^{o}C, less than a week for temperatures above 30^{o}C and 24 hours or less for hot oven treatments (Sundstol et al. 1978, Sundstol and Coxworth 1984, Moore et al 1985). When Solaiman et al. (1979) held treated wheat straw at 21-23^{o}C they found that the digestibility and total N content increased linearly with increasing time.

e) Moisture

Increasing moisture content of treated material up to 50% enhances the effects of ammoniation (Sundstol et al 1978, Sundstol and Coxworth 1984). Working with moisture levels of 10, 20, 30 and 50% Moore et al. (1985) and Solaiman et al (1979) found an increase in both digestibility and total nitrogen content with increasing moisture levels. Moore et al. (1985) and Grotheer et al. (1986) also reported an increase in hemicellulose solubilisation with increasing moisture. While some workers report an average of 30% moisture as being optimum and others conclude that less than 18% moisture is too low, Sundstol (1984) suggests that 15-20% may be a better range to reduce handling and storage problems. Sundstol and Coxworth (1984) report that treatment at very low moisture levels (3.3%) has been found to be ineffective.

It is also worth noting that Sundstol et al. 1978 found a decrease in in vitro DMD when the moisture content of untreated straw was raised from 12 to 25%.

f) Material under Treatment

Ammonia treatment of low quality roughages which include grass hays, cereal straws, corn residues and wood that have been tested has resulted in the improvement of nutritive value for most, if not all, of them. The improvement depends on the initial quality, the lower the quality, the greater the improvement.

Sunflower hulls with initial digestibility of 16.6% were not improved when treated with aqueous ammonia or urea and improved only slightly when anhydrous ammonia was used. The work of Kiangi et al. (1981) cited by Sundstol and Coxworth (1984), in which corn stover, wheat straw and rice hulls were compared, showed the greatest IVDMD improvement with rice hulls which had the lowest initial digestibility even though corn stover had the highest digestibility. The digestibility of treated corn stover has also been found to be greater than that of treated <u>chloris gayana</u> in experiments with steers. Treated corn cobs have reportedly resulted in higher daily gain than the untreated stover. Rivera-Villareal and Ellis (1985) found an increase in voluntary intake for hay cut at 6 and 12 week intervals but no difference for hay cut at 3 week intervals and treated with 4% ammonia. This shows that the more mature and therefore lower quality hay is improved by treatment. Alibes et al. (1984) summarize their work as showing that treating good quality straw results in only moderate increases in digestibility and a greater loss of nitrogen in feces.

When Ibbotson et al. (1984) carried out some work to assess the extent and effectiveness of on-farm ammonia treatment of straw in Norway, they found no difference between wheat, barley and oat straws. They found the greatest improvement for straws with initial digestibility of less than 42%, slight improvement for those with initial digestibility of 42-47% and no improvement for straws of at least 48% digestibility.

For materials with digestibilities above 55%, justification for ammonia treatment must be to provide NPN and/or as a preservative or to improve intake.

2.3.3 Sodium Hydroxide

Owen (1981) is quoted by Wilkinson (1984a) as asserting that NaOH treatment is the most cost-effective method for upgrading low quality roughages. In comparison with other single chemical treatments, NaOH is usually the most effective in increasing digestibility (Jackson, 1977, 1978, Klopfestein 1978, 1981, Waller 1976).

2.3.3.1 Methods of Treatment

a) The early methods - boiling methods:

Boiling in open vessels.

In the original treatment methods it was believed that boiling was necessary for effective treatment with NaOH. Lehmann (1891, 1895, 1904 cited by Homb 1984) boiled 100kg straw in a solution of 4kg NaOH in 200l water. This increased the digestibility even though the palatibility was poor. Kellner (1905 cited by Homb 1984) achieved an OMD of 88% with this method. After boiling, excess lye was washed off.

Boiling under pressure.

In this method straw was boiled in an autoclave with NaOH added at the rate of 40g/kg straw. During the process organic acids produced neutralized NaOH, eliminating the need for washing. Lehmann recommended boiling at 5-6 atmospheres for 6-8 hours (Homb 1984).

Colsman Method

Although this method did not strictly involve boiling, high temperatures were used. Chopped straw was mixed with lye solution (80g NaOH/kg straw) and allowed to stand for 12 hours. The material was then steamed at at least 100^{o}C and then washed (Homb 1984).

b) Industrial Treatment

Production of fodder cellulose by boiling.

The principles of the methods described above were used to turn straw or wood into animal feed during the two world wars in Europe (Rexen and Knudsen 1984). The material which was boiled under pressure in lye solution, was washed and dried before feeding to animals. Treatment was stopped when the feed situation improved after the wars.

Production of pellets and composite feeds.

The material to be treated is chopped or ground to required size. This depends on the intended use for the product--grinding being necessary for concentrate feed production and larger particles necessary for complete feeds. The roughage moisture content may also be adjusted to about 20%, the optimum for pellet strength (Tesic 1977, cited by Rexen and Knudsen 1984). NaOH is then added at the desired rate (average rate is 3-6% of straw DM) by spraying and mixed well with the straw. Uniform wetting can be achieved with as little water as 10-15l/100kg straw (Jackson 1977). The straw is then passed through a press producing pellets. The reaction between the NaOH and straw takes place at 80-100C under 50-100 atmospheres for less than a minute. The pellets are cooled by circulating air and are ready for storage or feeding. The method does not involve washing. This means that there is no DM loss and also that all added NaOH remains in the straw. Some of the NaOH may be neutralized by the addition of acidic gases (Rexen et al. 1975). It is recommended that free NaOH should not exceed 2% of straw DM. Reaction between NaOH and straw continues during storage as indicated by slight increases in digestibility and reduction in unreacted alkali during the first month of storage (Rexen and Knudsen 1984).

Production of composite feeds can be achieved in one or two steps (Rexen and Knudsen, 1984). In the two-step method the pellets of treated straw are crushed, mixed with other ingredients and the mixture pelleted. In the one-step method, which is cheaper, but results in reduced pellet density, durability and digestibility as well as a coarser structure, the straw, with NaOH already added is mixed with other feed components before pelleting. Heating the lye before treatment and addition of steam improves the effectiveness of treatment.

c) On-farm treatment.

Wet Treatment.

These are methods involving the use of large amounts of water.

Beckmann Process.

This method was developed to reduce high costs of the boiling procedures. The method involved the soaking of straw in NaOH solution (1.5-2% NaOH on straw DM) at ambient temperature for three days. Fingerling et al. (1923 cited by Homb 1984) recommended soaking for 12 hours since 3 days gave only small increases in digestibility. After soaking the straw was washed in water to remove exess NaOH and was then ready for feeding. This method was cheap in terms of capital investment, requiring only two vats, one for soaking and the other for washing. It also resulted in less DM loss than boiling. The resulting feed contained 25-30% less lignin and was more palatable. However, use on farms was limited by the high demand for labour. In Great Britain experiments showed that treatment at 7C was as effective as treatment at 30-40C. In both the U.K. and Scandinavian countries treatment facilities were built to allow the reuse of lye solution that drained from the straw before washing (Homb 1984).

Modification of the Beckmann Process.

Because of the high water requirement for the Beckmann process (40-50l water/kg straw) and the pollution of water with NaOH, alternatives were sought to reduce the amount of water that is used. This led to what Homb (1984) describes as closed systems, in which there is no risk of enviromental pollution. The first methods developed by Torgrimsby and by Wethje (Homb 1984), which utilized 4 or 5 interconnected vats, are too complicated for ordinary farm use.

Boliden Process/Air Circulation Method

Straw bales are sprayed with a solution of NaOH and calcium hydroxide [$Ca(OH_2)$]. The treated material is then sprayed with phosphoric acid to neutralize the alkali. The bales are left to stand while excess liquid drains off before feeding. Ingredients like urea, molasses, vitamins and trace minerals may be added to the neutralizing solution. Arnason (1980 cited by Homb 1984) found an increase in DMI for heifers compared to untreated straw. The OMD of the treated material in sheep was 66%.

Dip Treatment

This method involves the use of one vat. The roughage is soaked in lye solution for periods ranging from less than 1 hour to 18 hours (Homb 1984, Kategile et al. 1981). After soaking, roughage is lifted and excess solution allowed to drain into the vat for 1/2 to 2 hours. The straw is washed by a little sprayed water using such simple equipment as a garden watering can. The wash liquid also drains into the vat. The solution in the vat can be used as much as 20 times (after replenishing chemical to achieve desired concentration). The straw is left to stand for 3-6 days before feeding. To make a better feed, other components like urea can be added to the solution before treatment.

Ensiling

Storage of treated material results in a decrease in the amount of unreacted alkali. Santillana and Wilkinson (1978) concluded from their work that reaction between alkali and straw appeared to continue during storage of treated wet material even at -15^{o}C and would therefore continue above 0^{o}C. Ensiling results in reduced pH (Wilkinson and Santillana, 1978) and this can help intake when large amounts of treated material are fed. Ensiling can be a convenient way of storing treated material if daily treatment is undesirable. Straw spray treated with NaOH can be stored ensiled for up to a year (Jackson 1978). The NaOH makes the material stable for a few days after the silo is opened. It is important for the water content to be sufficient to absorb the heat from the NaOH-straw reaction to prevent scorching or combustion. In a review of some experiments with ensiled and non-ensiled NaOH treated straw Wilkinson (1984b) draws attention to inconsistent results for digestibility in vivo. He concludes that even though small increases in intake and digestibility occur with increasing storage time, ensiling of NaOH treated materials may not result in significant changes in the feeding value when compared with materials that are fed immediately after treatment.

Dry Treatment

Dry treatments involve the use of the minimum amount of water required for even distribution of the chemical. The recommended amount depends on the equipment being used.

Manual treatment.

The solution is added to the straw using a garden watering can or a pressure sprayer and the material mixed by hand using a fork. Horizontal batch mixers or cement mixers can also be used. The amount of solution ranges from 1 l/kg straw when a pressure sprayer is used to 2 l/kg when a watering can is used. Such treatment has been demonstrated to result in significant improvements in digestibility (Jayasuriya and Owen 1975).

Mechanical treatment.

Mechanical treatment eliminates the need to build special facilities for treatment. Instead, machinery already on the farm is utilized, with modifications as required. The material can be treated as the material is harvested in the field (Kellaway et al. 1978). The solution of alkali and any other nutrients are added as the forage passes through the chopping chamber of the forage harvester. When mixer wagons are used, the material is ground or chopped (1-5cm length) and then sprayed with the NaOH solution. Feed processors have also been used (Wilkinson 1984a). Benefits in in vivo digestibilities have been cited by Wilkinson (1984a).

2.3.3.2 Effects of Treatment on the Usefulness of Low Quality Roughages

a) Digestibility

Improvement in the nutritive value of NaOH-treated material is indicated by increases in digestibility. Increases have been shown both in vitro and in vivo and also using the nylon bag technique (Jackson 1977). Mora et al.(1983) found in sacco digestibility increases for treated soybean residue and corn stalks. Improvements in in vivo of various residues have been demonstrated by many workers including Nangole et al. (1983), Alawa and Owen (1985), Singh and Jackson (1971), Klopfenstein et al. (1972) and Lesoing et al. (1981a). Klopfenstein et al. (1972) found an increase in DMD of 6.8% for alfafa stems and 11.2% for corn cobs after treatment with 4% NaOH. For corn stover treated with 5% NaOH the increase in OMD was 20.5 percent units. The increase is attributed mostly to the increase in cellulose digestibility. Jackson (1977) quotes the work of Carmona and Greenhalgh (1972) and Sharma and Jackson (1975) in which increases of 24 and 15-20 percent units in cellulose digestibility of treated straw were obtained in vivo and in sacco respectively when compared to untreated controls.

Treatment with NaOH increases the rate and extent of cellulose and hemicellulose digestion (Jackson 1977, Klopfenstein 1978, 1981, Lesoing et al. 1981a). If treated material is fed at high levels the retention time is reduced and the rate of digestion increases as well (Klopfenstein 1981). A high level of concentrate supplementation also decreases straw digestibility, probably due to conditions that are not optimum for cellulosis. Increases in in vivo digestibility of straw seem to be maximal at about 4-5% NaOH even though in vitro values continue to increase even above 10% NaOH (Rexen et al. 1976, Rexen and Thomsen 1976). Up to the 4-5% level in vitro and in vivo, digestibilities largely agree, but above this the in vivo is consistently lower. From their work, Singh and Jackson (1971) concluded that spray treatment increases digestibility of wheat straw less than the Beckmann method.

b) Intake

Intake of low quality roughages treated with NaOH increases is higher when compared with the untreated material (Alawa and Owen 1985, Jackson 1977, Kellaway et al. 1978, Rexen et al. 1976). In addition to increasing DM intake, treatment also increases water intake (Robb 1976). Large increases in water intake may result in increased passage rate and thereby have the effect of decreasing digestibility. When making up rations with treated material it is important to take into consideration the amount of sodium that will be consumed (Robb 1976). When too much unreacted sodium is present in the treated material, intake may be improved by adding neutralizing compounds. Rexen et al. (1976) found that neutralizing treated straw with hydrochloric acid increased the dry matter intake from 8.7kg to 10.4kg in dairy cows, Koers et al. (1979) also reported the benefits of neutralization of treated corn cobs before feeding to lambs. Animals appear to take time to get used to treated material. Randby (1982, cited by Homb 1984) found a marked increase in straw intake (11-12kg DM/day) during the last week of a 6 week experimental period. The adjustment period may be as short as one month (Nangole et al. 1983).

c) Weight Gain

When compared with untreated materials, treated straws, stovers and other residues and poor quality roughages result in greater weight gain. Kellaway et al. (1978) found that feeding NaOH-treated straw to heifers grazing poor pasture resulted in weight gains of 23g/day whereas feeding untreated straw led to weight losses averaging 312g/day. Lesoing et al. (1981b) found that cattle fed diets containing 30 or 60% treated wheat straw had superior gains and feed efficiencies to those fed untreated straw at the same levels. In trials with lambs, Lesoing et al. (1981a) found significant increases in the rate of weight gain and efficiency of gain with NaOH treatment. This accompanied increases in the digestibilities of DM, OM, cellulose and hemicellulose. Klopfenstein and Woods (1970) also demonstrated benefits in weight gain when they fed treated straw and corn cobs to lambs. Urio (1981 cited by Homb 1984) found a positive response in terms of live weight gain, carcass weight and carcass % fat in goats fed treated corn cobs.

d) Energy

Treatment of straw with NaOH can double the net energy in a feed (Robb 1976). Robb and Pearson (1972 cited by Robb 1976) found that energy digestibility increased from 40.5 to 55.6% and energy metabolizability increased from 34.7 to 49.6% when they fed treated straw to goats. Increases were also found by Nangole et al. (1983) and Rexen and Thomsen (1976). Saxena et al. (1971) found lower levels of rumen ammonia and blood urea in lambs fed treated oat straw. They concluded that this was an indication that NaOH was effective in making more energy available for bacterial growth, resulting in better use of the NPN present.

e) Milk Production

Homb (1984) cites the work of Garmo (1981) who obtained higher milk yields from cows fed treated straws when compared with those fed the original. He also quotes Randby (1982) who did not find any differences in milk yield between cows fed grass silage and concentrate and those that had part of the grass silage replaced with treated straw. According to Jackson (1977) milk composition is not adversely affected by feeding NaOH-treated straw. Greenhalgh et al. (1976) found that milk composition for high yielding cows was improved by feeding 50% treated straw as opposed to untreated straw.

f) Composition

Generally, treatment of straw with NaOH solubilises some silica, CP, lignin and hemicellulose (Jackson 1977, Saxena et al. 1971). In literature there is agreement that treatment significantly reduces the hemicellulose component of straw (Klopfenstein 1978, Lesoing et al. 1981a, 1981b). The lignin content is not significantly changed by treatment (Klopfenstein 1978) except under extreme treatment conditions such as high temperature and pressure (Rexen et al. 1976). With the Beckmann method as much as 25-30% of the lignin is solubilised (Homb 1984). Cellulose is not solubilised by treatment. Saxena et al. (1971) reported increases in percent NDF and ADF with the treatment of oat straw. Mora et al. (1983) found decreases in NDF, ADF, ADL and CP as a result of treatment with NaOH and chelating metal caustic swelling (CMCS).

2.3.3.3 Factors Impacting the Effectiveness of Treatment

Levels of application for industrial treatment lie between 3 and 6% NaOH (Rexen and Thomsen 1984). For farm-scale treatment the rate lies within the same range (Klopfenstein et al. 1972). Singh and Jackson (1971) used 0, 3.3, 6.7 and 10% NaOH and found that the 3.3% was best. The highest intakes were obtained at this level and no further increases in digestibility were obtained above this level. Jayasuriya and Owen (1975) found the highest digestibility at 4.5gNaOH/100g straw. Increasing temperature and pressure was found to be beneficial in increasing lignin solubilisation (Rexen et al. 1976) and in vitro digestibility (Ololade et al. 1970). According to Rexen et al. (1976) there is little increase in digestibility when the pressure is increased above 500 atmospheres. At constant (atmospheric) pressure, increasing temperature up to 100C increased digestibility more than drying at room temperature (Singh and Jackson 1971).

In his review Jackson (1977) concludes that the amount of alkali is more important than its concentration. At the same time, he emphasizes that the amount of water or volume of solution added must be adequate to uniformly wet the treatment material to ensure efficient distribution of the chemical. This was demonstrated by Jayasuriya and Owen (1975).

Chandra and Jackson (1971) found a slight decrease in residual alkali with time. Santillana aand Wilkinson (1978) also demonstrated this when they stored treated material at -15C. As with treatment with other chemicals effectiveness depends on duration of treatment as well as the temperature at which the reaction takes place, with higher temperatures requiring less time.

Chandra and Jackson (1971) found no difference between chaffed and ground straw in the effectiveness of NaOH treatment. Alawa and Owen (1985) and Singh and Jackson (1971) however, found improvements in intake and digestibility to be higher for chopped than for milled straw.

Different materials are improved to different degrees by alkali treatment. In general, good quality materials are improved less compared to materials that have low initial digestibility. Legumes are more resistant to treatment than cereal straws (Chandra and Jackson 1971, Jackson 1977). Even though the poorer material is improved more, the better roughages remain superior after treatment (Jackson 1978).

NaOH effectiveness can be enhanced or depressed by other chemicals. $Ca(OH)_2$ enhances NaOH treatment in terms of digestibility and weight gain. Waller and Klopfenstein (1975) found a mixture of 3% NaOH and 1% $Ca(OH)_2$ to exceed NaOH alone in improving daily gain and feed efficiency in lambs and heifers. $NaHSO_3$ was found to depress intake of treated straw when straw was treated with 2.5% NaOH and 2.5% $NaHSO_3$ (Rexen et al. 1976).

2.3.4 Treatment with other Chemicals

Other chemicals besides those discussed above have also been researched to evaluate their potential for improving the nutritive value of low quality roughages. Sodium in NaOH-treated materials sometimes presents a problem in animals (Klopfenstein 1981). The excreted Na is also a potential pollution problem. Both ammonia and NaOH are potentially hazardous and present a handling problem for on-farm use.

2.3.4.1 Chemicals Tested under Laboratory Conditions

Owen (1977 cited by Owen et al. 1984) found formic, orthophosphoric and propionic acids, sodium chloride, sodium bicarbonate and sodium bisulfite to be ineffective in increasing in vitro digestibility. Some chlorine compounds have been shown to increase in vitro DMD and cell wall digestibility (Yu et al. 1970). The effect of residual chlorine, which appears to inhibit microbial activity can be alleviated by washing (Yu et al. 1975). Fahmy and Orskov (cited by Owen et al. 1984) found an increase in DMD (in sacco) when sulfuric acid was used to treat barley straw. Although Holzer et al. (1980) succesfully fed a mixture of NaOH-treated and sulfuric acid treated straw to cattle, routine use especially for on-farm treatment is unlikely to be widespread because the acid is both expensive and hazardous to handle.

Ben-Ghedalia and Miron (1981 cited by Owen et al. 1984) found that ozone treatment equaled NaOH treatment of wheat straw in increasing in vitro digestibility. The acid treated material has a low pH (2.3) which poses a potential intake problem in practical rations. The same workers found sulfur dioxide to be more effective than NaOH. Sodium sulfide and sodium sulfite also improved in vitro digestibility of straw (Owen 1977 cited by Owen et al. 1984) and in sacco digestibility of corn cobs (Chandra and Jackson 1971).

2.3.4.2 Chemicals Studied with Animals

a) Calcium Hydroxide ($Ca[OH]_2$)

$Ca(OH)_2$ is cheaper, safer to handle and does not pose residual problems like sodium. Owen et al. (1984) present developments in the use of $Ca(OH)_2$ up to 1981. This chemical increases intake and digestibility. Although from published research work $Ca(OH)_2$ is not as effective as NaOH, Owen et al. (1984) maintain that if optimum conditions are defined, this level of effectiveness might be realized. One problem is the length of time required for $Ca(OH)_2$ treatment to be effective. This is accompanied by the problem of molding because $Ca(OH)_2$ is not a preservative. Mixtures of $Ca(OH)_2$ and NaOH have been succesfully used to produce feed that is as good as or better than that from NaOH alone.

b) Potassium Hydroxide (KOH)

KOH is almost equal to NaOH for treating residues (Wilkinson and Santillana 1978) even though more weight (30%) of KOH is required to give the same results. Lesoing et al. (1981) showed that a combination of KOH and NaOH improved animal performance more than NaOH alone. Any excess potassium excreted does not pose a pollution problem since it is a fertilizer. Widespread use is unlikely because KOH is very expensive. However, a crude source of KOH which holds some potential especially in developing countries is wood ash. Some feeding work has been carried out with this (Owen et al. 1984, Adebowale 1985).

c) Sodium Carbonate (Na_2CO_3)

Although not much work has been done with this chemical, Na_2CO_3 shows digestibility improvements both in vitro and in vivo, the latter being consistently lower (Owen et al. 1984). Na_2CO_3 is only half as effective as NaOH. Na_2CO_3-treated material can be kept for as long as 90 days without moulding.

d) Magadi Soda

This is a product left over from the purification process for manufacturing sodium salts in East Africa. The main component (90%) is Na_2CO_3. Because it found in large quantities work is being done to develop a method to use it effectively to improve the nutritive value of roughages. Traditionally, magadi soda is sprinkled on dry roughages to improve palatability and intake. The product is promising in its potential. Nangole et al. (1983) fed treated maize cobs to sheep and found DMD coefficients of 44.7, 54.2 and 61.6% for cobs treated with distilled water, 4.5% NaOH and 9% Magadi soda respectively.

In the present study, the objective was to find (1) the improvement in digestibility, in situ, that can be achieved as a result of treating crop residues with sodium hydroxide, ammonium hydroxide and hydrogen peroxide and (2) if other treatment methods could replace NaOH treatment without losing the benefits of increased digestibility.

Besides improving digestibility, ammonium hydroxide can be a source of NPN to supplement the low CP in low quality roughages. Unlike NaOH, NH_4OH does not leave a polluting residue. Hydrogen peroxide was chosen for study because it does not pose handling or pollution problems.

CHAPTER THREE

MATERIALS AND METHODS

Three residues, corn cobs, corn stover and wheat straw, obtained from the Michigan State University research farms were treated with 4% chemical (4g chemical/100g residue DM). Six treatments were:

1. Untreated residue
2. H_2O_2 (31.3% Analytical Reagent, Mallinckrodt)
3. Alkaline H_2O_2 (AHP)
4. NH_4OH followed by H_2O_2
5. NH_4OH (29% 'Baker analyzed' Reagent)
6. NaOH (Analytical reagent, Mallinckrodt)

The residues were ground in a Wiley mill to pass through a 2mm screen. The chemical was mixed with enough water to bring the moisture content of the material to about 50%. The solution and the ground material were mixed by hand in a plastic bag for about 10-15 minutes and then transferred to glass jars (1 l capacity) which served as silos. The material was left to react at room temperature for 24 hours, 5 days and 28 days for HP, NaOH and NH_4OH treatments respectively. For the AHP treatment the H_2O_2 solution was brought to pH 11.5 using NaOH solution before treatment and subsequent storage at room temperature for 24 hours. After the reaction period the materials were dried at 55^oC for 48 hours. The NH_4OH-H_2O_2 treatment involved treating the dry NH_4OH-treated material with H_2O_2 as described above.

Two mature holstein cows, maintained on a diet of alfafa hay (15-19% CP) and trace mineralized salt (Table 1) and fitted with rumen cannulae were used for incubation. Guidelines outlined by Orskov et al. (1980) were followed for the in situ procedure. Approximately 1g of material was weighed into each nylon bag (with approximate pore size of 53mm). Thirty-six bags (six bags per treatment) were tied to a plastic template (about 40 x 6 cm) which was placed in the rumen of each cow. Bags were removed after 8, 24, and 72 hours of incubation. At each time 2 bags were removed per treatment from each cow. Two sets of incubations were made within a week for each residue. On removal from the rumen, bags were rinsed in icecold water and then washed in warm tap water until the effluent was clear. On reaching the laboratory the bags were washed in distilled water, dried to constant weight at 80^{o}C and then weighed. For the 0 hour (control), bags were soaked in warm tap water for 15 minutes and then washed as above before drying and weighing. All incubated materials were adjusted for the 0 hour weight loss (Orskov et al. 1980, Nocek and Grant 1987, Nocek and Hall 1984). DM, ADF, permanganate lignin and cellulose were determined on the residues. An additional incubation (24 and 72 hours) was done on each roughage and NDF content was determined on this.

Analyses for the fiber fractions were carried out using the methods of Goering and Van Soest (1970).

Table 1. Composition of trace mineralized salt block as specified by manufacturer.

Component	%
NaCL	95-99
Zinc	.350
Iron	.340
Manganese	.200
Copper	.033
Iodine	.007
Cobalt	.005

The data obtained in the experiment was analyzed by analysis of variance for a split plot using the Statistical Analysis Systems (SAS) General Linear Models Procedure. The means were compared to the control using Dunnett's test.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results and Discussion

4.1 Wheat Straw

4.1.1 Effect of treatment on composition

Washed samples of treated and control wheat straw were analyzed for ADF, NDF, permanganate lignin and cellulose content. The results are presented in Table 2. No significant changes were obtained in the ADF, cellulose and permanganate lignin content of wheat straw as a result of chemical treatment. Because of low replication, it was not possible to statistically determine if treatment changed the NDF content, although the values (Table 2) for the different treatments appear to be very similar. Gould (1984) and Gould and Freer (1984) reported an increase in cellulose content when wheat straw was treated with alkaline hydrogen peroxide. Kerley et al (1985) also found an increase in the ADF and cellulose concentrations as well as a decrease in acid detergent lignin as a result of AHP treatment. A decrease in lignin was also reported by Klopfenstein et al (1967) when they treated residues with HP and also hyrochloric acid under pressure. The process of AHP treatment proposed by Gould (1984) requires the maintenance of pH at 11.5 and continuous mixing throughout the reaction period for optimum lignin solubilization. In the present study the materials were

Table 2. Composition of treated wheat straw.

Treatment	Composition/Constituent (%)			
	ADF	CELLULOSE	LIGNIN	NDF
1.	58.8850	43.9900	11.9250	81.2600
2.	56.8750	43.8000	11.4550	81.6150
3.	58.2150	43.4100	11.7150	82.8500
4.	59.3750	44.5400	11.8050	83.9900
5.	60.5350	45.9300	11.9750	83.6450
6.	60.9350	45.4500	12.4450	82.3600
SE	0.9496[a]	0.9763[a]	0.3247[a]	

a. n = 4

Key to treatments.

Treatment	Chemical Used
1.	Control (no chemical)
2.	Hydrogen Peroxide (HP)
3.	Alkaline hydrogen peroxide (AHP)
4.	Ammonium hydroxide + hydrogen peroxide
5.	Ammonium hydroxide
6.	Sodium hydroxide

This key is applicable to the three residues used for this study.

mixed for a comparatively short time and the initial pH of 11.5 was not maintained. This may account for the lack of lignin solubilization. The method of treatment followed in this experiment was an attempt to use methods that would be easy enough and affordable for the small scale farmers in developing countries like Zimbabwe. While Gould (1984) has reported up to 50% solubilization of lignin due to chemical treatment of residues, other workers have obtained smaller changes. Williams (1984) found a decrease in permanganate lignin from 11.1% to 10.4% after treating barley straw with 3% ammonia at 95^{o}C. Additionally, the HP to substrate ratio (1 to 25) used in this study was lower than the 0.25 to 1 used by Gould.

4.1.2 Disappearance

When compared with the control, all treatments except treatment 2 significantly increased ($P < 0.01$) the extent of dry matter, ADF, NDF, and cellulose disappearance. Table 3 shows the values of DMD for control and treated wheat straw.

Table 3. Dry matter disappearance for wheat staw

Treatment	Dry matter disappearance (%)			
Incubation time:	8	24	72	Mean
1.	7.6338	24.2513	49.4350	27.1067
2.	8.9513	24.3788	50.3675	27.8992
3.	16.1025	41.9263	62.9838	40.3375
4.	14.0625	42.5513	65.8388	40.8175
5.	13.1200	38.1850	58.5013	36.6021
6.	18.0088	49.4650	72.8038	46.7592
SEM				0.7848[a]

a. n = 24

Mean DMD was increased by 13.2, 13.7, 9.5, and 19.1 percentage units (% units) for treatments 3, 4, 5, and 6 respectively. The difference between these treatments and the control are greater when comparisons are made separately for the 24 and 72 hour values. Numerically treatment 6 caused the greatest increase. The effectiveness of NaOH above other chemicals has been widely reported by many workers including Wanapat et al (1986). Disappearances of ADF, cellulose, and NDF are reflected by the proportion of the constituents remaining after incubation. These are given in Table 4.

Table 4. Mean residual constituents of wheat straw*

Treatment	Residual constituents (%) ADF	CELLULOSE	NDF	LIGNIN
1.	70.7548	63.4417	67.7319	100.2230
2.	73.8029	61.8302	67.7309	107.6757
3.	58.7213	53.7008	51.9072	81.9634
4.	57.9595	54.7113	52.4972	74.5603
5.	61.2279	55.9141	54.7855	83.2169
6.	52.5258	48.2090	44.0884	73.1846
SE	1.3408[a]	1.2441[a]	1.4824[b]	3.4955[a]

*Expressed as a proportion of constituent present before incubation.

a. n = 12
b. n = 4

The apparent increase in lignin presented in this table for treatments 1 and 2 is not a true gain in lignin. Rather, this is attributed to inaccuracy in the estimation of this component during analysis of the residue.

4.1.3 Rates of disappearance

Rates of disappearance were calculated for DM, ADF, cellulose, and NDF by dividing what was lost by the number of hours under consideration. The calculations were carried out for the first 24 hours and for the following 48 hours of incubation. The rates are presented in Table 5. Graphs (figures 1 to 3) also reflect the pattern of digestion.

The rates of disappearance for the first 24 hours were greater than the rates achieved for the 24 to 72 hour incubation period. For the 24-72 hour period, treatment did not alter the rate of disappearance for DM, ADF, NDF, and cellulose. For the first 24 hours of

Table 5. Wheat straw rates of disappearance.

Treatment	Rate of disappearance (% per hour)									
	DMD		ADF		CELLULOSE		NDF		LIGNIN	
	0-24	24-72	0-24	24-72	0-24	24-72	0-24	24-72	0-24	24-72
1	1.0105	0.5247	1.0872	0.5639	1.3846	0.5856	0.7146	0.6299	-0.1558	0.4979
2	1.0158	0.5408	1.0205	0.4738	1.4275	0.5835	0.7428	0.6017	-0.4130	0.5657
3	1.7471	0.4386	1.7933	0.4678	1.9624	0.5217	1.4192	0.5847	0.9737	0.3212
4	1.7735	0.4849	1.8387	0.5336	1.9827	0.5751	1.2786	0.7007	1.0979	0.426
5	1.5908	0.4233	1.6808	0.4745	1.8889	0.5253	1.2532	0.6307	0.8075	0.2979
6	2.0609	0.4862	2.1110	0.5199	2.2943	0.5547	1.7789	0.5508	1.2228	0.4965
SE	0.0586	0.0403	0.0756	0.0782	0.0853	0.0447	0.1081	0.0584	0.1309	0.0734

incubation all treatments except 2 significantly increased ($P < 0.01$) the rate of disappearance of DM, ADF, and cellulose. The rate of NDF disappearance was improved significantly by treatments 3, 4 ($P < 0.05$) and 6 ($P < 0.01$). These increased rates would be expected in view of the increased disappearance achieved as a result of treatment. An increase in the rate of digestion is important when one considers feeding treated material to animals. The increased rate especially early in incubation would mean that more material benefits the animal during the time the forage is retained in the rumen. Since treatment can increase passage rate, it is important that the rate of disappearance be accelerated.

4.2 Corn Stover

4.2.1 Effect of treatment on composition

The composition of washed samples of treated and control corn stover are given in Table 6. The cellulose content of corn stover was

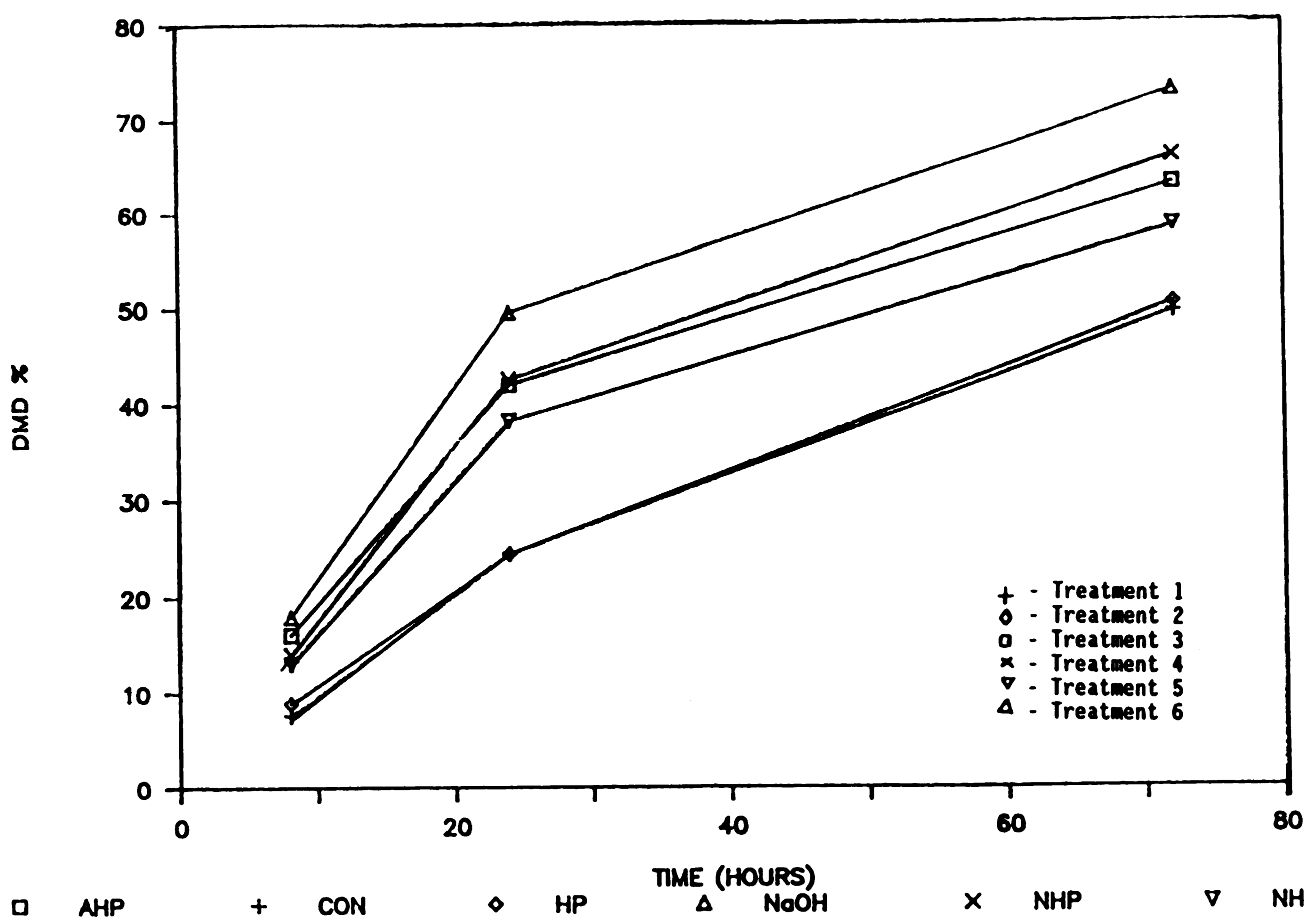

Figure 1. Dry Matter Disappearance: Wheat Straw

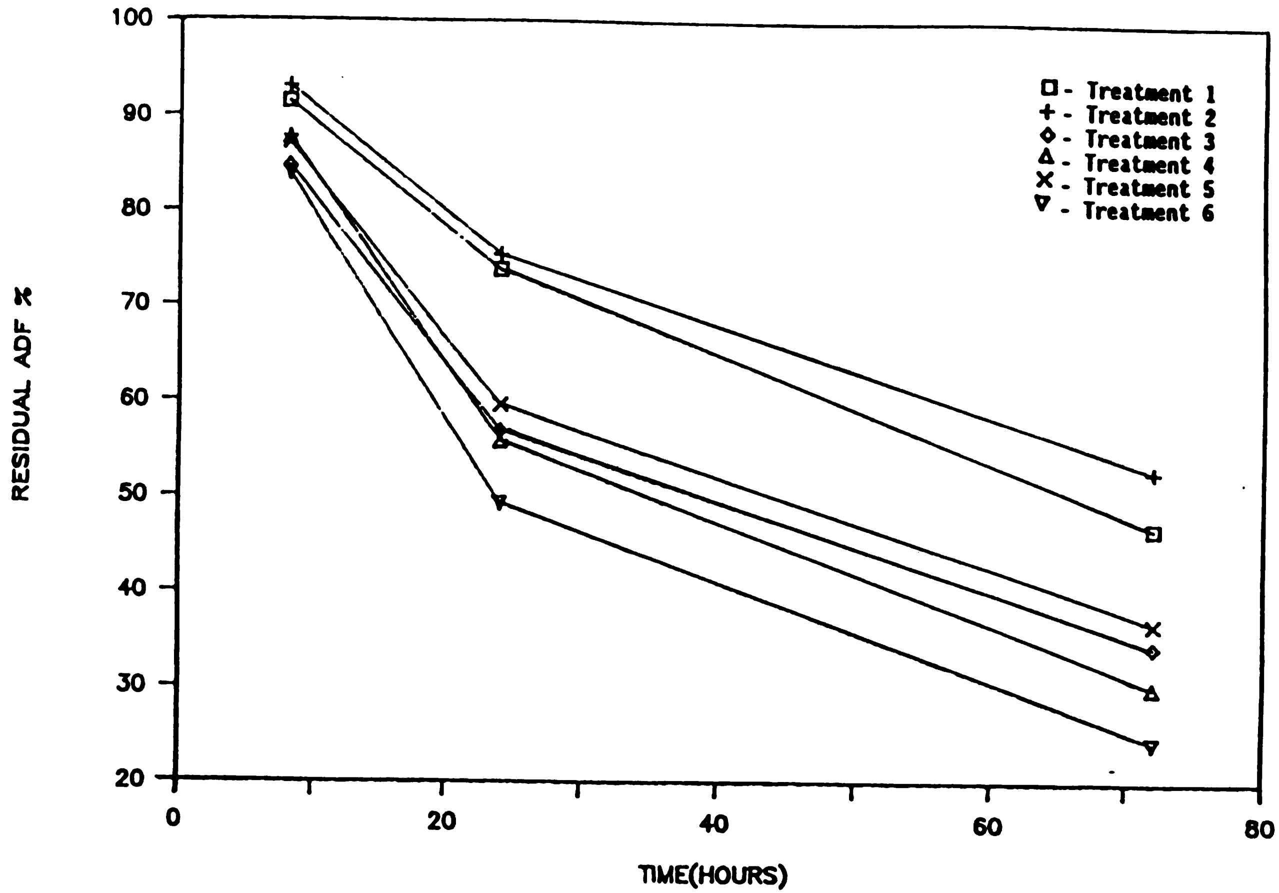

Figure 2. Residual Acid Detergent Fiber: Wheat Straw

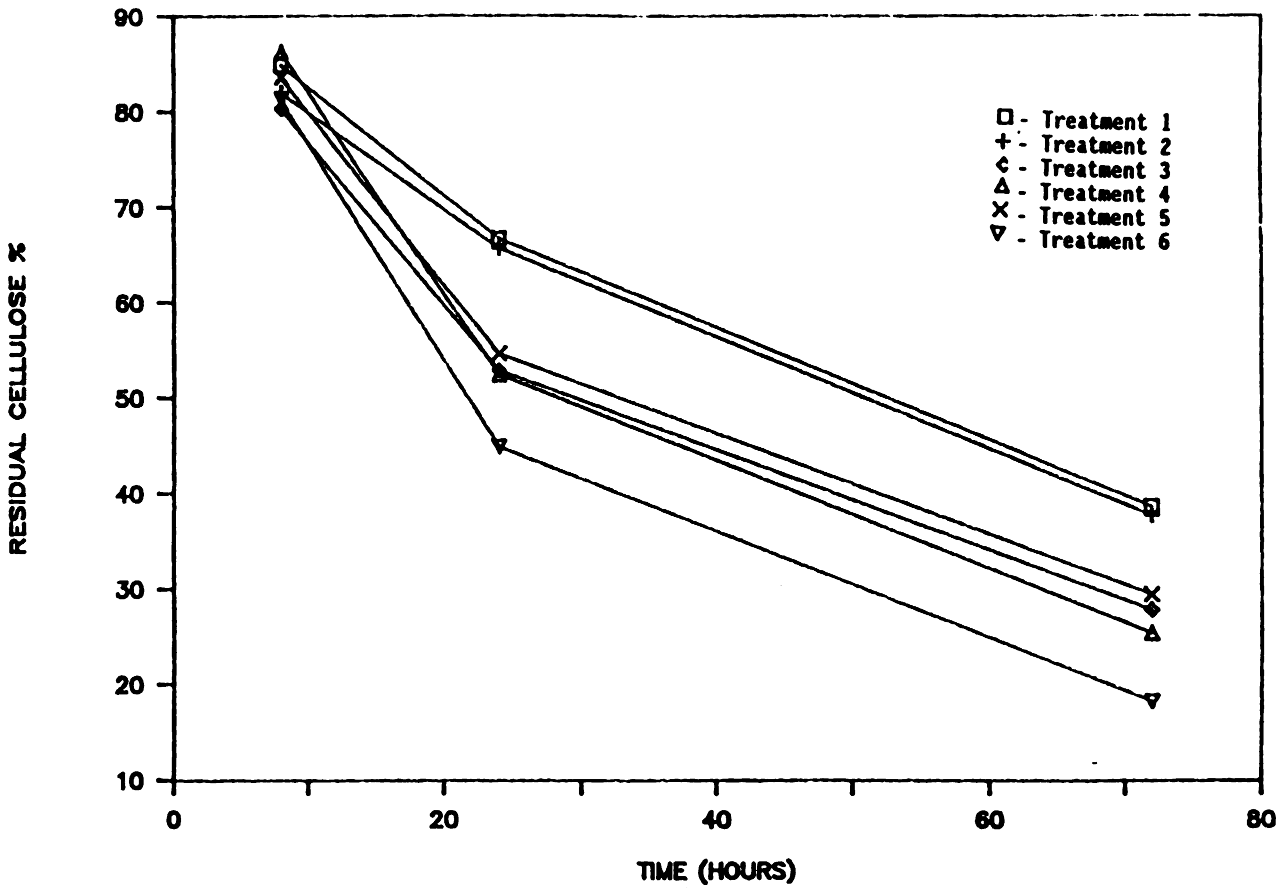

Figure 3. Residual Cellulose: Wheat Straw

Table 6. Composition of treated corn stover.

Treatment	Composition (%)			
	ADF	CELLULOSE	LIGNIN	NDF
1	50.8950	39.0850	9.5250	80.7200
2	53.6050	41.7900	9.9700	81.5050
3	54.6300	41.9000	11.1950	82.8950
4	57.7450	45.0000	11.1500	85.7800
5	57.7150	46.2500	9.7100	84.3850
6	58.0550	42.9200	10.1800	81.8600
SE	0.9721[a]	0.7215[a]	0.5430[a]	

a. n = 4

significantly increased by treatments 4, 5 ($P < 0.01$) and 6 ($P < 0.05$). These same treatments increased ($P < 0.05$) the ADF content of residue while lignin was not affected by treatment. Moore et al (1985) found no change in lignin and cellulose content upon ammoniation of orchard-grass. Mora et al (1983) reported a decrease in ADF, NDF, and ADL concentrations for cornstalks treated with NaOH and chelating metal caustic swelling. One constituent that seems to follow a consistent pattern is hemicellulose, which is decreased when residues are treated with chemicals. However, this constituent was not determined in the present study since ADF and NDF were determined on different samples.

4.2.2 Disappearance

The dry matter disappearance of corn stover was increased by treatments 3, 4, 6 ($P < 0.01$) and 5 ($P < 0.05$). Treatment 2 made no difference to the extent of digestion of DM, ADF, NDF, and cellulose.

Table 7. Dry matter disappearance of corn stover

Treatment	Dry matter disappearance (%)			
Incubation time (h)	8	24	72	Mean
1	4.9475	35.0875	60.3013	33.2613
2	6.7850	32.5937	54.4050	31.2612
3	10.8900	50.3150	65.0900	42.0983
4	10.7225	43.9150	70.5863	41.7413
5	6.7025	44.7200	69.8950	37.7614
6	15.7588	51.3525	76.9825	48.0313
SEM				1.0127[a]

a. n = 24

The greatest increase in DMD was obtained with NaOH. This is also reflected especially after 72 hours of incubation when the increase over the control was 16.6813% units. At the same time the least increase was 4.7888% units for the AHP treatment. After 24 hours of incubation, treatments 3 and 6 resulted in similar degradation (>15% units above control). Treatments 4 and 5 appear to have enhanced corn stover degradation to the same extent after both 24 and 72 hours. Increases obtained in this study were not as high as those reported by Kerley et al (1985), who found that the 48 hour in situ digestibility of corn stover increased from 59.6 to 95.6% as a result of AHP treatment.

With the exception of treatment 2, chemical treatment of corn stover was effective in increasing ($P < 0.01$) in situ digestion of ADF and cellulose (Table 8). Treatments 3, 4, 5 ($P < 0.05$) and 6 ($P < 0.01$) enhanced NDF loss. This indicates that these treatments increase the availability of cell wall carbohydrates for digestion. Mean lignin loss was greater than the control for treatments 3, 4, 6 ($P < 0.01$)

Table 8. Mean residual constituents of corn stover.

Treatment	Residual constituent (%)			
	ADF	CELLULOSE	NDF	LIGNIN
1	70.0322	68.1909	53.9750	90.6163
2	68.0220	65.1709	53.4170	88.6863
3	57.8214	55.2001	45.2251	69.6720
4	56.4391	55.2922	45.3533	66.7342
5	60.5115	58.5781	44.3754	76.7820
6	51.0406	54.6013	36.0966	59.2386
SE	3.5675[a]	8.2222[a]	1.0214[b]	3.0041[a]

a. n = 12
b. n = 4

and 5 ($P < 0.05$). This seems to indicate that as more carbohydrates were digested, some lignin particles were washed out of the bags. For treatments 3 to 6, the increase in DMD is reflected in the increased disappearance of the ADF, NDF, and cellulose fractions. Table 8 gives the mean proportion of ADF, cellulose, and NDF remaining after incubation.

4.2.3 Rates of disappearance

The rates of disappearance were calculated the same as for wheat straw. During the 0-24 hour period, the rate of dry matter disappearance was significantly increased by treatments 3, 6 ($P < 0.01$) and 5 ($P < 0.05$). The rate of ADF and lignin loss was increased ($P < 0.01$) by treatments 3 to 6 for the same period. Treatment did not alter the rate of disappearance for the 24-72 hour period for any of the components considered. The rates for this period were also lower than during the first 24 hours.

Table 9. Rates of disappearance for corn stover.

Treatment	Rate of disappearance (% per hour)									
	DMD		ADF		CELLULOSE		NDF		LIGNIN	
	0-24	24-72	0-24	24-72	0-24	24-72	0-24		0-24	24-72
1	1.4616	0.5254	1.3071	0.5272	1.3804	0.6070	1.3904	0.5273	0.3680	0.4207
2	1.3582	0.4542	1.3254	0.4708	1.4776	0.4978	1.4034	0.5376	0.3487	0.3672
3	2.0962	0.3077	2.0270	0.3456	2.1935	0.3727	1.7524	0.5299	1.4013	0.2256
4	1.8299	0.5556	1.9034	0.5513	1.9737	0.5848	1.6298	0.6471	1.3565	0.4509
5	1.8629	0.5305	1.9329	0.5134	2.0209	0.5269	1.7629	0.5686	1.2066	0.5146
6	2.1373	0.5352	2.1334	0.5626	1.9996	0.6546	2.0877	0.5750	1.6938	0.4872
SE	0.0969	0.0756	0.0883	0.0734	0.1172	0.0760	0.1080	0.0407	0.1448	0.1183

When compared to the control, the rate of loss of cellulose was increased by treatments 3, 5, 6 ($P < 0.01$) and 4 ($P < 0.05$). Only treatment 6 increased ($P < 0.05$) the rate of NDF loss significantly. Table 9 gives the rates of disappearance for the components considered in this study. Figures 4 to 6 represent graphically the pattern of disappearance for corn stover DM, ADF and cellulose.

4.3 Corn cobs

4.3.1 Effect of treatment on composition

When corn cobs were treated, only treatment 5 raised both the ADF ($P < 0.05$) and cellulose ($P < 0.01$) content. Treatment 4 increased the cellulose content ($P < 0.01$) only. Lignin content was not altered by treatment. Table 10 gives the composition of treated corn cobs as well as the control. While some researchers (Klopfenstein et al 1967, Wei and Cheng 1985, and Gould 1984) have obtained reduced lignin content as a result of chemical treatment of residues, others (Nangole et al 1983) have not. Waller (1976) also found no change in cellulose and lignin

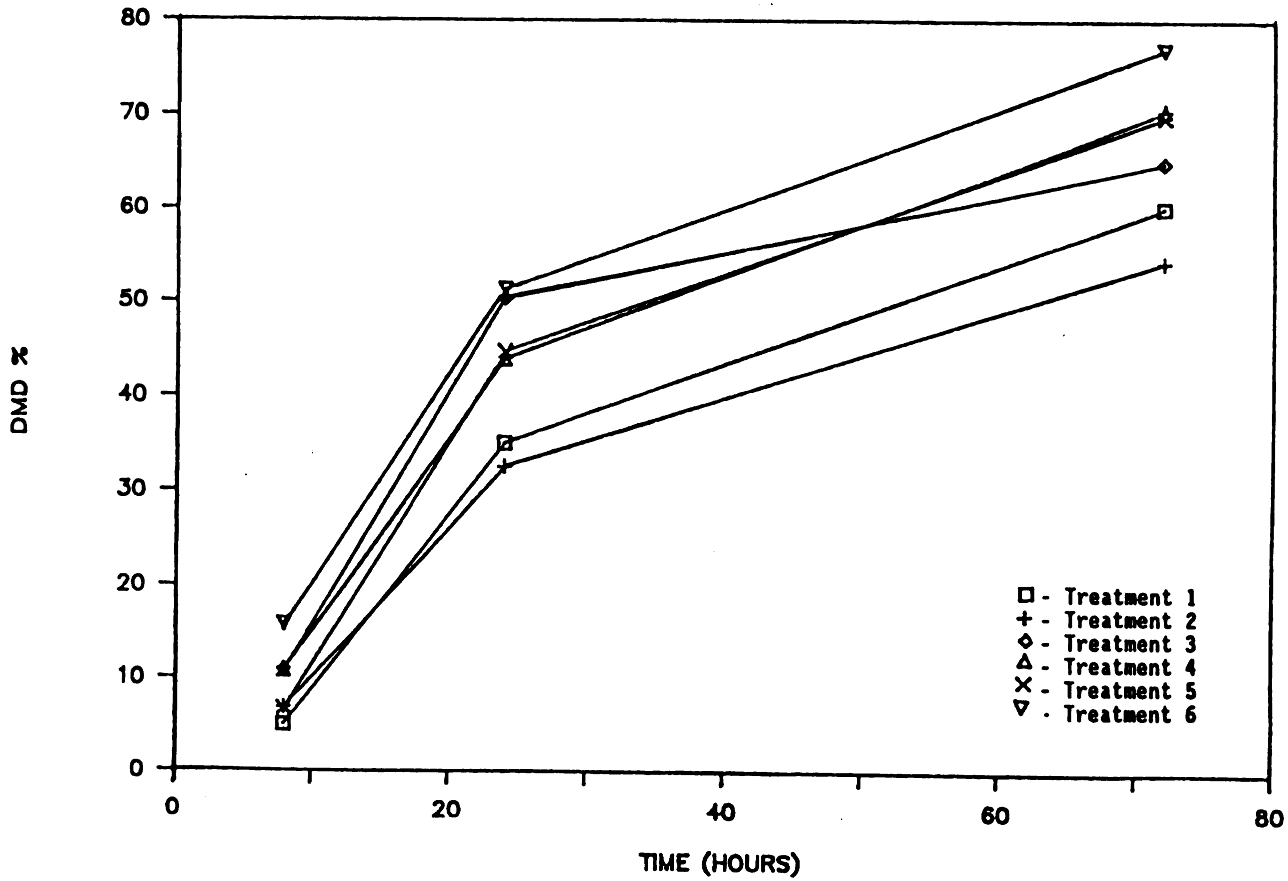

Figure 4. Dry Matter Disappearance: Corn Stover

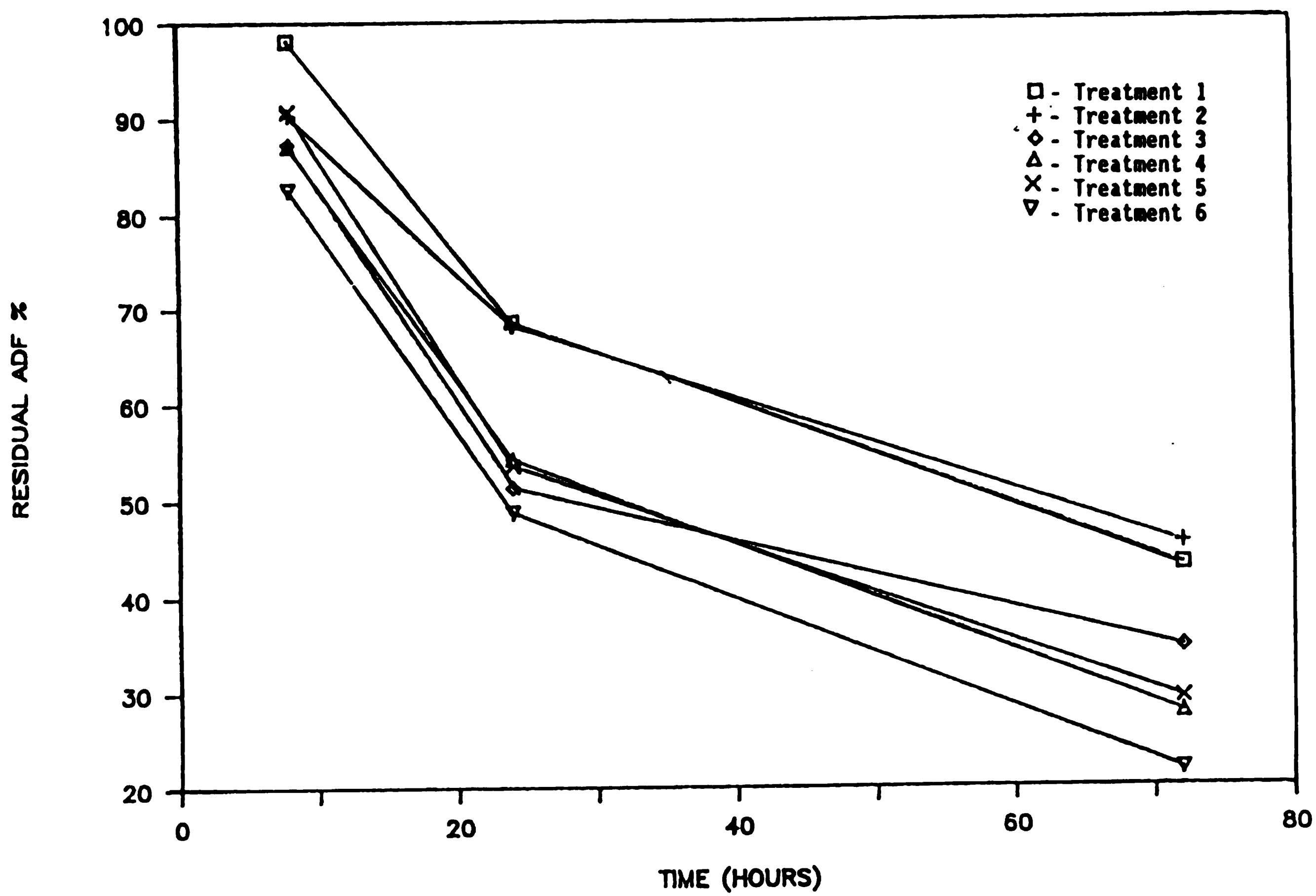

Figure 5. Residual Acid Detergent Fiber: Corn Stover

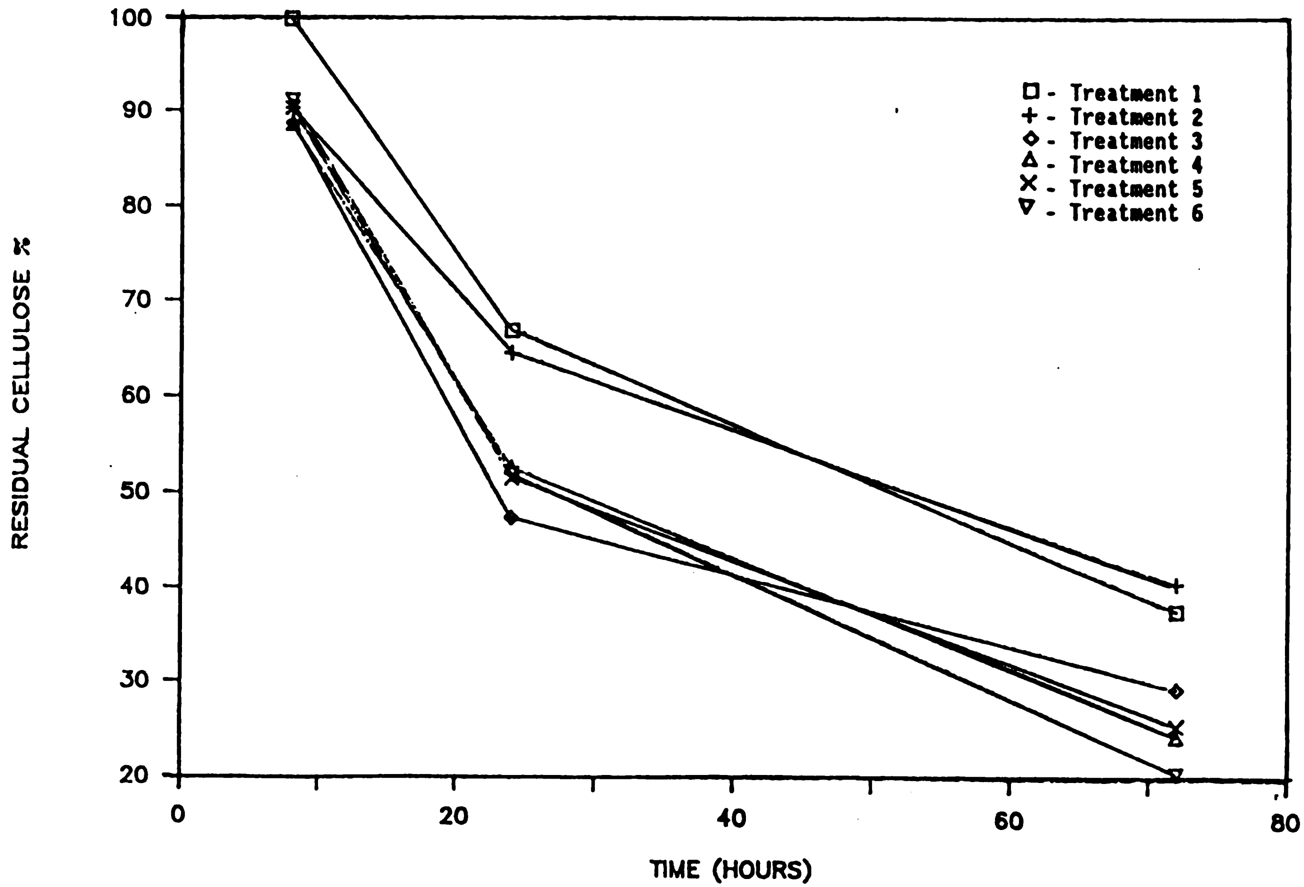

Figure 6. Residual Cellulose: Corn Stover

levels when corn cobs were treated with various combinations of NaOH, NH_4OH, and $Ca(OH)_2$. Because of low replication, it was not possible to determine statistically if treatment caused significant changes in the NDF content of corn cobs. From literature, it appears that even though changes in the composition of treated residues are sometimes obtained, this is not a prerequisite to obtaining increased digestibility.

Table 10. Composition of treated corn cobs*

Treatment	Composition (%)			
	ADF	CELLULOSE	LIGNIN	NDF
1	47.5350	38.7350	7.9600	85.9400
2	46.2350	37.6850	7.6800	82.8700
3	48.5300	39.1750	8.6200	85.6900
4	50.7500	42.4000	7.0800	85.8250
5	51.4550	43.7900	6.9850	87.2750
6	45.8650	37.3200	7.6750	83.5800
SE	0.4778a	0.4261[a]	0.3766[a]	

*Analysis for composition carried out on washed samples.
a. n = 4

4.3.2 Disappearance

Treatment of corn cobs resulted in increased ($P < 0.01$) mean DMD and NDF digestion for four of the five chemical treatments when all were compared with the control. The mean increases were 8.28, 6.76, 5.27, and 14.59 % units for treatment 3, 4, 5, and 6, respectively. Treatment 2 resulted in mean digestibility which was 1.20 % units above the control and this was not significant. As can be seen from Table 11, the magnitude of the difference between each of treatments 3 to 6 and the control is greater when the 24 hour and 72 hour values are observed separately.

Table 11. Dry matter disappearance for corn cobs.

Treatment	Dry matter disappearnce (%)			
Incubation time (h)	8	24	72	Mean
1	13.9525	35.4357	58.0363	35.8243
2	11.9713	39.4775	62.8529	37.0243
3	17.5063	46.1363	68.6725	44.1050
4	13.2643	43.2850	71.0886	42.5795
5	12.2200	40.1975	70.8613	41.0929
6	20.2788	53.8438	77.1150	50.4125
SE				0.5796[a]

a. n = 24

Increased ADF digestion was achieved by treatments 3, 6 ($P < 0.01$) and 5 ($P < 0.05$). These same treatments increased ($P < 0.01$) the disappearnce of cellulose (Table 12). It has been suggested that the increased digestibility of treated material is largely due to increased cellulose digestibility (Jackson 1977, Garrett et al 1974). The increase in DMD in the present study was also evident in the increased digestibility of the different constituents. For treatment 4, only the NDF digestibility was significantly higher than the control. The increase in DMD was not as high as that obtained by Kerley et al (1985). In their experiment, the 48 hour in situ digestibility increased from 47.5 to 95.4% as a result of AHP treatment.

Table 12. Mean residual constituents for corn cobs.

Treatment	Residual constituents			
	ADF	CELLULOSE	NDF	LIGNIN
1	64.3422	60.0044	54.5225	89.2468
2	65.4584	60.8911	55.5259	92.0246
3	57.1935	54.3286	43.5400	70.2581
4	61.4050	57.0155	41.2156	91.1915
5	59.5275	52.7298	44.7851	103.9953*
6	56.3628	52.2005	42.2368	79.2133
SE	1.0284[a]	1.0467[a]	.9564[b]	3.9978[a]

*This value is probably a reflection of inaccurate estimation since a gain in lignin is impossible.
a. n = 12
b. n = 4

4.3.3 Rates of disappearance

The rate of disappearance of DM and the constituents measured in this study was higher for the first 24 hours than for the last 48 hours. Significant increases ($P < 0.01$) above the control were obtained for the first 24 hours. Only treatment 5 resulted in a rate higher ($P < 0.05$) than the control for cellulose disappearance for the 24 to 72 hour incubation period. When Kerley et al (1985) incubated AHP treated wheat straw, corn cobs, and corn stalks in nylon bags for 48 hours, they found that treatment resulted in a doubling of the rate of DM digestion. Table 13 gives the rates obtained when corn cob disappearance was determined in the present study. In addition, figures 7 to 9 show the pattern for the disappearance of dry matter, cellulose, and ADF over time. Treatments 3 to 6 increased ($P < 0.01$) the rate of digestion of the ADF, NDF, and cellulose fractions during the first 24 hours. Only treatment 4 had a rate that was significantly higher ($P < 0.05$) than the control for cellulose digestion in the last phase of incubation. Waller (1976) reported an increased rate of corn cob cellulose digestion after chemical treatment. Only AHP increased ($P < 0.01$) both the rate and extent of lignin loss.

Table 13. Rates of disappearance for corn cobs.

Treatment	Rate of disappearance (% per hour)									
	DMD		ADF		CELLULOSE		NDF		LIGNIN	
	0-24	24-72	0-24	24-72	0-24	24-72	0-24	24-72	0-24	24-72
1	1.4834	0.4674	1.4946	0.5104	1.7326	0.5480	1.3429	0.5520	0.1635	0.4005
2	1.6505	0.4665	1.5729	0.5006	1.7797	0.5607	1.2477	0.6051	0.3773	0.2865
3	1.9224	0.4695	1.9521	0.4959	2.0941	0.5535	1.8609	0.4916	1.2785	0.2694
4	1.8036	0.5875	1.8561	0.6151	2.0495	0.6995	1.8880	0.5613	0.7141	0.0614
5	1.6745	0.6390	1.7395	0.6466	2.0406	0.6740	1.7001	0.6005	0.2569	0.5309
6	2.2433	0.4883	2.0867	0.5410	2.2882	0.5863	2.0702	0.3366	1.0149	0.3280
SE	0.0198	0.0421	0.0379	0.0437	0.0427	0.0323	0.0315	0.0497	0.1814	0.1218

For the crop residues studied in this experiment, no significant change in lignin occurred. Delignificatin has been sought as a way of improving the nutritive value of poor quality roughages. Gaillard's proposition (Nangole et al 1983) that delignification can occur without a reduction in lignin content would make sense in this case. Although lignin content did not change, significant improvement in digestibility occurred for all the residues. Even though lignin is indigestible, losses were obtained for some treatments. It is assumed that these losses were due to wash out. If this is the case, treatment causes greater breakdown of lignin into particles that can pass through the pores of the bags. Since lignin loss occurs at the same time that

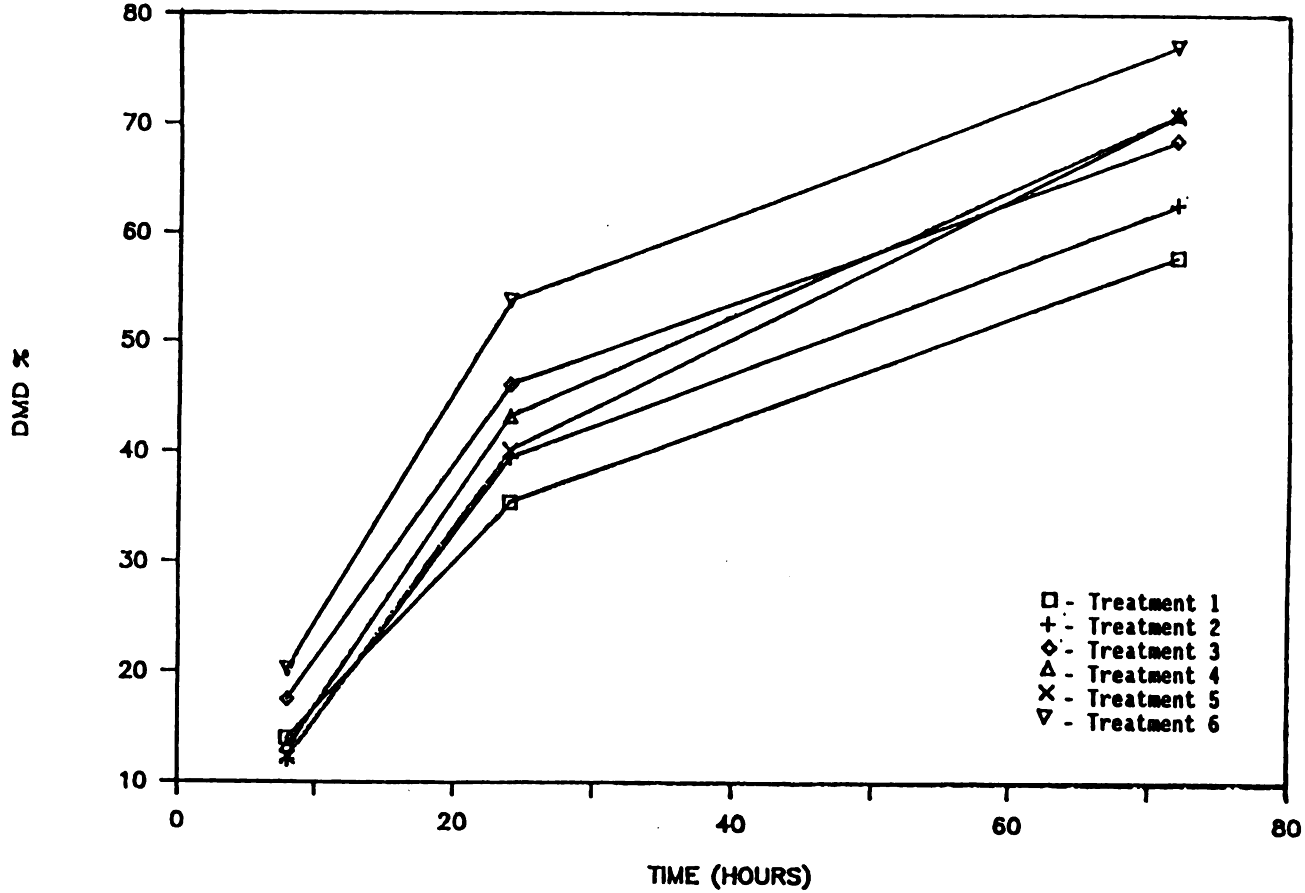

Figure 7. Dry Matter Disappearance: Corn Cobs

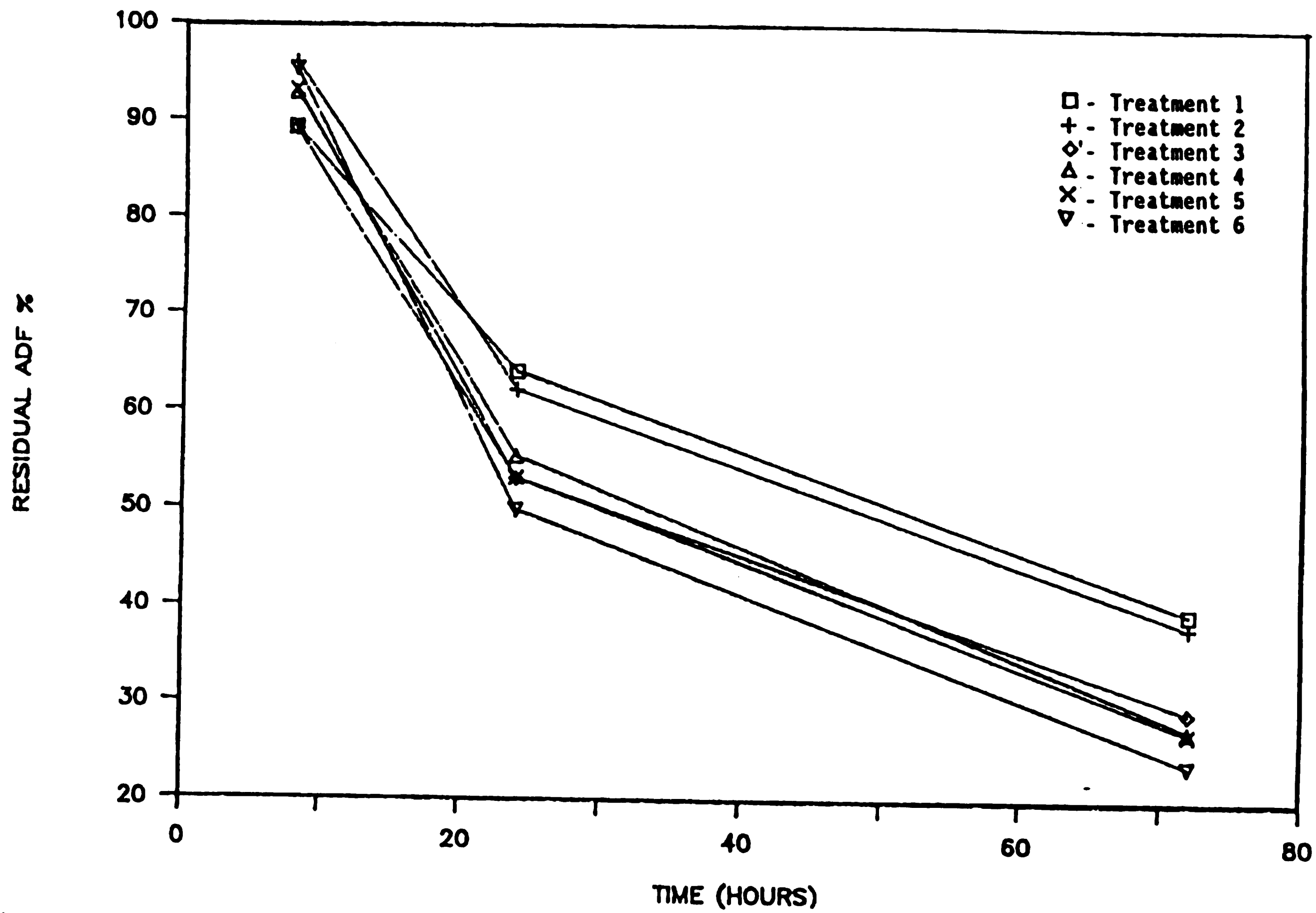

Figure 8. Residual Acid Detergent Fiber: Corn Cobs

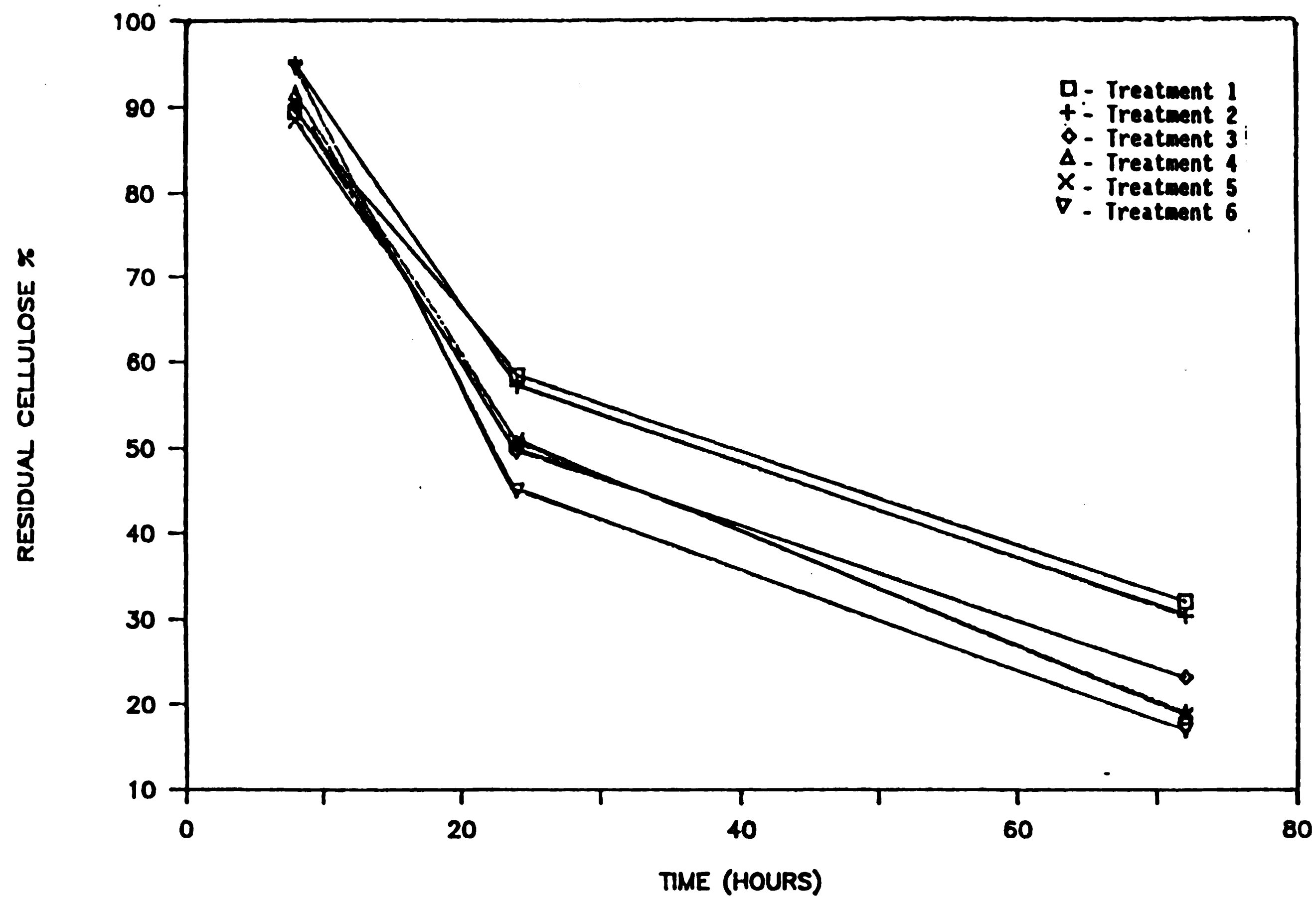

Figure 9. Residual Cellulose: Corn Cobs

increased digestibility takes place, one can conclude that treatment causes the breakdown of the cell wall complex making carbohydrates more accessible to rumen microorganisms and their enzymes. As the carbohydrates are digested, indigestible lignin particles are also released and those that are small enough are washed through the nylon bag pores to the outside.

The extent of digestibility obtained with the nylon bag technique depends on the diet of the incubator animal. Dryden and Kempton (1984) found that if the animal was fed an untreated straw diet, the digestibilities of control and treated barley straw were 51.3 and 64.7% respecively. If the animal was fed alfalfa, the digestibilities were 62.5 and 76.7% reflecting the higher protein content of the alfalfa. While one would not be able to very accurately assess how much material will be digested, this technique is sufficient for screening potential treatments.

The rates of DMD obtained in this study were not as high as those reported by other workers. Kerley et al (1984a) reported rates of 2.79,. 3.96 and 3.45% per hour for untreated wheat straw, corn cobs and corn stalks, respectively. After treatment with AHP, the rates increased to 5.13, 8.98 and 7.83% per hour respectively for the same residues. The reason for the big differences probably lies in the methods used for the calculations. The regression method used by Kerley et al (1984a, 1985) would be preferable. However, this requires more values obtained at more frequent intervals than used in this study.

Hydrogen peroxide alone did not improve the nutritive value for

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any of the three residues studied while the other four treatments proved beneficial. Lewis et al (1984) report that treating wheat straw with HP did significantly affect in situ dry matter disappearance. In the same experiment, these workers found no NH_3 x HP interaction when these two chemicals were used to treat wheat straw. More work is required to see if a method can be developed that would make the use of a combination of these two chemicals as effective as or better than ammonia alone and also be comparable to NaOH. It is hoped that such a method would not require the use of as much ammonia as is needed when ammonia is used alone. The ammonia would, in addition to improving digestibility, provide some nitrogen that the animals need to meet requirements. This would eliminate even the smaller quantities of NaOH required for alkaline peroxide treatment, which has proven beneficial in practical diets (Kerley et al 1986).

Corn cobs and corn stover are the main crop residues that are available to small scale farmers in Zimbabwe. It is encouraging that treatment of these materials resulted in an increase in digestibility. Treatment of these residues could help those farmers that are going into commercial dairy production to reduce feed costs. With feed costs on the rise, one is likely to find the adoption of this method of supplementing livestock feed, even on the large commercial farms of Zimbabwe.

4.4 Conclusions

1. HP alone is not effective in improving digestibility under the treatment conditions used in this experiment.

2. NaOH appears to be superior to the other three treatments that improved digestibility. More work needs to be done to compare treatments in order to have more information on which choice or recommendations of treatment chemicals can be made. The chemical of choice for use by the farmers would depend mostly on safety and economic considerations.

3. The treatment method used in the present study is simple and can be easily performed on the farm by an interested farmer. One modification that might be required is the drying of treatment material. If it is necessary or preferable that the treated residues be dried, this could be done by spreading the material out to dry in the sun, eliminating the need to invest in a drying system. It is recommended that the treated residues be fed without drying.

REFERENCES

Adebowale, E.A. 1985. Organic waste ash as possible source of alkali for animal feed treatment. An. Feed Sci. Technol. 13:237.

Aines, Glen E., R. Britton and T. Klopfenstein. 1985. Effects of alkali source and level on ruminal fiber digestion rate and rumen turnover kinetics. J. Anim. Sci. 61: Supplement 1:1355 (Abstr.)

Alawa, J.P. and E. Owen. 1985. The effect of supplementing grass silage with sodium hydroxide treated chopped or milled straw on intake and digestibility by wether sheep. Animal Feed Sci. Technol. 12:215.

Alibes, F., Munoz and R. Faci. 1984. Anhydrous ammonia-treated cereal straw for animal feeding. Some results from the Mediterranean area. Anim. Feed Sci. Technol. 10:239.

Arthur, J.C., Jr. 1971. Reactions Induced by High Energy Radiation. In: Bickales and Segal (eds.). <u>Cellulose and Cellulose Derivatives</u>. Wiley Interscience, p. 937

Birkelo, C.P., D.E. Johnson and G.M. Ward. 1985. Net energy value of ammoniated wheat straw. J. Anim. Sci. 61 Supplement 1:354 (Abstr.)

Borhami, B.E.A., F. Sundstol and T.H. Garmo. 1982. Studies on Ammonia-treated straw. II. Fixation of ammonia in treated straw by spraying with acids. Anim. Feed Sci. Technol. 7:53

Brown, W.F., J.D. Phillips and D.B. Jones. 1987. Ammoniation or cane molasses supplementation of low quality roughages. J. Anim. Sci. 64:1205

Chandra, S. and M.G. Jackson. 1971. A study of various chemical treatments to remove lignin from coarse roughages and increase their digestibility. J. Agric. Sci., Camb. 77:11

Chestnut, A.B., L.L. Berger and G.C. Fahey Jr. 1985. Effects of ammoniation of tall fescue on digestion of fiber fractions and disappearance of alkali-labile cell wall phenolic acids. J. Anim. Sci. 61 Supplement 1:354 (Abstr.)

Dehority, B.A. and Johnson R.R., 1961. Effect of particle size upon the in vitro cellulose digestibility of forages by rumen bacteria. J. Dairy Sci. 44:2242

Dias-da-Silva, and F. Sundstol. 1986. Urea as a source of ammonia for improving the nutritive value of wheat straw. Anim. Feed Sci. Technol. 14:67.

Dolberg, F., M. Saadullah, M. Haque and R. Ahmed. 1981. Storage of urea-treated straw using indigenous material. World Animal Review 38:37

Dryden, G. McL. and T.J. Kempton. 1984. Digestion of organic matter and nitrogen in ammoniated barley straw. Anim. Feed Sci. Technol. 10:65.

Dryden, G. McL. and R.A. Leng. 1986. Treatment of barley straw with ammonia and sulphur dioxide gases under laboratory conditions. Anim. Feed Sci. Technol. 14:67.

Forney, L.J., C.A. Reddy, M. Tien and S.D. Aust. 1982. The involvement of hydroxyl radical derived from hydrogen peroxide in ligin degradation by White Rot Fungus. J. Biol. Chem. 257:11455.

Frape, D.L. 1984. Straw etc. in practical diets of other ruminants and non-ruminants. In: Sundstol and Owen (eds.). Straw and other fibrous by-products as feed. Elsevier, p. 487.

Garrett, W.N., H.G. Walker, G.O. Kohler, A.C. Waiss, Jr., R.P. Graham, N.E. East, and M.R. Hast. 1974. Nutritive value of NaOH and NH_3 treated rice straw. J. Anim. Sci. 38:1342 (Abstr.).

Garrett, W.N., H.G. Walker Jr., G.O. Kohler, M.R. Hart and R.P. Graham. 1981. Steam treatment of crop residues for increased ruminant digestibility. II. Lamb feeding response. J. Anim. Sci. 51:409.

Gill, J.L. 1978a. Design and analysis of experiments in the Animal and Medical Sciences. Vol. I. Iowa State University Press.

Gill, J.L. 1978b. Design and analysis of experiments in the animal and Medical and Sciences. Vol. 2. Iowa State University Press.

Gill, J.L. 1978c. Design and analysis of experiments in the Animal and Medical Sciences. Vol. 3. Iowa State University Press.

Goering, H.K. and P.I. Van Soest. 1970. Forage fiber analysis (Apparatus, Reagents, Procedures and some Applications). U.S.D.A. Agricultural Research Service. Agriculture Handbook No. 379.

Gould, J.M. 1984. Alkaline peroxide delignification of agricultural residues to enhance enzymatic saccharification. Biotechnology and Bioengineering 26:46.

Gould, J.M. 1985a. Studies on the Mechanism of alkaline peroxide delignification of agricultural residues. Biotechnol. and Bioengin. 27:225.

Gould, J.M. 1985b. Enhanced polysaccharide recovery from agricultural residues and perenial grasses treated with alkaline hydrogen peroxide. Biotechnol. and Bioengin. 27:893.

Gould, J.M. and S.N. Freer. 1984. High efficiency residues pretreated with alkaline hydrogen peroxide. Biotechnol. and Bioengin. 26:628.

Graham, H., and P. Aman. 1984. A comparison between degradation in vitro and in sacco of constituents of untreated and ammonia-treated barley straw. Anim. Feed Sci. Technol. 10:199.

Greenhalgh, J.F.D., r. Pirie and G.W. Reid. 1976. Alkali-treated barley straw in complete diets for lambs and dairy cows. Anim. Prod. 22:159 (Abstr.)

Grotheer, M.D., D.L. Gross and L.W. Grimes. 1986. Effect of ammonia level and time of exposure to ammonia on nutritional and preservatory characteristics of dry and high moisture coastal bermuda grass hay. Anim. Feed Sci. Technol. 14:55.

Hackett, M.r., J.K. Hillers, R.P. Kraman and E.L. Martin. 1975. Evaluation of wheat straw in feeder lamb rations. Proc. Western Section. Am. Soc. Anim. Sci. 26:143.

Hart, M.R., H.G. Walker, Jr., R.P. Graham, P.G. Hanni, A.H. Brown and G.O. Kohler. 1981. Steam treatment of crop residues for increased ruminant digestibility. 1. Effects of process parameters. J. Animal Sci. 51:402.

Herrera-Saldana, R., D.C. Church and R.O. Kellems. 1982. The effect of ammoniation treatment on intake and nutritive value of wheat straw. J. Anim. Sci. 54:603.

Holzer, Z., Levy D. and Folman Y. 1980. Perfomance of fattening cattle and lactating beef cows on diets high in chemically treated wheat straw and poultry litter. Anim. Feed Sci. Technol. 5:299.

Homb, T. 1984. Wet treatment with sodium hydroxide. In Sundstol and Owen (eds.) 1984. Straw and other fibrous by-products as feed. Elsevier. p. 106.

Huber, J.T. and L. Kung (Jr.). 1981. Protein and non-protein nitrogen utilization in dairy cattle. J. Dairy Sci. 64:1170.

Ibbotson, C.F., R. Mansbridge and A.H. Adamson. 1984. Commercial experience of treating wheat straw with ammonia. Anim. Feed Sci. Technol. 10:223.

Jackson, M.G. 1977. Review Article: The alkaline treatment of straws. Anim. Feed Sci. Technol. 2:105.

Jackson, M.G. 1978. Treating straw for animal feeding: an assessment of its technical and economic feasibility. FAO Animal Production and Health Paper 10. U.N. Rome.

Jayasuriya, M.C.N. and E. Owen. 1975. Sodium Hydroxide treatment of barley straw; effect of volume and concentration of solution on digestibility and intake by sheep. Anim. Prod. 21:313.

Jones, M.J. and T.J. Klopfenstein, 1967. Chemical treatments of poor quality roughages. J. Anim. Sci. 26:1492 (Abstr.).

Kategile, J.A., N.A. Urio, F. Sundstol and Y.G. Mzihirwa. 1981. Simplified method for alkali treatment of low quality roughages for use by small-holders in developing countries. Anim. Feed Sci. Technol. 6:133.

Kellaway, R.C., F.C. Crofts, L.R.L. Thiago, R.G. Redman, J.M.L. Leibholz and C.A. Graham. 1978. A new technique for upgrading the nutritive value of roughages under field conditions. Anim. Feed Sci. Technol. 3:201.

Kerley, M.S., G.C. Fahey Jr., L.L. Berger and J.M. Gould. 1984a. Effects of pretreating lignocellulosic materials with alkaline hydrogen peroxide on in situ dry matter disappearance and nutrient digestibility by lambs. J. Anim. Sci. 61: Supplement 1:357 (Abstr.).

Kerley, M.S., G.C. Fahey Jr., L.L. Berger and J.M. Gould, 1984b. Effects of pretreating wheat straw with alkaline hydrogen peroxide on site and extent of digestion in sheep. J. Anim. Sci. 61, Suppl. 1:357 (Abstr.).

Kerley, M.S., G.C. Fahey Jr., L.L. Berger, J.M. Gould and F. Lee Baker, 1985. Alkaline hydrogen peroxide treatment unlocks energy in agricultural by-products. Science 230:820.

Kerley, M.S., G.C. Fahey Jr., L.L. Berger, N.R. Merchen and J.M. Gould, 1986. Effects of alkaline hydrogen peroxide treatment of wheat straw on site and extent of digestion in sheep. J. Anim. Sci. 63:868.

Klopfenstein, T.J. and W. Koers. 1973. Agricultural cellulasic wastes for feed. In: Inglett (ed.): Symposium: Processing Agricultural and Municipal Wastes, Avi. Publishing Co., Westport, Conn. p. 38.

Klopfenstein, T.J., R.P. Graham, H.G. Walker, Jr., and G.O. Kohler. 1974. Chemicals with pressure treated cobs. J. Animal Sci. 39:243 (Abstr.)

Klopfenstein, T.J. 1978. Chemical treatment of crop residues. J. Anim. Sci. 46:841.

Klopfenstein, T. 1981. Increasing the nutritive value of crop residues by chemical treatment. In: J.T. Huber (ed) Upgrading residues and by-products for animals. CRC Press. p. 39.

Klopfenstein, T.J. and K.K. Bolsen. 1971. High temperature pressure treated crop residues. J. Anim.Sci. 33:290 (Abstr.)

Klopfenstein, T.J., R.R. Bartling and W.R. Woods, 1967. Treatment for increasing roughage digestibility. J. Anim. Sci. 26:1492 (Abst.)

Klopfenstein, T.J., V.E. Krause, M.J. Jones and W. Woods. 1972. Chemical treatment of low quality roughages. J. Anim. Sci. 35:418.

Klopfenstein, T. and W.R. Woods, 1970. Sodium and potassium hydroxide treatment of wheat straw and corn cobs. J. Anim. Sci. 31:246 (Abstr.).

Koers, W.C., W. Woods, and T.J. Klopfenstein, 1969. Sodium hydroxide treatment of corn cobs. J. Anim. Sci. 29:163.

Koers, W.C., W. Woods and T. Klopfenstein, 1972. Sodium hydroxide treatment of corn stover and cobs. J. Anim. Sci. 31:1030 (Abstr.).

Lesoing, G., T. Klopfenstein, I. Rush and J. Ward. 1981. Chemical treatment of wheat straw. J. Anim. Sci. 51:263.

Lesoing, G., I. Rush, T. Klopfenstein and J. Ward. 1981. Wheat straw in growing cattle diets. J. Anim. Sci. 51:257.

Lewis, S.M., L.L. Berger, G.C. Fahey Jr., G.F. Fanta and J.M. Gould 1984. Effects of neutralization, washing and drying on in situ disappearance of alkaline peroxide treated wheat straw. J. Anim. Sci. 61, Suppl. 1:357 (Abstract).

McManus, W.R., L. Manta, J.D. McFarlane and A.C. Gray. 1972. The effects of diet supplements and gamma irradiation on dissimilation of low quality roughages by ruminants. III. Effects of gamma irradiation and urea supplementation on dissimulation in the rumen. J. Agric. Sci. (Camb.) 79:41.

Mehrez, A.Z., and E.R. Orskov. 1976. A study of the artificial fiber bag technique for determining the digestibility of feeds in the rumen. J. Agric. Sci., Camb. 88:645.

Mira, J.J.F., M. Kay and E.A. Hunter. 1983. Treatment of barley straw with urea or anhydrous ammonia for growing cattle. Animal Production 36:271.

Moore, K.J., V.L. Letchenberg and K.S. Hendrix, 1985. Quality of orchardgrass hay ammoniated at different rates, moisture concentrations and treatment durations. Agronomy Journal 77:67.

Mora, M.I., G.C. Fahey Jr., P.J. Van de Aoar and L.L. Berger. 1983. Improving utilization of crop residues: evaluation of two chemicals used to improve digestibility of crop residues. Anim. Feed Sci. Technol. 9:205.

Morrison, I. M. and R.E. Brice. 1984. The digestion of untreated and ammonia-treated barley straw in an artificial rumen. Anim. Feed Sci. Technol. 10:229.

Nangole, F.N., H. Kayongo-Male and A.N. Said 1983. Chemical composition, digestibility and feeding value of maize cobs. Anim. Feed Sci. Technol. 9:121.

Ndhlovu, L.R. and J.G. Buchanan Smith 1983. The effect of alfafa supplementation on rumen parameters and fiber digestion in sheep fed poor quality roughages. J. Anim. Sci. 57 (Abstr.).

Nicholson, H.H., R. Chaplin, E.M. Coxworth and J.A. Kernan. 1977. Chemical treatment of wheat straw with anhydrous ammonia. Can. J. Anim. Sci. 57:828 (Abstr.).

Noceck, J.E. and A.L. Grant. 1987. Characterization of in situ nitrogen and fiber digestion and bacterial nitrogen contamination of hay crop forages preserved at different dry matter percentages. J. Anim. Sci. 64:552.

Noceck, J.E. and M.B. Hall. 1984. Characterization of soyhull fiber digestion by in situ and enzymatic procedures. J. Dairy Sci. 67:2599.

Oji, U.I. and D.N. Mowat. 1977. Breakdown of urea to ammonia for treating corn stover. Can. J. Anim. Sci. 57:828 (Abstr.).

Oji, U.I., D.N. Mowat and J.E. Winch. 1977. Alkali treatment of corn stover to increase nutritive value. J. Anim. Sci. 44:798.

Ololade, B.G., D.N. Mowat and J.E. Winch 1970. Effect of processing methods on the in vitro digestibility of sodium hydroxide-treated roughages. Can. J. Anim. Sci. 50:657.

Orskov, E.R. 1984. Evaluation of crop residues and agro-industrial by-products using the nylon bag method. In: Preston, T.R., V.L. Kossila, J. Goodwin and S.B. Reed (eds.). Proceedings of the FAO/ILCA Expert Consultation. Addis Ababa. FAO Animal Production and Health paper 50:153.

Orskov, E.R., F.D. DeB Hovel and F. Mould. 1980. The use of the nylon bag technique for the evaluation of feedstuffs. Tropical Animal Production 5:195.

Owen, E. 1978. Processing of roughages. In Haresgin Ward and D. Lewis (ed.) Recent advances in Animal nutrition. Butterworths. p. 127.

Owen, E., T. Klopfenstein and N.A. Urio. 1984. Treatment with other chemicals. In Sundstol and Owen (ed.) Straw and other fibrous by-products as feed. Elsevier. p. 248.

Pritchard, G.I., W.J. Pigden and D.J. Minton. 1962. Effect of gamma radiation on the utilization of wheat straw by rumen micro-organisms. Can. J. Anim. Sci. 42:215.

Puri, V.P. 1984. Effect of crystallinity and degree of polymerization of cellulose on enzymatic saccharification. Biotechnol. and Bioengineering 26:1219.

Ragnekar, D.V., V.C. Badre, S.T. Kharat, D.N. Sobale and A.L. Toshi. 1982. Effect of high-pressure steam-treatment on chemical composition and digestibility in vitro of roughages. Anim. Feed Sci. Technol. 7:61.

Reddy, G.V.N. and M. Reddy. 1986. Effects of ammoniation and processing of cotton straw as the sole source of roughage in complete feeds on rumen characteristics with Murrah buffaloes. Anim. Feed Sci. Technol. 14:95.

Reed, J.D. and P.J. Van Soest. 1984. Estimating the nutritive value of crop residues and agro-industrial by-products by chemical methods. In: Preston T.R., V.L. Kossila, J. Goodwin and S.B. Reed (eds.). Proceedings of the FAO/ILCA Expert Consultation. Addis Ababa. FAO animal production and health paper. 50:117.

Rexen, F.P. and K.E. Bach Knudsen. 1984. Industrial-scale dry treatment with sodium hydroxide. In: Sundstol and Owen (eds.) 1984. Straw and other fibrous by-products as feed. Elsevier. p.127.

Rexen F., P. Stigsen and V.F. Kristensen. 1976. The effect of a new alkali technique on the nutritive value of straws. In: Swan and Lewis (ed). Feed energy sources for livestock. Butterworth. p.65.

Rexen, F. and K.V. Thomsen 1976. The effect on digestibility of a new technique for alkali treatment of straw. Anim. Feed Sci. Technol. 1:73.

Rivera-Villarreal E. and W.C. Ellis. 1985. Effect of ammoniation upon intake and masticative comminution of various maturities of bermuda grass hay by cattle. J. Anim. Sci. Supplement 1:355. (Abstr.)

Robb J. 1976. Alternatives to conventional cereals. In: Swan and Lewis (ed.) Feed energy sources for livestock. Butterworth. p.13.

Rounds, W., T. Klopfenstein, J. Waller and T. Messersmith. 1976. Influence of Alkali treatment of corn cobs on in vitro dry matter disappearance and lamb performance. J. Anim. Sci. 43:478.

Santillana, R.G. and J.M. Wilkinson. 1978. Effect of time of storage and method of drying on the digestibility in vitro of alkali treated barley straw. Anim. Feed Sci. Technol. 3:381.

Saxena, K., D.E. Otterby, J.D. Dorker and A.L. Good. 1971. Effects of feeding alkali treated oat straw supplemented with soybean meal or nonprotein nitrogen on growth of lambs and on certain blood and rumen liquor parameters. J. Anim. Sci. 33:485.

Shirley, R. 1986. Nitrogen and energy nutrtion of ruminants. Academic Press. p. 147.

Singh, M. and M.G. Jackson. 1971. The effect of different levels of sodium hydroxide spray treatment of wheat straw on composition and digestibility by cattle. J. Agric. Sci. (Camb.) 77:5.

Solaiman, S.G., G.W. Horn and F.N. Owens. 1979. Ammonium hydroxide treatment of wheat straw. J. Anim. Sci. 49:802.

Sundstol, F. and E.M. Coxworth. 1984. Ammonia treatment. In: Sundstol and Owen (eds.) Straw and other fibrous by-products as feed. Elsevier. p. 196.

Sundstol, F., E. Coxworth and D.N. Mowat. 1978. Improving the nutritive value of straw and other low-quality roughages by treatment with ammonia. World Anim. Rev. 26:13.

Van Soest, P.J., A.M. Fereira and R.D. Hartley. 1984. Chemical properties of fibre in relation to nutritive value of ammonia treated forages. Anim. Feed Sci. Technol. 10:155.

Verma, M.L. and M.G. Jackson. 1981. Staw etc. in practical rations for cattle and buffaloes with special reference to developing countries. In: Sundstol and Owen (eds.) Straw and other fibrous by-products as feed. Elsevier, p. 414.

Waiss, A.C., Jr., J. Guggolz, G.O. Kohler, H.G. Walker, Jr. and W.N. Garrett. 1972. Improving digestibility of straws for ruminant feed by aqueous ammonia. J. Anim. Sci. 35:109.

Walker, H.G. 1984. Physical treatment. In: Sundstol and Owen (eds.) Straw and other fibrous by-roducts as feed. Elsevier, p. 79.

Waller, J. and T. Klopfenstein, 1975. Hydroxides for treating crop residues. J. Anim. Sci. 41:424.

Waller, J.C. 1976. Evaluation of sodium, calcium and ammonium hydroxides for treating crop residues. M.S. Thesis, University of Nebraska, Lincoln.

Wanapat, M., F. Sundstol and T.H. Garmo. 1985. A comparison of alkali treatment methods to improve the nutritive value of straw. I. Digestibilty and Metabolizability. Anim. Feed. Sci. Technol. 12:295.

Wanapat, M., F. Sundstol and J.M.R. Hall. 1986. A comparison of alkali treatment methods used to improve the nutritive value of straw. II. In sacco and in vitro degradation relative to in vivo digestibility. Anim. Feed Sci. Technol. 14:215.

Weakley, D.C., M.D. Stern and L.D. Salter. 1983. Factors affecting disappearance of feedstuffs from bags suspended in the rumen. J. Anim. Sci. 56:493.

Wei, Chia-Jenn and Chung-Yueh Cheng. 1985. Effects of hydrogen peroxide pretreatment on structural features and the enzymatic hydrolysis of rice straw. Biotechnol. and Bioengineering. 27:1418.

Wilkinson, J.M. 1984a. Ensiling with sodium hydroxide. In: Sundstol and Owen (eds.). Straw and other fibrous by-products as feed. Elsevier, p. 181.

Wilkinson, J.M. 1984b. Farm scale dry treatment with sodium hydroxide. In: Sundstol and Owen (eds.). Straw and other fibrous by-products as feed. Elsevier, p. 162.

Wilkinson, J.M. and R. Gonzalez Santillana. 1978. Ensiled alkali-treated straw. I. Effect of level and type of alkali on the composition and digestibility in vitro of ensiled barley straw. Anim. Feed Sci. Technol. 3:117.

Williams, P.E.V. 1984. Digestibility studies on ammonia-treated straw. Anim. Feed Sci. Technol. 10:213.

Wilms, C.L., L.L. Berger, D.P. Holzgraefe, D.L. Hartlieb, G.C. Fahey, Jr., S.M. Lewis and J.M. Gould. 1984. Effects of alkali source and treatment conditions on in situ disappearance of alkaline hydrogen peroxide treated wheat straw.

Yu Yu, Thomas J.W. and R.S. Emery. 1970. Laboratory evaluation of chemically treated straw. J. Anim. Sci. 31:1031 (Abstr.)

Yu Yu, Thomas J.W. and R.S. Emery. 1975. Estimated nutritive value of treated forages for ruminants. J. Anim. Sci. 41:1743.