AN ABSTRACT OF THE THESIS OF

DANIEL CRAIG ANDERSON for the DOCTOR OF PHILOSOPHY
(Name) (Degree)

in ANIMAL SCIENCE presented on May 3 1972
(Major) (Date)

Title: IN VITRO AND IN VIVO EVALUATIONS OF CHEMICALLY TREATED RYEGRASS STRAW

Redacted for Privacy

Abstract approved: [redacted]
Dr. A. T. Ralston

Seven in vitro trials were conducted to compare the effects of soaking annual ryegrass straw in solutions of sodium hydroxide (NaOH), potassium hydroxide (KOH), ammonium hydroxide (NH_4OH), or sodium formate ($NaCHO_2$) at varying levels. Dry matter digestibility (DDM) was the criterion used to measure treatment response. A 3 x 3 Latin square designed lamb digestion trial, replicated three times, followed these screening trials. Its purpose was to study the effects that NaOH-treated straw had on animal health, feed and water intake, urine excretion and pH, apparent digestibility, nitrogen and energy utilization and sodium and potassium balances.

Three feeding trials were also carried out to measure the performance of heifer calves fed untreated, but supplemented ryegrass straw based rations. A 3 x 3 Latin square designed sheep digestion trail supplied additional data on apparent digestibility and nitrogen and energy utilization for three of these rations.

Spraying a two percent NaOH solution on straw did not significantly improve DDM while soaking at the same level produced a significant ($P< .01$) increase. There was no significant difference among particle sizes or treatment times for straw soaked in two percent NaOH. Two, four, six or eight percent levels of either NaOH or KOH solutions significantly ($P< .01$) enhanced DDM. No significant improvement was noted above the eight percent level. $NaCHO_2$ significantly ($P< .01$) increased DDM above native straw, but higher treatment levels were necessary to achieve an equal magnitude of improvement than for NaOH. NH_4OH treatment produced variable results which could not be consistently repeated, but the crude protein (CP) content of treated straw was consistently increased. This was in contrast to NaOH soaking, which significantly ($P< .01$) degraded CP, acid detergent fiber (ADF) and acid detergent lignin (ADL) with each increase in level. All treatment combinations also produced significant ($P< .01$) cell wall constituents (CWC) declines below native straw. Straw treated on a solution basis was significantly ($P< .01$) higher in DDM than that treated on a dry matter basis. However, treated straw DDM was significantly ($P< .01$) greater in either case than that recorded for untreated straw. Draining off of the NaOH effluent prior to drying significantly ($P< .01$) reduced DDM. There was a trend for water soaking to depress DDM, but significance was not reached until samples were drained prior to drying.

No detrimental effects were noted when lambs consumed unwashed NaOH-soaked straw. Daily dry matter (DM) intake per kg of body weight was significantly ($P < .05$) reduced for treated straw when compared to untreated. Increased water consumption and urninary excretion ($P < .01$) were evident when straw soaked in a one percent NaOH solution (ration three) was fed. Urine pH for sheep consuming straw treated on an eight percent dry matter basis (ration two) was significantly ($P < .05$) reduced below that recorded for urine from sheep fed the other two rations. However, none of the pH's were outside the normal range for ruminants. Treatment two significantly ($P < .05$) reduced apparent digestibilities for straw, DM, organic matter (OM), energy, CP, ash and cell contents below that for the other two treatments. Treatment three significantly ($P < .05$) increased straw, ash, ADF, hemicellulose and CWC apparent digestibilities when compared to untreated straw (ration one). The digestibility of CP was significantly ($P < .01$) greater in the untreated straw ration.

All sheep were in a positive nitrogen balance for the duration of the trials. There was no significant difference in nitrogen balance for lambs fed rations one and three. However, nitrogen retention for lambs receiving ration two was significantly ($P < .05$) depressed below the quantity retained by lambs on the other two rations. Ration three was clearly superior in terms of either percent nitrogen intake or percent of digested nitrogen. Untreated straw supported a statistically ($P < .05$) higher level of digestible energy per g DM intake than did either of the treated straw rations. Utilization of the gross energy of ration two was significantly ($P < .05$) less than that from the other two rations. Ration three supported lower average daily gains than the other two rations ($P < .01$).

No definite conclusions can be drawn from the sodium and potassium balances. Evidently, sodium residue levels were not large enough to cause any problems as there were no observable side effects and potassium excretion was not increased.

A series of feeding trials demonstrated that ryegrass straw can successfully comprise from 45 to 86% of a ration for growing heifers. Feeding value of the straw was improved to support gains from 0.38 kg to 0.80 kg per day by the use of a variety of feed ingredients that corrected the straw's deficiencies. Performance data suggested that the maximum level of urea that can be used in such high roughage rations is about 1.5%. Above this level gains and feed efficiency were depressed.

Digestion trial data showed that DDM for untreated, supplemented straw was from 47.5 to 50.4%. From 61.5 to 67.5% of the CP and 39.9 to 43.2% of the CWC was digestible. The CP was least digestible in the ration containing alfalfa. Nitrogen retention ranged from 6.1 to 7.1 g per day. The superior ration in this respect was ration 5, which contained whey.

In Vitro and *In Vivo* Evaluations of Chemically Treated Ryegrass Straw

by

Daniel Craig Anderson

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1972

APPROVED:

Redacted for Privacy

Professor of Animal Science
in charge of major

Redacted for Privacy

Head of Department of Animal Science

Redacted for Privacy

Dean of Graduate School

Date thesis is presented May 3, 1972

Typed by Muriel Davis for Daniel Craig Anderson

ACKNOWLEDGMENTS

Without the help of a host of people this project could not have been successfully completed. It is impossible to thank each one personally.

However, sincere thanks are extended to Dr. A. T. Ralston, my major professor, for his assistance and advice throughout my graduate study. Also appreciation is expressed to Dr. D. C. Church, who provided innumerable ideas and suggestions throughout the course of this study. Thank you's must also be given to Drs. J. E. Oldfield, P.H. Weswig, D. O. Chilcote and R. A. Schmitt, who capably served on my graduate committee, and to my fellow graduate students, laboratory, secretarial, beef barn and farm services personnel, who in one way or another contributed to this research project.

To my fiancee, Pat, gratitude and appreciation are expressed for her endless understanding and encouragement. Finally, the motivation and inspiration provided by my parents, Mr. and Mrs. D. Clifford Anderson, has given stimulation for continuing my education.

TABLE OF CONTENTS

Page

INTRODUCTION 1

LITERATURE REVIEW 5

- NaOH Studies 5
- Other Chemicals 9
- Fecal Recycling 11
- Enzymes 13
- Irradiation 13
- Wood By-Product Utilization 15

EXPERIMENTAL PROCEDURE 17

- Laboratory Trials 17
  - Straw Treatment 17
  - *In Vitro* 19
- Sheep Digestion Studies 19
- Feeding Trials 23
- Statistical Treatment 27
  - Laboratory Trials 27
  - Digestion Studies-NaOH-Treated Straw 27
  - Feeding Trials 27
  - Statistical Analysis 29

RESULTS AND DISCUSSION 30

- Laboratory Evaluations of Chemical Straw Treatment 30
  - Trial 1 30
  - Trial 2 32
  - Trial 3 34
  - Trial 4 35
  - Trial 5 37
  - Trial 6 42
  - Trial 7 45
  - Water Soaking 55
- Lamb Digestion Trials 56
  - Straw Composition 56
  - General Health and Feed Acceptance 57
  - Digestibility 62

Page

Nitrogen Balance 66
Energy Balance 69
Lamb Performance 69
Sodium and Potassium Balances 70
Heifer Feeding Trials 70
Feeding Trial Digestion Studies 76

SUMMARY 81

BIBLIOGRAPHY 85

LIST OF TABLES

Table		Page
1	Ration ingredients for sheep digestion trials with NaOH-treated ryegrass straw..	21
2	Chemical composition of rations used for NaOH soaked straw digestibility trials.	21
3	Ingredients and chemical composition of heifer rations based on poor quality ryegrass hay (Trial 1).	24
4	Ingredients and chemical composition of ryegrass straw based rations (Trial 2) fed to heifer calves.	25
5	Ingredients and chemical composition of ryegrass straw based rations fed to heifer calves (Trial 3).	26
6	Ingredients of rations used for sheep digestibility trials with untreated ryegrass straw.	28
7	Chemical composition of untreated ryegrass straw based rations used for sheep digestibility trials.	29
8	Ryegrass straw *in vitro* dry matter digestibility after spraying or soaking with water or a 2% sodium hydroxide solution.	30
9	Effect of treatment time and particle size on *in vitro* dry matter digestibility of ryegrass straw soaked in a 2% sodium hydroxide solution.	32
10	*In vitro* dry matter digestibility improvement of ryegrass straw soaked in sodium and potassium hydroxide solutions.	33
11	*In vitro* dry matter digestibility of ryegrass straw soaked in sodium and sodium plus potassium hydroxide solutions.	35
12	*In vitro* dry matter digestibility of ryegrass straw soaked in sodium formate and ammonium hydroxide solutions.	36

Table		Page
13	*In vitro* dry matter digestibility of ryegrass straw soaked in sodium and ammonium hydroxide solutions.	38
14	Crude protein composition of ryegrass straw soaked in sodium and ammonium hydroxide solutions.	39
15	Acid detergent fiber and lignin of ryegrass straw soaked in sodium hydroxide solutions.	41
16	Effects of sodium and ammonium hydroxide treatment upon ryegrass straw dry matter digestibility.	43
17	The effects of sodium hydroxide soaking and pre-drying treatment on ryegrass straw dry matter digestibility.	46
18	Crude protein composition of sodium hydroxide-treated ryegrass straw.	48
19	Cell wall constituent composition of sodium hydroxide-treated straw.	50
20	Acid detergent fiber composition of sodium hydroxide-treated ryegrass straw.	52
21	Acid detergent lignin composition of sodium hydroxide-treated ryegrass straw.	54
22	Composition of sodium hydroxide-treated straw and its parent material.	56
23	Effect of sodium hydroxide soaking upon voluntary dry matter intake and apparent digestibility of annual ryegrass straw by sheep.	59
24	Water consumption, urinary excretion and urine pH for sheep fed sodium hydroxide-treated ryegrass straw rations.	61
25	Effect of sodium hydroxide soaking upon nitrogen balance, energy utilization and animal performance of annual ryegrass straw by sheep.	67

Table		Page
26	Animal performance. Feeding Trial 1. (leached ryegrass hay).	71
27	Animal performance. Feeding Trial 2.	73
28	Animal performance. Feeding Trial 3.	73
29	Voluntary dry matter intake and apparent digestibility for ryegrass straw based rations fed to sheep.	77
30	Nitrogen balance, energy utilization and animal performance for ryegrass straw based rations fed to sheep.	79

IN VITRO AND *IN VIVO* EVALUATIONS OF CHEMICALLY TREATED RYEGRASS STRAW

INTRODUCTION

The expansion of human populations and the possibilities of food shortages suggest that a smaller supply of cereal grains will be available for ruminant feeding. Future livestock production may well depend on the ability of cattle and sheep to utilize materials which are now regarded as waste products. Ruminants possess a high capacity for digesting the cellulose and hemicellulose of plant cell walls.

Low quality roughages (straw in particular) represent a large potential source of feed energy. Crop residues currently contribute only a small part of their potential to livestock feeding. Although straws are produced in large quantities in most parts of the world, they are generally not well utilized as a feedstuff. The low economic value attached to them is primarily related to their low nutritive values. High levels of fiber and lignin, but low protein, mineral and vitamin levels are characteristic. Extreme bulkiness is also common. The slow rate of fiber digestion limits consumption, and low digestibility of the organic matter further reduces straw feeding value. If the feeding value of crop residues could be increased, it would offer increased opportunity for utilizing these by-products in sheep and beef cattle production.

After harvesting seed crops, disposal of the remaining residue also becomes a problem. The customary practice has been to burn the straw in the field. Conservative estimates suggest that 750, 000 tons of grass straw are annually burned in the Willamette Valley of Oregon. Annual ryegrass straw contributes the largest part of this volume. Establishment and enforcement of stringent air pollution laws makes it imperative to change current disposal practices. Straw cannot be left on the ground as it harbors harmful pests and diseases and interferes with future harvests. Consequently, it must be removed from the field. Successful adaptation of grass straws to inclusion in ruminant diets offers some relief to an urgent problem.

Ruminants are unable to avail themselves of a large portion of the energy from native straw cellulose and hemicellulose. Periodic attempts have been made to increase the available energy content of poor quality roughages. Treatment with sodium hydroxide (NaOH) has been shown to effectively improve digestibility and nutritive value of straws (Godden, 1942; Ferguson, 1942; Kehar, 1954; Stone, Morris and Frye, 1965; Ololade and Mowat, 1969; and Chandra and Jackson, 1971). Alternate chemicals have not been widely tested.

Early NaOH treatment procedures washed treated straw to remove unreacted alkali residue, and later studies neutralized the residue with mineral or organic acids. Both were thought to be necessary to insure consumption and to avoid undesirable side effects.

Washing was a slow, tedious process that required large volumes of water. In addition sizeable quantities of alkali-soluble nutrients were lost. Washing and neutralization both increased the cost of the finished product. Chandra and Jackson (1971) suggested that until a six percent alkali treatment was reached, the residual alkali was not high enough to require washing or neutralization.

Successful adaptation of straw to ruminant rations also depends upon enrichment with supplementary nutrients. There are a variety of feed ingredients available for use. However, they have not been adequately evaluated.

Ololade, Mowat and Winch (1970) pointed out that the response of roughages to NaOH varied with the type of roughage. Cereal straws, bagasse and corn cobs and stover have been the prinicple substrates previously studied. Prior to the appearance of the results of three studies in 1971 (Guggolz, Kohler and Klopfenstein, 1971; Guggolz, _et al._, 1971; and Guggolz, _et al._, 1971), there was no information available on ryegrass straw. This apparent lack of information initiated interest in this investigation.

The objectives of this study were to:

1. Compare the ability of a number of chemicals at a range of levels to improve _in vitro_ dry matter digestibility (DDM) of annual ryegrass straw.

2. Study the effects of NaOH soaking on feed intake, animal health, water consumption, urine excretion and pH, _in vivo_ digestibility,

nitrogen and energy utilization and sodium and potassium balances.

3. Evaluate the effectiveness of untreated ryegrass straw supplemented rations to promote gains of heifer calves.

4. Supply specific data on digestibility and nitrogen and energy utilization for untreated ryegrass straw rations.

LITERATURE REVIEW

This review was in no way intended to be exhaustive. Pertinent literature has been cited as the results of each phase of this research project were discussed. Therefore, to avoid duplication, the information presented here was intended to be only of a supplementary nature, and indirectly related to ryegrass straw studies.

Even with NaOH's effectiveness substantiated, there is room for other imaginative approaches for unlocking the energy in poor quality roughages. Consequently, alternative procedures, such as use of sodium chlorite, irradiation or enzyme treatment, have been alluded to. The limited amount of research reported on chemical treatment of feces prior to recycling for livestock feed might contribute to the total picture of use of low quality roughages as both are high fiber by-products. Similarly, the increased frequency of utilizing wood chips or sawdust fiber (treated or untreated) is closely allied to straw utilization and merited some discussion.

NaOH Studies

Godden's report (1920) was among the earliest to mention alkali treatment of straw. He gave some details of early history that have been impossible to find elsewhere in the literature. According to Godden, in 1900, Kellner showed that straw pulp prepared for paper making by the sulphite process was highly digestible by ruminants. This prompted Lehman to set up one of the first straw treatment experiments. His process involved boiling straw in a one to two percent caustic soda solution for six hours. Numerous studies with a variety of chemicals have been conducted since that time, but NaOH has been the most effective and economical one available. Godden (1920) refined the treatment process to make it more adaptable to farm use, and subsequently it was used by several European countries that had been forced to find a means of utilizing home-grown roughages. Even though fiber digestibility was improved and animal intake not impaired, caustic soda treatment caused a loss of crude protein (CP), ether extract (EE), and nitrogen-free-extract (NFE). Beckman (1921) also proposed some of the original treatment procedures, which were later modified in various ways.

While feeding trials with treated straw have centered around ruminant animals, at least one study (Williamson, 1941) has investigated its use by the horse. A series of trials at his research station clearly demonstrated that rye, barley or wheat straw organic matter (OM) and crude fiber (CF) digestibilities were increased when treated straw was fed to horses along with oats.

The recent search by many for new and cheaper sources of feed has led to a number of applied studies. Javed and Donefer (1970) treated straw with a NaOH solution in a horizontal feed mixer. After the treated material was neutralized with acetic acid, it was mixed with molasses and protein and mineral supplements and compared to dehydrated alfalfa meal. The increased nutritive value of the chemically treated and supplemented straw, due to improved digestibility and voluntary intake, yielded growth results approaching those obtained with the control alfalfa ration.

The necessity for all straws to be supplemented with a source of nitrogen, prompted Saxena et al., (1971) to study growth and nitrogen metabolism of lambs fed alkali-treated oat straw supplemented with either soybean meal, urea or diammonium phosphate. Animals fed treated straw had lower levels of rumen ammonia and blood urea indicating that straw treatment was effective in bringing about the release of energy to stimulate bacterial growth in accord with the non-protein nitrogen present. Only small differences were detected in the rumen pH and proportions of volatile fatty acids.

Hogan and Weston (1971) have presented data on the extent of bacterial protein synthesis from alkali-treated and urea-supplemented wheat straw. Their data indicated that treated straw served as an effective energy source for promoting nitrogen incorporation into bacterial cells.

The value of treating straw can come from both increasing digestibility and removing harmful substances. Kehar (1954) emphasized that alkali treatment had special importance for rice straw in India since it removed 70 to 80% of the deleterious potassium oxalate. The net effect was an improvement in calcium assimilation from the ration.

A considerable amount of attention has been focused on improving the feeding value of crop residues, such as corn cobs, stalks, stover and/or husklage, which are available in large quantities in the midwestern U.S. The results published by Klopfenstein et al., (1970) clearly indicated that animal performance was significantly increased by treating either with NaOH or potassium hydroxide (KOH) when these materials were ensiled. Steers fed NaOH-treated corn cob silage with added potassium chloride gained significantly ($P<.05$) faster and more efficiently compared to untreated corn cobs (Koers, Klopfenstein and Woods, 1970). Klopfenstein and Woods (1970) treated corn cobs with four percent NaOH and KOH to produce varying sodium to potassium ratios. Lambs consuming this material had faster average daily gains, but the sodium to potassium ratio only had a slight effect within the ranges investigated.

Koers, Klopfenstein and Woods (1969) reported lower rumen ammonia levels and significantly ($P<.05$) higher nitrogen retention for lambs that consumed treated corn cobs. Steers that received treated corn cobs (Koers, Woods and Klopfenstein, 1970) were in less of a negative nitrogen balance than those fed untreated cobs. Treated corn cobs significantly ($P<.05$) reduced rumen pH while total volatile fatty acids increased in the latter trial. There was no significant effect on CP, OM or dry matter (DM) digestibility in either metabolism trial.

Krause, Klopfenstein and Woods (1968) compared NaOH-treated corn stover with treated whole corn plant silage. When fed to lambs, the alkali treatment improved the quality of the corn stover to the greatest extent. This illustrated that chemical treatment was most effective and valuable for poor quality roughages.

Other Chemicals

High temperature and pressure treatments have also been proposed as a means for increasing the DDM of low quality forages. This, along with chemical additions, including hydrogen peroxide and hydrochloric acid, has been demonstrated to increase DDM and reduce cell wall constituents (CWC) for alfalfa stems, prairie hay, wheat straw and corn cobs.(Klopfenstein, Bartling and Woods, 1967). However, the available literature was conflicting since Bartling, Klopfenstein and Woods (1968) also presented data to show that alfalfa stems digested at 28 Kg/cm^2 pressure for 45 seconds were inferior in DDM when compared to untreated material. The inclusion of hydrogen peroxide and/or sodium meta bisulfite did not enhance digestibility. Corn stalks responded more positively which indicated substrate specificity and a possible influence of differences in CWC.

Additional chemical compounds have been evaluated as to their effectiveness for improving DDM of poor quality roughages. Alfalfa stems and corn cobs treated with solutions of NaOH, sodium peroxide or a sodium, hydrogen peroxide mix had significantly increased *in vitro* DDM (Jones and Klopfenstein, 1967). Hydrogen peroxide alone also reduced DDM. Results were similar on an *in vivo* basis when the same roughages were treated with four percent solutions of these chemicals. Chemical composition was not changed for alfalfa stems following chemical treatments, but acid detergent lignin (ADL) and CWC were significantly ($P<.01$) reduced by the same treatments for corn cobs.

Chlorine compounds, including organic chloride, chlorine gas, sodium chlorite, sodium hypochlorite bleach and potassium chlorate, have been examined by Yu, Thomas and Emery (1970) for their effectiveness in improving the nutritive value of straw in laboratory silos. All treatments were effective to a limited extent, but the degree of effectiveness varied widely.

Goering (1968) reported that ensiling wheat straw with three percent of the straw DM as sodium chlorite for 30 days boosted digestibility from 53 to 93%. Peanut hulls responded even more dramatically, and a wide range of other forages gave similar improvements. Research is continuing to attempt to overcome the high cost. The heat produced during treatment is a fire hazard without proper ventilation, and toxic gases can affect both man and animals. Finally, consumption of treated material is often limited due to the salt that is a by-product of sodium chlorite reactions. Goering and Van Soest (1968) explained that sodium chlorite was studied because of its specificity as a lignin oxidizing agent and because of the possibility of high OM recovery. They also pointed out that the length of treatment was dependent upon the substrate, sodium chlorite level, temperature, moisture content and pH. All of these affected the resulting digestibility of the treated roughage too. Goering et al., (1969) found no significant differences in daily DM intake between the control and sodium chlorite treated barley straw. Digestibility of CWC, cellulose and hemicellulose were equally increased by chlorite treatment, which could be directly related to lignification of the barley straw. Also, large scale treatments were less efficient than those conducted on a laboratory scale. These results were confirmed by Sullivan and Hershberger (1959) when they reported that chlorine dixoide treatment yielded a product that was lower in lignin and higher in cellulose digestibility, as indicated by the artificial rumen, than untreated wheat straw.

Fecal Recycling

About 40 to 60% of the potential energy from plant cell walls escapes digestion and appears in the feces. As a result, millions of tons of undigested CWC residues are excreted by ruminants annually. Such material along with other agricultural refuse repesents a vast potential source of energy for microbial fermentation. Recent increases in public concern about disposal of solid wastes and preservation of environmental quality has led to studies on the recycling of animal wastes as livestock feeds.

Smith, Goering and Gordon (1970) have investigated the capacity of various chemicals to disrupt the intricate polysaccharide-lignin complex in the indigestible CWC of bovine excreta. Increasing the availability of these CWC would seem to be a necessary prerequiste before animal wastes could be successfully refed. Their results showed that chemical treatment of indigestible alfalfa or sudax fecal CWC resulted in greater than 90% digestion. These workers grouped the chemicals studied. The alkalies included sodium peroxide, sodium hydroxide and calcium hydroxide, all of which caused non-specific degradation of hemicellulose, cellulose and lignin. The second class was the oxidants, such as calcium hypochlorite, sodium chlorite and acetyl peroxide. These caused relatively little hydrolysis of hemicellulose and cellulose but were more specific towards lignin. The use of sodium peroxide, sodium chlorite or calcium hypochlorite with organic materials is potentially dangerous due to the possibility of explosions and emissions of chlorine dioxide gas. NaOH was by far the most economical chemical studied.

Enzymes

Cellulose from lowly-lignified plant fiber is degraded by cellulase enzymes secreted by cellulolytic microorganisms during the normal ruminant digestive process. Consequently, there have been proposals that straw be treated with enzyme preparations to depolymerize the complex cellulose molecule. The narrow and specific pH range for optimum function of each enzyme has been a major disadvantage. Conditions under which enzymes are expected to function must be precisely monitored. With available technology and under current economic circumstances enzyme straw treatment on a volume basis would not be commercially feasible. But a real hindrance has been the fact that lignin is not susceptible to attack by any of the known enzymes. Therefore, the physical association between lignin and cellulose in mature forages prevented the enzyme from reaching its site of attack, the cellulose molecule. Ralston, Church and Oldfield (1962) have reported that the results have been too variable to draw conclusions for practical use of enzymes to improve the utilization of low quality roughages. Enzyme treatments with bagasse were effective only when treated first with NaOH (Stone, Girouard, and Frye, 1965).

Irradiation

Irradiation with high energy cathode rays caused depolymerization of the polymer chains and units within the cellulose molecule

(Saeman and Millett, 1952). This increased the availability of the cellulose, and subsequently glucose. However, the irradiation dose required to produce any appreciable change was large. Eight percent less cellulose and 56% less CF were present in samples of peanut hulls, corn cobs, and sugar cane bagasse after they were irradiated with total doses of 40 megaroentgens compared to the control (Ammerman, et al., 1959). The data of Pritchard, Pigden and Minson (1962) confirmed the fact that entrapped nutrients can be made available to rumen microorganisms. This was shown by increased in vitro DDM and volatile fatty acid formation following gamma irradiation of wheat straw. However, the levels of gamma irradiation necessary for nutrient release were well above what is currently practical for commercial operations. At high dosage rates an excessive loss of DM was also noted. Irradiation of alfalfa, birdsfoot trefoil and/or timothy with Cobalt 60 caused an increase in in vitro DDM of the mature materials. Volatile fatty acid production from treated feeds was generally reduced (Pigden, Pritchard and Heaney, 1966). While improvement in utilization of mature forages seems possible with irradiation, at least on a laboratory scale, it has not been practical nor economical to conduct large scale commercial straw treatments in this manner. More refinement of technique and understanding is required before such a procedure can gain widespread acceptance and use.

Wood By-Product Utilization

Wood by-products are available in sizable quantities and in some geographical locations their disposal has become an environmental problem. Sawdust and chips have attracted attention as roughage substitutes in high concentrate rations (Anthony and Cunningham, 1968; Cody, Morrill, and Hibbs, 1968; Kinsman *et al.*, 1969; Dinius *et al.*, 1970). El-Sabban, Long and Baumgardt (1971) compared oak sawdust as a roughage replacer for timothy hay in beef cattle finishing rations. Their feedlot performance data indicated that coarse sawdust particles can be successfully used up to 15% of the ration. The incidence of liver abscesses was reduced on the sawdust rations, but the rumens were only slightly parakeratotic.

If the full potential from wood carbohydrate is to be achieved, it must be removed from the chemical and/or physical barrier imposed by lignin. Feist, Baker and Tarkow (1970) presented data to show that *in vitro* rumen digestibility of quaking aspen and red oak increased following treatment with dilute NaOH for one to four hours, and that this response varied inversely with the lignin content of treated materials. Millett *et al.*, (1970) showed that treatment with one percent NaOH solutions raised the *in vitro* digestibility of a number of hardwood species to equal the digestibilities of medium quality hay. Hardwoods were more responsive to treatment than softwoods.

In addition, the results were quite species dependent. Barks, with the added nutritional potential of their fatty constituents, were generally more digestible than their corresponding woods. Mellenberger et al., (1971) reported that untreated sawdust and bark were readily consumed and provided considerable digestible energy for the ruminant. However, their data also indicated that alkali treatment increased the digestibility of aspen by a factor of approximately 25%, making it equivalent to low-quality hay as an energy source. Wilson and Pigden (1964) increased the in vitro digestibility of poplar sawdust as much as ten times with alkali steeping. Percentage of cellulose and acid detergent fiber (ADF) was increased following NaOH treatment of alder, fir and poplar (Huffman, Kitts and Krishnamurti, 1971). However, ADL was not affected while in vitro DDM was increased compared to untreated samples.

These workers also reported that four species of wood were lower in cellulose, ADF and ADL content than untreated samples following exposure to gamma irradiation. In vitro DM and cellulose digestion and volatile fatty acid production were higher. Millet et al., (1970) reported that electron irradiation was successful in raising wood digestibility, but there was considerable variation among species tested. Also, from a rough estimate of overall costs irradiating by high-energy electrons was the most expensive of four treatment procedures.

EXPERIMENTAL PROCEDURE

Laboratory Trials

Straw Treatment

Annual ryegrass straw was chopped through a silage chopper into approximately one inch lengths. Then either 10 or 15 grams of straw were immersed in 15 times its weight of chemical solution for 24 hours. Six hundred ml beakers served as the soaking containers. Solutions of sodium, potassium and ammonium hydroxide along with sodium formate at levels ranging from 0.5 to 10.5% were the chemicals studied. Treatment level was expressed in two ways: either as a percent solution or as percent of DM. The amount of chemical required for the latter treatment level was calculated as a percentage of the straw DM being soaked. For an example, compare the amount of NaOH used in 150 ml of solution for a ten percent dry matter and a ten percent solution treatment respectively. For 10 g of straw the former treatment required 1 g NaOH, but 15 g were necessary to mix a ten percent solution. In other words, a ten percent solution was 15 times as concentrated as a ten percent dry matter treatment. Therefore, the net result was a difference in strength of treatment solutions.

At the termination of the soaking period, the straw was dried for 24 to 48 hours at 96° C in a forced draft oven. Two procedures were followed prior to drying (referred to as predrying treatment). A majority of the treatments were dried without draining the alkali solution. However, to compare drained samples with undrained ones in several of the latter trials the treatment effluent was drained before drying. Dried straw was ground in a Wiley mill fitted with a 60-mesh screen, and stored in a desiccator.

For each trial, one treatment consisted of water soaking straw, so that its contribution to the DDM of straw could be ascertained. A "dry" control was also included, so that untreated straw could be used as a base to compare to.

The design for each trial was intended to accomplish the following purposes: The initial pilot trial compared the effects of treatment time and method and particle size upon DDM. Trial 2 compared the effectiveness of NaOH and KOH solutions of four strengths to improve DDM. Trial 3 tested NaOH and combinations of NaOH and KOH at levels ranging from 8.0 to 10.5 percent. Trial 4 evaluated the effectiveness of sodium formate ($NaCHO_2$) and ammonium hydroxide (NH_4OH) to improve straw DDM. Trial 5 compared NaOH and NH_4OH as well as checking for repeatability of results for the latter. Trial 6 evaluated the ability of NH_4OH solutions and NaOH on a dry matter basis to promote increased DDM. The final laboratory trial was designed to compare NaOH soaking on a dry matter or solution basis and also to determine the effects of draining for these two treatment methods.

In Vitro

The in vitro rumen fermentation technique resembled closely that reported by Anderson (1969). Percent in vitro dry matter dis appearance (IVDDM) was calculated according to the following equation:

$$\%\ \text{IVDDM} = \frac{\underset{\text{in substrate}}{\text{g DM}} - \left(\text{residual DM} - \underset{\text{45 ml inoculum}}{\text{g DM in}}\right)}{\text{g DM in substrate}} \times 100$$

Sheep Digestion Studies

Prior to the initiation of these trials, ryegrass straw was soaked for 24 hours in NaOH solutions. One percent solution (Treatment three) and eight percent DM (Treatment two) comprised the two treatment levels (see Table 2). The basis for determining the amount of NaOH necessary for each treatment level followed the rationale explained previously for the laboratory trials. The one percent solution was mixed in a galvanized stock water tank and bailed into the treatment container until the straw was immersed in the solution. For the eight percent DM treatment, the required amount of NaOH, for the straw being treated was sprinkled on a screen over the top of the straw. Then water was run over the top until the NaOH was thoroughly solubilized and the straw was covered. After a 24-hour soaking period the NaOH solution was drained off.

Wet straw was dried using heat produced by a conventional grain dryer. Dried straw was finely ground and pelleted (0.95 cm) into a complete ration. The ration ingredients and chemical composition appear in Tables 1 and 2, respectively.

Wether lambs with an average weight of 33.2 kg served as the experimental animals. Preceding enclosure in the digestion crates, each sheep was treated for stomach, intestinal and lung worms with Tramisol and the feet were trimmed as precautionary measures. During a three-week adaptation period all sheep received the untreated straw ration (Treatment one). This permitted the lambs to adjust to eating pellets, established a uniform consumption pattern, allowed them to adapt to the confined life of a digestion crate and provided time for the rumen microflora to adjust to the ration.

The lambs were confined to the digestion crates throughout the experiment. Ten-day preliminary and seven-day collection periods were used. At the end of each collection period, each lamb was weighed. This weight served as both the terminating weight for one period and the beginning weight for the next period.

Free access was allowed to water, and water consumption was measured daily. Lambs were fed twice daily. All feed was carefully weighed and a representative sample selected at each feeding for

Table 1. Ration ingredients for sheep digestion trials with NaOH-treated ryegrass straw.[a]

Ingredient	%
Annual Ryegrass Straw	74.50
Molasses	7.00
Barley	10.00
Urea	1.30
Cottonseed Meal	6.70
Trace Mineral Salt[b]	0.25
Tricalcium Phosphate[c]	0.25

[a] The ration also contained 1100 IU Vitamin A per kg.

[b] Mortons

[c] Profos by Olin Manufacturing Co.

Table 2. Chemical composition of rations used for NaOH soaked straw digestibility trials.[a]

Treatment Nutrient %	1[b]	2[c]	3[d]
Dry Matter	90.48	90.21	87.92
Organic Matter	93.86	95.00	91.49
Crude Protein	12.43	10.77	11.39
Ash	6.13	5.00	8.50
Acid Detergent Fiber	40.27	47.02	44.65
Acid Detergent Lignin	6.88	8.49	7.89
Residual Ash	2.46	2.39	2.16
Hemicellulose	23.22	25.15	17.51
Cellulose	30.87	36.24	34.60
Cell Wall Constituents	63.44	72.17	62.16
Cell Contents	35.56	27.83	37.84
Sodium	0.27	0.21	1.50
Potassium	0.85	0.53	0.66
Gross Energy, Kcal/gDM	4.032	4.103	3.854

[a] Actual analysis of nine samples for each treatment.

[b] Untreated control.

[c] 8% dry matter.

[d] 1% solution.

compositing. Any feed refusals were accounted for. Level of feed intake was adjusted at the beginning of each period to establish consumption at approximately 4.3% of body weight. Each day, fecal output was weighed and urine excretion was measured in terms of both weight and volume. A ten percent aliquot of each was randomly selected and added to a composite sample for the collection period. Fecal samples were frozen in plastic bags while the urine was refrigerated in glass fruit jars. Prior to conducting the nutrient analysis, fecal samples were thawed, thoroughly mixed, and sub-samples randomly selected for drying. The latter was carried out for 24 to 48 hours at 70° C in a forced draft oven. Feed was dried for 24 hours at 70° C in the same oven. Both feed and fecal samples were ground in a Wiley mill through a 60-mesh screen. To prevent the loss of nitrogen via ammonia volatilization from the urine, five to ten mls of H_2SO_4 were added to the collection buckets each morning during the seven-day collection period. Urine pH was measured daily during the preliminary period.

All DM, nitrogen and ash determinations were carried out in accordance with the A.O.A.C. (1960) procedures. A Parr oxygen bomb calorimeter was employed to arrive at gross energy values. ADF, ADL, residual ash and CWC data were obtained by following the procedures of Goering and Van Soest (1970). Cell contents, hemicellulose, and cellulose were all determined by difference.

Atomic absorption spectrophotometric techniques were used to determine sodium and potassium levels. Urine nitrogen procedures were prescribed by the A. O. A. C. (1960). Five mls of weighed urine were used.

Feeding Trials

For three successive years intake and performance data were collected from feeding trials with ryegrass straw based rations. The first year's (Trial 1) studies dealt with supplementation of ryegrass hay that was of similar nutritive content to the straw (3.4% CP). Optimum levels of nitrogen-free-extract and non-protein nitrogen supplementation for ryegrass straw pellets to support economical growth in young cattle were studied the second year (Trial 2). The third year the efficacy of several feed ingredients to enrich ryegrass straw based rations was considered (Trial 3). Ration ingredients and chemical composition for the three trials are shown in Tables 3, 4 and 5, respectively. Response to each treatment was measured primarily in terms of average daily gain.

Thirty uniform heifer calves were annually selected as replacements for OSU's commercial cow herd. These were stratified according to weight prior to treatment assignment. Group feeding of the (2.54 cm) pelleted ration followed. Length of the experimental periods averaged 105 days. Individual weights were taken at the

Table 3. Ingredients and chemical composition of heifer rations based on poor quality ryegrass hay. (Trial 1)

Rations	1	2	3
Ingredient, %			
Ryegrass Hay	67.1	77.0	84.2
Molasses	7.0	7.0	7.0
Alfalfa	15.0	--	--
Urea	0.9	--	1.8
Cottonseed Meal	--	16.0	--
Barley	--	--	7.0
Mustard Seed	10.0	--	--
Chemical Composition, %			
Crude Protein	12.4	13.7	14.7
Acid Detergent Fiber	25.5	25.8	29.6
Cell Wall Constituents	44.2	43.4	47.5

Table 4. Ingredients and chemical composition of ryegrass straw based rations[a] (Trial 2) fed to heifer calves.

Rations	1	2	3	4	5	6
Ingredient, %						
Molasses	7.0	7.0	7.0	7.0	7.0	7.0
Wheat, ground	5.0	7.5	10.0	5.0	7.5	10.0
Urea	1.3	1.3	1.3	1.8	1.8	1.8
Ryegrass Straw	86.2	83.7	81.2	85.7	83.2	80.7
Tricalcium Phosphate[b]	0.5	0.5	0.5	0.5	0.5	0.5
Chemical Composition, %						
Dry Matter	91.0	90.8	88.6	90.3	90.2	89.8
Crude Protein	9.5	10.2	10.0	11.2	11.8	11.6
Acid Detergent Fiber	44.0	41.1	40.5	43.5	41.5	39.1
Cell Wall Constituents	68.0	67.5	64.7	68.6	64.3	59.5

[a] 227.7 IU Vitamin A added per kg of feed.

[b] Profos by Olin Manufacturing Co.

Table 5. Ingredients and chemical composition of ryegrass straw based rations fed to heifer calves (Trial 3).[a]

Rations	1	2	3	4	5	6
Ingredient, %						
Ryegrass Straw	77.5	74.8	44.5	44.5	72.8	70.0
Molasses	7.0	--	--	--	7.0	--
Dried Whey	--	10.0	--	--	--	10.0
Urea	1.8	1.5	--	--	1.5	1.3
Barley	10.0	10.0	--	--	5.0	5.0
Wheat	--	--	--	--	5.0	5.0
Alfalfa	--	--	55.0	55.0	5.0	5.0
Cottonseed Meal	3.2	3.2	--	--	3.2	3.2
Tricalcium Phosphate[b]	0.5	0.5	0.5	0.5	0.5	0.5
Chemical Composition, %						
Dry Matter	85.8	90.2	89.2	89.4	85.6	89.8
Crude Protein	13.4	13.5	12.7	12.9	12.9	13.1
Acid Detergent Fiber	32.3	32.4	40.2	39.0	30.3	33.6
Cell Wall Constituents	60.9	61.2	64.9	63.1	59.0	53.5

[a] 454.5 IU Vitamin A added per kg feed.

[b] Profos by Olin Manufacturing Co.

initiation and termination of each trial.

Statistical Treatment

Laboratory Trials

Factorial arrangements of treatments were used for this series of chemical treatment studies. IVDDM was the experimental parameter used to measure the treatment response.

Digestion Studies - NaOH-Treated Straw

A Latin square-designed experiment replicated three times, with nine wether lambs was used. The three treatments differed only in the way the straw had been treated. That is, the ration ingredients for all treatments were identical. Rations were rotated so that following three successive digestion trials each of the nine sheep had been subjected to each of the three treatments for a total of nine observations per treatment. Rations were rotated in a manner that attempted to minimize any residual treatment effect.

Feeding Trials

Trials 1 and 3 were set up as completely randomized experiments with three and six treatment groups respectively. Trial 2 was a 2 x 3 factorial arrangement of treatments.

A 3 x 3 Latin square designed digestion trial involving three wether lambs was used to further evaluate three of the rations from Trial 3. The ingredients and composition of the experimental rations are shown in Tables 6 and 7. Rations 4, 5 and 6 for untreated ryegrass straw sheep digestion trials corresponded to rations 1, 2 and 3 from feeding Trial 3 with cattle (see Table 5). The primary difference was the lower level of urea offered the sheep. Otherwise quantity of ingredients was the only alteration from the heifer rations. This was necessary to balance the ration for all nutrients.

Table 6. Ingredients of rations used for sheep digestibility trials with untreated ryegrass straw.[a, b]

Ration	4	5	6
Ingredient, %			
Ryegrass Straw	74.5	74.8	37.5
Molasses	7.0	--	--
Dried Whey	--	10.0	--
Urea	1.5	1.5	--
Barley	10.0	10.0	--
Alfalfa	--	--	62.0
Cottonseed Meal	6.5	3.2	--
Tricalcium Phosphate[c]	0.5	0.5	0.5

[a] All rations contained 1100 IU Vitamin A per kg.

[b] Rations resemble rations 1, 2 and 3 of the cattle rations in Trial 3.

[c] Profos by Olin Manufacturing Co.

Table 7. Chemical composition of untreated ryegrass straw based rations used for sheep digestibility trials.[a]

Treatment	4	5	6
Nutrient, %			
Dry Matter	90.33	90.26	88.83
Organic Matter	93.68	92.81	91.52
Crude Protein	12.31	12.40	11.69
Ash	6.32	7.09	8.48
Acid Detergent Fiber	39.98	37.47	41.98
Acid Detergent Lignin	7.17	6.88	8.53
Residual Ash	2.31	2.57	2.59
Hemicellulose	23.23	22.13	20.98
Cellulose	30.50	28.02	30.87
Cell Wall Constituents	63.21	59.60	62.96
Cell Contents	36.79	40.40	37.04
Gross Energy, Kcal/g DM	4.121	3.984	4.113

[a] Actual laboratory analysis of three samples for each treatment.

Statistical Analysis

All data were tested by the appropriate analysis of variance, and Duncan's New Multiple Range Test was employed to separate the means (Steel and Torrie, 1960). Digestion trial analysis was set up in such a way as to isolate variation from treatment, period, sheep and experimental error.

RESULTS AND DISCUSSION

Laboratory Evaluations of Chemical Straw Treatment

Trial 1

The results showed that spraying a two percent solution of NaOH on annual ryegrass straw had no significant effect in improving DDM above that of untreated straw (Table 8). It appeared that for this type of application a two percent solution was not strong enough to bring about lignin degradation or to increase cellulose availability. Support for this hypothesis was provided in the work of Chandra and Jackson (1971) who reported that spraying a 3.3% solution of NaOH on several roughages increased DDM. In vitro digestibility of wheat straw has also been improved by spraying with nine percent NaOH (Wilson and Pigden, 1964).

Table 8. Ryegrass straw in vitro dry matter digestibility after spraying or soaking with water or a 2% Sodium Hydroxide solution.[a, b]

Treatment	Water IVDDM %	2% NaOH IVDDM %
Spray	28.6^c	33.6^d
Soak	32.8^d	63.3^c

[a] Untreated dry control = 33.2% dry matter digestibility.

[b] NaOH solution not drained prior to drying.

[c, d] means in the same line and column bearing different superscripts are significantly different ($P < .01$).

Straw soaking in the same two percent NaOH solution nearly doubled digestibility, an increase that was statistically significant ($P < .01$). Evidently, the soaking process made more complete contact between the NaOH solution and straw, so that cellulose-lignin complex breakdown was more complete. When water replaced NaOH, spraying significantly ($P < .01$) depressed digestibility while water soaking had no effect when compared to untreated straw.

There was no significant difference among particle sizes or treatment times for straw soaked in two percent NaOH (Table 9). This left room for consideration of practicality and convenience in the selection of procedures for the remaining trials. With no differences noted among particle sizes, field chopped straw was successfully treated. These conclusions generally agreed with the data of Godden (1942) and Ferguson (1943). The latter compared long, unchopped straw (previously baled) and found that it was as efficiently treated as chopped straw if it was not packed too tightly in the soaking tank.

The 24-hour soaking was chosen because it fit most conveniently into the author's schedule. Either the 12 or 48-hour times would have been as effective (Table 9). Stone, Girouard and Frye (1965) published information from studies with alkali treatment of bagasse, which indicated that an incubation period of six hours was as effective as 24 hours. A majority of the alkali treatment studies reported have used treatment periods from 20 to 24 hours.

Table 9. Effect of treatment time and particle size on *in vitro* dry matter digestibility of ryegrass straw soaked in a 2% Sodium Hydroxide solution.[a, d]

Particle Size	Treatment Time 12 hr. IVDDM %	 24 hr. IVDDM %	 48 hr. IVDDM %
Fine[b]	61.9	61.6	62.0
1/4 inch	65.4	63.8	62.9
Field Chop[c]	69.9	63.0	62.0

[a] Untreated dry control = 33.2% dry matter digestibility.

[b] Ground in a Wiley Mill fitted with a 60-mesh screen.

[c] Approximately 1-inch lengths.

[d] NaOH solution not drained prior to drying.

Trial 2

All treatments, with the exception of the two eight percent levels were significantly ($P < .01$) different (Table 10). There was no consistency with which either chemical was superior.

The trends for percent improvement among levels were varied slightly. NaOH enhanced digestibility at an increasing rate up to the six percent level. At this point the increase plateaued and further improvements were at a decreasing rate. KOH produced its most marked improvement at the four percent level.

As for the percent improvement over the untreated straw, similar rises for both chemicals were noted. The improvement continued at an increasing rate through the eight percent level. All treatments produced significant $(P < .01)$ improvements in digestibility over either the native or water soaked straw. No benefit was detected for water soaking.

Table 10. *In vitro* dry matter digestibility improvement of ryegrass straw soaked in Sodium and Potassium Hydroxide solutions.[a,b]

Solution Strength %	NaOH			KOH		
		% Improvement			% Improvement	
	Mean IVDDM %	Among Levels	Over Dry Control	Mean IVDDM %	Among Levels	Over Dry Control
2	67.8[c]	--	90.5	65.0[d]	--	82.6
4	73.1[e]	7.9	105.5	77.1[f]	18.7	116.6
6	85.5[g]	16.9	140.1	82.8[h]	7.4	132.7
8	90.2[i]	5.6	153.4	89.1[i]	7.6	150.3

[a] Untreated dry control = 35.6% dry matter digestibility.
Water soaked = 35.3% dry matter digestibility.

[b] No draining prior to drying.

[c,d,e,f,g,h,i] Means on the same line and column bearing different superscripts are significantly $(P \leq .01)$ different.

DDM was also approximately doubled when straw was soaked in a 0.5% NaOH solution. Combinations of alkalies have no advantage over the single chemicals.

Recent research efforts with alkali treatment of straws has focused a considerable amount of attention on the question of what level of alkali will give the maximum effect. In the experiments of

Chandra and Jackson (1971) the nylon bag rumen digestibility of NaOH treated roughage increased linearly up to a level of 10 g NaOH/100 g of roughage and leveled off thereafter. Studies with wheat straw by Wilson and Pigden (1964) and Wilson and O'Shea (1964) showed similar curves. In both instances, NaOH treatment up to about nine percent of the DM caused marked increases in in vitro digestibility, but above this level no further increases were obtained. No benefit in digestibility was derived above a four percent alkali-wash level in experiments conducted on bagasse by Stone, Morris and Frye (1965). The most marked improvement in the digestibility of rice straw has been achieved at four percent NaOH by weight of straw (Guggolz et al. 1971). According to Guggolz, Kohler and Klopfenstein (1971), digestibility of grass straws was more than doubled when three percent NaOH was added with steam treatment.

Trial 3

Trial 3 provided data to support the conclusion that no additional significant improvement came from soaking straw in solutions stronger than eight percent (Table 11). Essentially DDM has reached a plateau at these levels. There was little further improvement over the native straw. However, each treatment promoted digestibility that was significantly ($P < .01$) greater than untreated straw. Ololade, Mowat and Winch (1970) also found increased in vitro DDM with each rise in NaOH concentration up to eight percent on a dry matter basis. Above this point no further increase occurred.

Table 11. In vitro dry matter digestibility of ryegrass straw soaked in Sodium and Sodium plus Potassium Hydroxide solutions.[a,b]

	NaOH		NaOH + KOH	
Solution Strength %	Mean IVDDM %	% Improvement over dry control	Mean IVDDM %	% Improvement over dry control
8.0	88.3	175.2	88.6	176.3
8.5	87.6	172.9	88.1	174.6
9.0	88.0	174.4	89.0	177.4
9.5	89.3	178.5	88.8	176.9
10.0	90.1	181.0	88.1	174.6
10.5	90.0	180.6	90.1	180.7

[a] Untreated dry control = 32.1% dry matter digestibility
Water soaked = 31.7% dry matter digestibility.

[b] No draining prior to drying.

It should be emphasized that these treatment levels were too strongly alkaline to be practically implemented. The caustic nature of such a solution would make handling of large volumes of straw difficult and severely limit consumption.

Trial 4

The results of this trial are shown in Table 12. They illustrated that $NaCHO_2$ has considerable potential for releasing the potential energy of ryegrass straw. All levels of $NaCHO_2$ significantly ($P < .01$) boosted DDM above that for the next lower level. However, the percent improvement among levels plateaued at four percent and increased at a declining rate thereafter. In contrast, the percent improvement above the control rose at an increasing rate through the ten percent level. The digestibility for all treatments was significantly ($P < .01$) greater than that for the untreated or water soaked straws. Presumably the beneficial effect noted can be attributed to the formation of NaOH when $NaCHO_2$ was mixed with water.

Table 12. In vitro dry matter digestibility of ryegrass straw soaked in Sodium Formate and Ammonium Hydroxide Solutions.[a,b]

Solution Strength %	$NaCHO_2$			NH_4OH	
	Mean IVDDM %	% Improvement Among Levels	% Improvement Over Dry Control	Mean IVDDM %	% Improvement Over Dry Control
2	44.2[c]	--	37.8	35.3[d]	10.0
4	54.5[e]	23.4	70.0	34.1[d]	6.4
6	64.2[f]	17.8	100.3	36.2[d]	12.9
8	69.8[g]	8.6	117.5	34.8[d]	8.6
10	73.0[h]	4.7	127.7	34.8[d]	8.6

---

[a] Untreated dry control = 32.1% dry matter digestibility; water soaked = 31.6% dry matter digestibility

[b] No draining prior to drying.

[c,d,e,f,g,h] Means in the same row and column bearing different superscripts are significantly ($P < .01$) different.

$NaCHO_2$ has not been previously used in this regard. Its use has centered around the role of a silage preservative. The net effect was to prolong fermentation, lower the ultimate pH, and produce more lactic and less butyric acid so that silage quality was higher (Axelsson and Kivimae, 1954).

The data in Table 12 also showed that $NaCHO_2$ promoted statistically ($P < .01$) greater gains in digestibility than did respective levels of NH_4OH. There was no significant change in digestibility among NH_4OH levels. But all NH_4OH treatments gave statistically ($P < .05$) greater digestibilities than what the untreated straw supported. NH_4OH was a weaker base than either NaOH or KOH. Also, liquid NH_4OH was highly volatile and difficult to work with. These facts might have contributed to the inferior results obtained.

Trial 5

Data from Trial 5 cast further doubts about the capacity of NH_4OH to improve the digestibility of low quality roughages (see Table 13). No significant difference in digestibility was evident for levels from 0.5% to 6.0% NH_4OH due to the high variability of the data. However, the eight percent NH_4OH treatment caused a significant ($P < .01$) decline in DDM below both the control and other treatments. No explanation, other than experimental error, can be offered for this effect at this time.

NaOH effectively altered straw so that its digestibility was significantly ($P < .01$) greater with each successive level. It also produced straw with a significantly ($P < .01$) higher digestibility than the native straw. The percent improvement among levels slowed at the four percent level and increased at a declining rate thereafter.

However, the percent improvement over the control rose at an increasing rate through the eight percent level. At all treatment levels the digestibility promoted by NaOH soaking was significantly ($P < .01$) greater than that for NH_4OH treated straw.

Table 13. *In vitro* dry matter digestibility of ryegrass straw soaked in Sodium and Ammonium Hydroxide solutions.[a,b]

Solution Strength %	NaOH Mean IVDDM %	NaOH % Improvement Among Levels	NaOH % Improvement Over Dry Control	NH_4OH Mean IVDDM %
0.5	62.3^{c}	--	85.1	33.9^{d}
2.0	67.7^{e}	8.6	101.1	33.3^{d}
4.0	75.7^{f}	11.8	124.8	32.9^{d}
6.0	83.6^{g}	10.5	148.4	36.4^{d}
8.0	88.3^{h}	5.7	162.4	29.1^{c}

[a] Untreated dry control = 33.7% dry matter digestibility
Water soaked = 31.5% dry matter digestibility.

[b] No draining prior to drying.

[c,d,e,f,g,h] Means in the same row or column bearing different superscripts are significantly ($P < .01$) different.

CP composition and percent change with treatment for NaOH and NH_4OH treated straw is shown in Table 14. It can be noted that the CP content of NH_4OH treated straw increased considerably when compared to the control. The CP content of straw at all treatment levels was significantly ($P < .01$) greater than for the control. This demonstrated that a possible advantage for NH_4OH could be the supplementary nitrogen that the ammonium radical supplies. Nitrogen provided in this manner would reduce the quantity of supplemental nitrogen required from other sources. The nutritional availability of this source of nitrogen is currently being studied by Guggolz et al. (1971).

Table 14. Crude protein composition of ryegrass straw soaked in Sodium and Ammonium Hydroxide solutions.[a]

Solution Strength %	NaOH			NH_4OH	
	CP %	% Decline Among Levels	% Decline Below Untreated Straw	CP %	% Increase Over Dry Control
0.0	3.55^{d}	--	--	3.55^{d}	--
0.5	3.30^{d}	7.0	7.0	5.35^{e}	50.7
2.0	2.48^{b}	24.9	30.1	5.95^{ef}	67.6
4.0	1.99^{b}	19.8	43.9	5.83^{ef}	64.2
6.0	1.07^{c}	46.2	69.9	6.71^{f}	89.0
8.0	0.97^{c}	9.4	72.7	6.51^{f}	83.4

[a] No draining prior to drying.

[b,c,d,e,f] All means in the same row and column bearing different superscripts are significantly ($P < .05$) different.

On the other hand, CP values for NaOH treatments illustrated a progressive decline for each change in treatment level (Table 14). All CP values for NaOH-treated straw were significantly ($P < .01$) smaller than those for NH_4OH-treated straw. NaOH treatment at all levels, except 0.5%, significantly ($P < .05$) reduced CP composition below that of untreated straw. CP in straw treated with 0.5% NaOH was significantly ($P < .05$) higher than straws from all other treatment levels. The six and eight percent NaOH-treated straws were significantly ($P < .05$) lower in CP than the lower levels of treatment.

The remaining differences were not significant.

These data indicated that a large portion of the CP in straws or any mature, low-quality roughage was probably tied up in an unavailable complex. Furthermore, it strongly suggested that destruction and loss of a considerable amount of the straw protein occurred after strong alkali treatments. However, with the low inherent CP content of straw such losses were not of much nutritional importance.

Table 15 tabulated the progressive declines in ADF and ADL that occurred with increasing levels of NaOH treatment. The percent decline below untreated straw for both constituents was at an increasing rate, reaching the highest change at the eight percent level. The percent decline in ADF among levels fluctuated, but for ADL the decline was at an increasing rate up to the six percent level of treatment where values plateaued and then declined further at a diminishing rate. At eight percent, the ADL content of straw was so low that one might question the sensitivity of permanganate procedure to detect such minute quantities. ADF content significantly ($P < .01$) decreased with each proportionate NaOH increase until the six percent level was reached, and ADL values followed an identical pattern. NaOH treatment at all levels significantly ($P < .01$) reduced ADF and ADL values below native straw.

Table 15. Acid detergent fiber and lignin of ryegrass straw soaked in Sodium Hydroxide solutions.[a]

Solution Strength %	ADF			ADL		
		% Decline			% Decline	
	ADF %	Among Levels	Below Untreated Straw	ADL %	Among Levels	Below Untreated Straw
0.0	49.09^{b}	--	--	10.62^{b}	--	--
0.5	43.16^{c}	12.1	12.1	8.55^{c}	19.5	19.5
2.0	26.46^{d}	38.7	46.1	4.79^{d}	44.0	54.9
4.0	19.13^{e}	27.7	61.0	2.60^{e}	45.7	75.5
6.0	9.59^{f}	49.9	80.5	1.22^{f}	53.1	88.5
8.0	8.05^{f}	16.1	83.6	0.86^{f}	29.5	91.9

[a] No draining prior to drying.

[b,c,d,e,f] Means in the same column bearing different superscripts are significantly ($P < .01$) different.

These results on compositional changes of straw following alkali soaking agreed, in part, with those reported for oat straw (Saxena et al., 1971). Their data showed a marked decline in CP for alkali-treated straw as compared to its parent material. However, the decline in lignin with alkali treatment was not as dramatic as the results reported herein for ryegrass straw. In contrast, the increase in ADF noted by Saxena et al. (1971) was in conflict with our data. Ololade, Mowat and Winch (1970) also found that the treatment of barley straw with eight percent NaOH on a dry matter basis did not significantly ($P < .05$) reduce ADF or lignin contents.

The early work of Godden (1920) and McAnally (1942) had supported the theory that lignin served as an encrusting substance which prevented the degradation of cellulose. They had postulated further that digestibility was improved drastically if the physical association between these two constituents was broken by some means. The proportionate increased *in vitro* DDM and corresponding declines in ADF and ADL lent strong support to their theories and suggestions.

Van Soest and Jones (1968) have suggested that silica was as important as lignin in preventing cellulose digestion in mature forages. Silica assays were not conducted for the trials reported herein. However, it would have been interesting to have such data since there are strong possibilities that annual ryegrass straw is relatively high in this mineral. Field removal can incorporate a large quantity of dust and soil, which is rich in mineral matter, especially silica, into the straw.

Trial 6

The results of Trial 6 are shown in Table 16. A two percent NH_4OH solution produced treated material that was significantly ($P < .01$) lower in DDM than the four, six, eight or ten percent solutions. The data was marked by a high degree of variability within treatment which accounted for no further significant differences among treatment levels. Nevertheless, with the exception of two percent NH_4OH, all levels of treatment gave treated straw that was significantly ($P < .01$) higher in digestibility than the dry control. Although the percent improvement over the control straw fluctuated some, an average of nine percent improvement was noted.

Table 16. Effects of Sodium and Ammonium Hydroxide treatment upon ryegrass straw dry matter digestibility.[a,b]

Treatment Level %	NaOH[c] Mean IVDDM %	NaOH[c] % Improvement Among Levels	NaOH[c] % Improvement Over Dry Control	NH_4OH Mean IVDDM %	NH_4OH % Improvement Over Dry Control
2	34.8^d	--	5.7	33.7^d	0.26
4	41.5^f	19.4	26.2	37.2^e	12.95
6	44.6^g	7.8	36.1	36.7^e	11.58
8	51.5^h	15.0	56.5	35.6^e	8.24
10	56.5^i	9.7	71.6	36.7^e	11.68

[a] Untreated dry control = 32.9% dry matter digestibility
Water soaked = 24.3% dry matter digestibility.

[b] All samples were drained free of solution prior to drying.

[c] Quantity of NaOH required to make up solutions for each treatment level was based on a percent of the straw dry matter being soaked.

[d,e,f,g,h,i] Means in the same row and column bearing different superscripts are significantly ($P < .01$) different.

It must be concluded at this time on the basis of the results from Trials 4, 5 and 6 that the variability was too high and the repeatability too low among trials to recommend NH_4OH as a chemical that would consistently improve the nutritive value of straw. More controlled treatment conditions need to be employed before widespread commercial use can be made of this chemical. However, a small degree of improvement in DDM over native straw can be expected. Whether the degree of improvement would justify the cost of treatment is doubtful.

Other work with ryegrass straw (Guggolz et al., 1971) has indicated that NH_4OH mixed with straw in a closed container caused a good improvement in digestibility. It should be pointed out, though, that their treatment also included heat and pressure, which could have beneficially affected straw digestibility. These authors also mentioned that problems were encountered in NH_4OH handling and disposal following treatment.

Even though the percent improvement among levels fluctuated for NaOH-treated straw, the percent improvement over the control rose steadily and at an increasing rate up through the ten percent level (Table 16). Each treatment level produced treated material that was significantly ($P < .01$) higher in DDM than either the level immediately below it or the untreated straw. With the exception of the two percent level, straw treated at all levels of NaOH was significantly ($P < .01$) higher in digestibility than straw treated with NH_4OH at corresponding levels.

It was evident that the extent of improvement was not as marked for NaOH on the dry matter basis (NaOH-DM) as for NaOH soaking on a solution basis (NaOH-Sol.) reported for trials 2, 3 and 5. The ultimate digestion coefficients reached on the former basis were not as high nor was the rate of improvement as rapid as for the latter treatment basis. Draining had similar effects. Some of this difference in effect was attributed to loss of solubilized nutrients with draining and/or weaker alkali solutions that result when NaOH-DM was used. It was concluded then, that NaOH-DM treatment plus draining prior to drying of straws was advantageous, but not to the extent of treatment with NaOH-Sol. and no predrying draining.

Trial 7

Irrespective of treatment, DDM was significantly ($P < .01$) lower at all levels when the NaOH effluent was drained off prior to drying (Table 17). These data offered strong evidence that a considerable quantity of material was solubilized following NaOH treatment and that this solubilized material played an important role in enhancing straw digestibility. Furthermore, draining must have removed a sizeable portion of the soluble material, so that it was unavailable as a readily available energy source for rumen microbes to draw on to support their activities in digesting cellulose. Consequently, the advantage gained can be partially offset if effluent draining becomes necessary, as it would seem to be in a commercial process. One alternative to draining might be to evaporate the water and recover the dried material. If this was carried on in large volumes, the recovered material could be readded to the treated straw before a complete ration was prepared. Even with draining losses, NaOH treatment was beneficial since all treatment means for digestibility were significantly ($P < .01$) greater than the digestibility of the native straw. The percent improvement among levels was inconsistent. However, the percent improvement over

Table 17. The effects of Sodium Hydroxide soaking and pre-drying treatment on ryegrass straw dry matter digestibility.[a]

Treatment Level %	Drained[c]			Undrained		
		% Improvement			% Improvement	
	Mean IVDDM %	Among Levels	Over Dry Control	Mean IVDDM %	Among Levels	Over Dry Control
			Sodium Hydroxide-DM[b]			
6	39.9^{d}	--	32.2	56.2^{e}	--	86.0
8	50.1^{f}	25.6	66.1	63.2^{g}	12.6	109.4
10	56.6^{g}	12.9	87.5	63.9^{f}	1.0	111.6
			Sodium Hydroxide-Sol.[b]			
2	47.5^{f}	--	57.6	64.5^{g}	--	113.5
4	49.4^{f}	4.2	63.7	67.2^{e}	4.3	122.6
6	56.6^{g}	14.5	87.5	79.9^{d}	17.7	162.0

[a] Untreated dry control = 30.2% dry matter digestibility
water soaked
drained = 24.3% dry matter digestibility
undrained = 32.3% dry matter digestibility.

[b] DM = NaOH quantity used for treatment based on a percent of straw dry matter treated
Sol. = NaOH quantity used for treatment based on grams NaOH per 100 ml. water.

[c] liquid drained off prior to drying.

[d,e,f,g] means in the same column or row bearing different superscripts are significantly ($P < .01$) different.

the dry control was greater for the undrained samples than for the drained ones. Lower numerical treatment levels of NaOH-Sol. were more effective in improving DDM than higher levels of NaOH-DM. With only one exception, straw soaked in NaOH-Sol. was significantly ($P < .01$) higher in DDM than straw treated on a dry matter basis. This can be attributed to the stronger alkali solution of the former since more NaOH was used for treatment on a solution basis than for treatment on a dry matter basis.

The CP composition of treated and untreated straw is shown in Table 18. The characteristic effect of NaOH-Sol. (undrained) established in Trial 5 of this study was supported, although the decline in CP was not as marked. Comparable CP reductions have been reported for alkali-treated oat straw by Saxena et al., (1971). Singh and Jackson (1971) also noted a slight reduction in wheat straw CP after alkali spray treatment.

The CP percentage decline with each treatment level increase was smaller for NaOH-DM samples than for the NaOH-Sol. ones irregardless of predrying treatment. Presumably, the greater CP loss was due to the stronger alkaline nature of NaOH-Sol.

For NaOH-DM, draining depressed CP at an increasing rate up to the eight percent level where the decline plateaued and continued on at a decreasing rate. This contrasted to a decline at an increasing rate up through ten percent NaOH-DM for undrained straw.

Table 18. Crude protein composition of Sodium Hydroxide-treated ryegrass straw.

Treatment Level	Sodium Hydroxide-DM				Treatment Level	Sodium Hydroxide-Sol.			
	Drained CP		Undrained CP			Drained CP		Undrained CP	
	% of DM	% Decline Below Control	% of DM	% Decline Below Control		% of DM	% Decline Below Control	% of DM	% Decline Below Control
0	4.48^{b}	--	4.48^{b}	--	0	4.48^{b}	--	4.48^{b}	--
6	3.85^{a}	14.1	4.28^{b}	4.5	2	2.72^{c}	39.3	2.92^{c}	34.8
8	3.55^{a}	20.8	4.23^{b}	6.0	4	2.33^{c}	48.0	2.63^{c}	41.3
10	3.65^{a}	18.5	3.94^{a}	12.1	6	1.75^{d}	60.9	1.64^{d}	63.4

^{a,b,c,d} Means in the same line and column bearing different superscripts are significantly ($P <.01$) different.

The level of decline was higher for drained samples also. Loss of released CP following draining accounted for these differences. Draining NaOH-Sol. samples produced no significant changes in CP content when compared to undrained ones. Statistical differences were difficult to segregate. But at all levels and for both predrying treatments NaOH-DM produced larger ($P < .01$) straw CP values than did NaOH-Sol. This reflected the ability of NaOH-Sol., as a stronger alkali solution, to degrade straw. With the exception of six and eight percent NaOH-DM undrained treatments, all treatments were successful ($P < .01$) in reducing CP composition below that of untreated straw. Even though there were slight CP declines among levels with increasing treatment level, significance was not reached for NaOH-DM until the ten percent undrained treatment was reached. Similar effects could be noted for NaOH-Sol. as CP values among levels declined with increasing levels, but significant CP value differences were not apparent until the ten percent treatment.

Undrained samples showed a markedly greater decline in CWC below that for untreated straw, than did the drained ones for either NaOH-DM or NaOH-Sol. (Table 19). Larger percentage declines in CWC were produced from treating straw with NaOH-Sol. as compared to treatment with NaOH-DM. All declines in CWC below native straw were at an increasing rate. The CWC increase over control straw at the six percent NaOH-DM level was unexplainable. However, one report

Table 19. Cell wall constituent composition of Sodium Hydroxide-treated straw.

	Sodium Hydroxide-DM					Sodium Hydroxide-Sol.			
	Drained CWC		Undrained CWC			Drained CWC		Undrained CWC	
Treatment Level	% of DM	% Decline Below Control	% of DM	% Decline Below Control	Treatment Level	% of DM	% Decline Below Control	% of DM	% Decline Below Control
0	74.2^{a}	--	74.2^{a}	--	0	74.2^{a}	--	74.2^{a}	--
6	75.8^{a}	+2.3	61.6^{b}	16.9	2	52.8^{c}	28.9	31.1^{d}	58.1
8	71.0^{b}	4.2	55.3^{c}	25.4	4	46.5^{e}	37.3	23.6^{f}	68.2
10	68.2^{c}	8.0	52.0^{d}	29.9	6	32.9^{g}	55.6	11.4^{h}	84.7

^{a,b,c,d,e,f,g,h}Means in the same line and column bearing different superscripts are significantly ($P < .01$) different.

in the literature (Ololade, Mowat and Winch, 1970) has shown a similar response for barley straw With the exception of the difference between the untreated control and six percent NaOH-DM, all treatment combinations produced significant ($P < .01$) CWC declines among levels and below the native straw.

ADF composition appears in Table 20. It should be pointed out that with NaOH-DM, ADF increased with each treatment level rise irrespective of predrying treatment. However, statistical signficance ($P < .01$) was reached only when samples were not drained. Significant ($P < .01$) ADF rises can also be noted through the four percent drained NaOH-Sol. treatment. ADF values were significantly ($P < .01$) greater than the control at all levels except the latter. The six percent drained NaOH-Sol. treatment and all undrained ones produced significant ($P < .01$) ADF reductions both among levels and below native straw. The ADF decline for NaOH-Sol. undrained samples was at an increasing rate.

Similar results have been evident throughout other phases of these experiments (Tables 2 and 22). Saxena _et al._, (1971) also observed ADF increases in oat straw following a 22-hour soaking in 1.5% NaOH solution. They mentioned that such findings were definitely contrary to what would be expected. Our data suggested that ADF increases are related to the strength of the alkali solution. Perhaps soaking in weak NaOH solutions predisposed the formation of additional

Table 20. Acid detergent fiber composition of Sodium Hydroxide-treated ryegrass straw

Treatment Level	Sodium Hydroxide-DM				Treatment Level	Sodium Hydroxide-Sol.			
	Drained ADF		Undrained ADF			Drained ADF		Undrained ADF	
	% of DM	% Change Above Control	% of DM	% Change Above Control		% of DM	% Change Above Control	% of DM	% Change Above Control
0	47.0^{a}	--	47.0^{a}	--	0	47.0^{a}	--	47.0^{a}	--
6	52.1^{b}	10.9	56.2^{c}	19.6	2	51.2^{d}	8.9	28.9^{e}	-38.5
8	51.9^{b}	10.4	51.3^{b}	9.2	4	47.7^{a}	1.5	23.1^{c}	-50.9
10	52.4^{b}	11.5	50.0^{d}	6.4	6	34.0^{e}	-27.7	13.4^{f}	-71.5

^{a,b,c,d,e,f} Means in the same line or column bearing different superscripts are significantly (P <.01) different.

complexes that were insoluble in acid detergent solutions. The stronger solutions in NaOH-Sol. treatments were more effective in reducing ADF content, but draining had its influences also.

ADL changes followed closely the pattern established for ADF (Table 21). NaOH-DM treatment for both predrying procedures caused an increase in ADL among levels and above the dry control that occurred in a decreasing fashion. Every treatment combination for NaOH-DM caused a significant ($P < .01$) increase in ADL above that of the untreated straw. However, the six percent treatment caused the maximum rise and the mean at this level was significantly ($P < .01$) higher than for those at the two higher levels, which were not significantly different. Similar increases, although not as marked, were noted in other phases of these studies (Tables 2 and 22). Possibly the heat from drying and/or pelleting could have damaged a portion of the straw so that ADL values were skewed by artifact lignin.

These results were in definite conflict with those reported by Saxena et al., (1971). These workers showed a ten percent ADL decline in NaOH soaked oat straw. Ololade, Mowat and Winch (1970) also found a slight decline in barley straw lignin subsequent to its treatment with either two, four, or eight percent NaOH on a dry matter basis. Increases in digestibility roughly proportional to the degree of lignin breakdown have been reported following NaOH

Table 21. Acid detergent lignin composition of Sodium Hydroxide-treated ryegrass straw.

	Sodium Hydroxide-DM					Sodium Hydroxide-Sol.			
	Drained ADL		Undrained ADL			Drained ADL		Undrained ADL	
Treatment Level	% of DM	% Change Above Control	% of DM	% Change Above Control	Treatment Level	% of DM	% Change Below Control	% of DM	% Change Below Control
0	7.3^{a}	--	7.3^{a}	--	0	7.3^{a}	--	7.3^{a}	--
6	15.0^{b}	51.3	10.5^{d}	43.8	2	7.1^{a}	-2.7	4.0^{c}	-45.2
8	9.2^{c}	26.0	9.0^{c}	23.3	4	7.2^{a}	--1.4	3.2^{d}	-56.2
10	8.3^{c}	13.7	8.6^{c}	17.8	6	5.2^{d}	-28.8	1.5^{b}	-79.5

^{a,b,c,d} Means in the same line or column bearing different superscripts are significantly ($P < .01$) different.

treatment (Chandra and Jackson, 1971 and Guggolz et al., 1971).

All NaOH-Sol. treatments, regardless of predrying handling, caused a decline in ADL among levels and below untreated straw. These differences were statistically significant ($P < .01$) when compared to the control or among levels except for the two and four percent drained samples. Furthermore, the percentage decline for undrained samples was at an increasing rate.

Water Soaking

The design for each laboratory trial included a dry control and a water soaked treatment. The DDM for these have been shown in the table footnotes accompanying each trial. The average digestion coefficient for untreated straw was 33.3%. In other words, only one third of the straw dry matter was available for animal use. Since a large portion of straw is cellulose, which is a potential ruminant energy source, there is opportunity for making it more available to rumen microorganisms. This series of laboratory trials showed that NaOH did effectively increase DDM.

Water soaking tended to depress DDM below the dry control (32.5% vs. 33.3%) when samples were not drained prior to drying, but this depression was not statistically significant. On the other hand, water soaked samples that had been drained were significantly ($P < .01$) lower in digestibility than either the dry control or the undrained water soaked samples (24.3% vs. 33.3% and 32.3%). Loss of solubilized material upon draining, which would otherwise support microbial activity, most likely explained this response.

Lamb Digestion Trials

Straw Composition

A comparison of NaOH-treated straw with its parent material is shown in Table 22. These values represent analysis of straw sampled prior to its incorporation into complete rations. NaOH soaking caused a decline in CP below the content of untreated straw. Even though the reduction was not as marked, these data were in accord with observations from earlier laboratory trials (Tables 15 and 19) and with the data reported by Saxena et al., (1971).

Table 22. Composition of Sodium Hydroxide-treated straw and its parent material.

Constituent, % of DM	1[a]	2[b]	3[c]
Crude Protein	4.3	4.0	3.4
Acid Detergent Fiber	45.6	53.3	53.7
Acid Detergent Lignin	7.2	7.8	8.2
Residual Ash	3.0	2.8	2.2
Cell Wall Constituents	75.4	86.7	74.5
Sodium	0.18	1.7	3.8

[a] Untreated control. [b] 8% DM. [c] 1% solution.

NaOH soaking caused ADF and ADL to increase in both treatments. For the eight percent dry matter treatment (Treatment two) this agreed with comparable laboratory trials (Tables 21 and 22). There was no directly comparable laboratory trials with which to contrast the results of the one percent solution treatment (Treatment three). However, the trend for increased ADF was consistent with ADF rise noted for two percent NaOH-SOL. (drained) treatment (see Table 21). But the ADL increase was in definite conflict with ADL values recorded for NaOH-Sol. drained treatments shown in Table 22.

Treatment two greatly increased CWC above that for untreated straw, and this did not agree with the decrease reported by Ololade, Mowat and Winch (1970) for NaOH-treated barley straw. On the other hand, Treatment three reduced CWC below the content of native straw, but not at a significant level. Evidently, eight percent NaOH of the dry matter did not produce a strong enough solution to break down the cell wall. The drying process might also have caused some heat damage and complexing of otherwise available constituents.

Sodium levels of the straw increased with each treatment. However, when the straw was mixed with the remainder of the ration ingredients this level was diluted considerably (see Table 2).

General Health and Feed Acceptance

The general health of the sheep consuming NaOH soaked straw was not impaired. Adjustment to the rations came quickly, and each feeding was accepted eagerly. Kehar (1954) also has reported that cattle preferred alkali-treated rice straw and spent less time in eating their quota. No detrimental effects were noted throughout a 17-day feeding period. These observations agreed with the data of Singh and Jackson (1971) who fed cattle for six months on unwashed, spray-treated wheat straw without any adverse effects. These studies and the work reported herein have been the only experiments where unwashed straw has been fed to livestock. They do point out that washing can be eliminated if lower levels of NaOH soaking are followed. They also suggested that advantages of greater digestibility can be offset by adverse effects of residual alkali at high levels of treatment. Chandra and Jackson (1971) presented data that showed the amounts of residual alkali in treated roughage as a function of alkali concentration. It was obvious from this information that there was no unreacted alkali unless more than one percent alkali was used in treatment. Although specific information was not obtained on the unreacted alkali in these studies, the satisfactory animal acceptance and absence of detrimental effects suggested that higher levels can be successfully fed and utilized. It also demonstrated the effectiveness of the rumen buffering system and the ability of rumen microbes to adapt to widespread pH variations without detrimental effects on feed utilization.

There was limited refusal of ration two. When ration switches were made lambs adjusted to it more slowly than to the other two rations. A part of this refusal can be assigned to the extreme hardness of the pellets. Another factor limiting the palatability might have been the migration of urea to the outside of the pellet and the establishment of a bitter taste.

Daily DM intake per kg of body weight was significantly ($P < .05$) reduced for straw soaked in NaOH when compared to native straw (Table 23).

Table 23. Effect of Sodium Hydroxide soaking upon voluntary dry matter intake and apparent digestibility of annual rye grass straw by sheep.

Ration[a]	1[e]	2[f]	3[g]
Daily Dry Matter Intake, g/kg Body Weight	38.5^{b}	36.2^{c}	36.7^{c}
Apparent Digestibility, %			
Straw	37.2^{b}	29.3^{c}	42.0^{d}
Dry Matter	48.3^{b}	41.6^{c}	51.9^{b}
Organic Matter	49.3^{b}	42.7^{c}	51.4^{b}
Energy	44.7^{b}	37.6^{c}	44.2^{b}
Crude Protein	67.2^{b}	57.2^{c}	58.9^{c}
Ash	28.9^{b}	13.1^{c}	53.9^{d}
Acid Detergent Fiber	33.8^{b}	33.5^{b}	35.4^{c}
Hemicellulose	51.5^{b}	47.8^{b}	75.7^{c}
Cellulose	41.5	39.3	41.8
Cell Wall Constituents	40.4^{b}	38.7^{b}	46.8^{c}
Cell Contents	61.4^{b}	48.2^{c}	59.5^{b}

[a] See Tables 1 and 2 for ingredients and chemical composition of rations.

[b, c, d] Means in the same line bearing different superscripts are significantly ($P< .05$) different.

[e] Untreated control. [f] 8% dry matter. [g] 1% solution.

Singh and Jackson's data (1971) with cattle showed an increase in DM intake when wheat straw was sprayed with 3.3% NaOH, but a decline at higher levels of treatment. With sheep no difficulty coping with any residual alkali was noted if 6% alkali treated material was neutralized by mixing with silage or pelleted with ground alfalfa hay (Pigden, 1969). However, the animals drank a lot more water than when fed untreated material. In our studies, mixing with other ingredients for a complete ration most likely also had a similar diluting effect on the residual unreacted NaOH.

Increased water consumption was also evident in our studies. Daily water consumption is shown in Table 24. There was no significant ($P < .05$) difference in water intake, regardless of the manner of expression, between rations one and two. On the other hand, ration three caused a marked boost in daily water consumption that was statistically ($P < .01$) significant. The change in water consumption occurred very quickly (within one day) after lambs were switched to ration three. Evidently at this level of NaOH treatment there was a larger quantity of unreacted residual alkali than was present on the straw of ration two.

Such a dramatic fluctuation in water consumption was not reported for calves fed an alkali spray-treated wheat straw ration (Singh and Jackson, 1971). Part of the difference no doubt was due to species differences. It should also be pointed out that straw for ration three of this report was treated in a manner that permitted more straw contact with a stronger solution than that fed to calves.

Table 24. Water consumption, urinary excretion, and urine pH for sheep fed Sodium Hydroxide-treated ryegrass straw rations.

Ration[a]	1[d]	2[e]	3[f]
Daily Water Consumption			
Total Intake, mls	4428.6	3994.8	6970.7
Intake, mls/kg Body Weight	10.7[b]	9.5[b]	16.3[c]
Intake, ml/g DM Feed Intake	2.8[b]	2.6[b]	4.4[c]
Daily Urine Excretion			
Total Volume, mls	1078.0	546.1	4048.4
Output, mls/kg Body Weight	26.3[b]	12.8[b]	95.0[c]
Urine Excreted, mls/g DM Feed Intake	0.69[b]	0.35[b]	2.58[c]
Urine pH	8.3[b]	7.5[c]	8.5[b]

[a] See Tables 1 and 2 for ingredients and chemical composition of rations.

[b, c] Means in the same line bearing different superscripts are significantly ($P < .05$) different.

[d] Untreated control. [e] 8% dry matter. [f] 1% solution.

The average water intake is largely a function of DM consumption and ambient temperature. However, there are enormous individual variations, and sheep vary more widely than cattle.

Roubicek (1969) stated that the ratio of water drank to kg of DM ingested for cattle was approximately three liters. Water intake by sheep in our studies for rations one and two approached this ratio, but the high NaOH residue of ration three pushed water consumption up. Comparison of feed intake data (Table 23) with water consumption information of Table 24 brought out an interesting point. On the basis of DM intake one would predict that the largest volume of water consumption would accompany ration one. However, this was not the case.

Following the water consumption pattern, daily urinary excretion, regardless of manner of expression, was significantly ($P < .01$) greater for ration three than it was for the other two. Even though urine output for sheep on ration two was reduced below that of sheep for ration one, this difference was not significant. Urine pH for sheep of ration two was significantly ($P < .05$) reduced below that recorded for urine from sheep fed the other two rations. However, all readings were within the basic range that Church (1969) reported for ruminants. Perhaps if water intake would have been restricted more sizeable urine pH differences would have been detected.

Digestibility

Table 23 shows the apparent digestion coefficients for the three experimental rations. Straw digestibility was calculated after assuming book values for digestion coefficients of all other ration ingredients (Morrison, 1959). The average apparent digestibility of straw in ration three was significantly ($P < .05$) greater than that for either untreated straw or eight percent dry matter treated straw. The superiority of the straw in this ration was attributed to the significantly ($P < .05$) greater utilization of its components ADF, CWC, and hemicellulose. These data showed that NaOH soaking effectively increased the nutritional availability of the fiber fraction of mature forages. But it also indicated that improvement was dependent upon NaOH solution strength since straw digestibility for ration two was significantly lower than that for ration three.

For all constituents, apparent digestion coefficients for ration two were lower than those for the other two rations, although the differences were not always statistically significant. It was difficult to pinpoint the causes of such responses. A portion of it might be due to the failure of the NaOH to make contact with part of the straw during the soaking process. The net effect, then, would be conditions of water soaking, which has been shown in our laboratory trials to depress digestibility.

The marked increase ($P < .01$) in the availability of the straw hemicellulose of ration three compared favorably with the reports of McAnally (1942), who demonstrated that the digestibility of the pentosan, xylan, which is a major constituent of hemicellulose, was notably increased. These data reemphasized the susceptibility of plant hemicellulose to alkali, and its subsequent higher solubility. The digestibility of hemicellulose for ration three was significantly ($P < .01$) greater than that for either the untreated straw or the lower NaOH treatment. The latter was lower than that for the control straw, but this difference was not significant.

ADF and CWC digestibility for ration three was significantly ($P < .05$) higher than that calculated for the other two rations. Once again ration two was lower in digestibility than the untreated straw ration but this difference was not significant. The improvement in CWC and ADF was most likely due to the dramatic increase in hemicellulose solubility.

Even though there was a slight numerical depression for the cellulose digestibility of ration two, there was no significant difference among rations for cellulose digestibility. Although NaOH soaking was successful in breaking apart a portion of the straw fiber fraction, evidently some factor(s) were still preventing the cellulolytic microorganisms from degrading cellulose.

The digestibility of cell contents declined for rations two and three below the level of the untreated straw ration. However, this decline was only significant ($P < .01$) for the former. This agreed with the contentions of Hogan and Weston (1971) who have presented evidence to support the fact that the material released from CWC during alkali treatment was poorly digested in the whole tract.

There was no statistical differences between rations one and three concerning energy digestibility, but energy from ration two was significantly ($P < .05$) lower in availability than either of the remaining two rations. Perhaps these results were linked to the lack of improvement in cellulose digestibility. Since cellulose's energy is released to the animal as volatile fatty acids, a poor cellulose digestibility should also adversely affect the energy availability.

Soaking straw in a one percent solution of NaOH caused a numerical increase in ration DDM over the untreated straw ration but this difference did not reach significance. This was contrary to what one would expect when straw digestibility has been significant between the two treatments. The variation among animals within each treatment probably accounted for this discrepancy. On the other hand, DDM of ration two was significantly ($P < .01$) reduced below that calculated for either of the other two rations following a trend established for straw digestibility. A pattern of results similar to those for DDM was evident for DM digestibility.

Ash digestibility for ration three was significantly ($P < .01$) greater than for either rations one or two. The ash of ration two followed the pattern of the other constituents as it was markedly ($P < .01$) lower in digestibility than were either rations one or three.

The utilization of CP from ration one was markedly superior (P < .01) to that for the remaining two rations. Ration three was numerically greater in CP digestibility than was ration two, but this difference did not approach statistical significance. The very definite superiority of CP digestibility for the untreated straw ration was difficult to explain, especially where ration ingredients were common to all rations and where the non-protein nitrogen source, urea, composed 35% of the CP equivalent. Furthermore, there were conflicts with other research reported in the literature. Lampila (1963) suggested that a small amount of residual alkali was good for the utilization of non-protein nitrogen. His hypothesis was that the alkalinity of treated straw acted through the pH of the rumen contents to increase the utilization of urea. Donefer's work (1968) also showed improved utilization of urea from treated straw. Saxena et al., (1971) reported that alkali-treated oat straw served very effectively as a source of energy for non-protein nitrogen use. Lambs in their experiments showed significant improvements in feed consumption and consequently gains and feed efficiency were improved when treated straw was incorporated into the rations.

Nitrogen Balance

Data relating to daily nitrogen balance are shown in Table 25. It should be pointed out that the nitrogen intake of the control ration

Table 25. Effect of Sodium Hydroxide soaking upon nitrogen balance, energy utilization, and animal performance of annual ryegrass straw by sheep.

Ration[a]	1[e]	2[f]	3[g]
Daily Nitrogen Balance, g			
Nitrogen Intake	31.7	26.3	28.3
Nitrogen in Feces	10.4	11.0	11.6
Nitrogen in Urine	15.3	10.5	10.7
Nitrogen Retained	6.0[b]	4.8[c]	6.0[b]
Percent of Intake	18.9	18.3	21.2
Percent of Digested	28.2	31.4	35.9
Partition of Energy, Kcal/day			
Energy Intake	6443.0	6243.5	5993.1
Fecal Energy	3561.0	3889.7	3345.5
Digestible Energy	2882.0	2353.8	2647.6
Digestible Energy, Kcal/g DM Intake	1.807[b]	1.541[c]	1.702[d]
Animal Performance			
Average Daily Gain, g/day	151.8[b]	146.8[b]	67.1[c]

[a] See Tables 1 and 2 for ingredients and chemical composition of rations.

[b, c, d] Means in the same line bearing different superscripts are significantly ($P < .05$) different.

[e] Untreated control

[f] 8% dry matter.

[g] 1% solution.

was greater than the nitrogen consumption for the other two rations. This difference was proportional to that for feed intake (Table 23). The slight difference in ration CP contents might have contributed a small part also (Table 2). The latter was a result of poor mixing during the pelleting process and the use of book values as a basis for formulating the rations, which did not specifically represent the nutrient composition of the particular feedstuffs used. The low nitrogen intake experienced for ration two probably was due to its relative higher fiber and lower CP nature. The lower intake no doubt also contributed. Routes of excretion varied somewhat. Approximately equal amounts were voided via the feces and urine for the NaOH-treated rations (two and three). But the control had 25% more nitrogen excreted in the urine than in the fecal matter.

All sheep were in a positive nitrogen balance for the duration of the trials. There was no significant difference in daily nitrogen retention between lambs fed rations one or three because of the equalization of nitrogen output of lambs on ration three. In other words, the higher nitrogen intake for ration one was offset by the larger urinary nitrogen excretion. Nitrogen retention for lambs receiving ration two was significantly ($P < .05$) depressed below the quantity retained by lambs on the other two rations. If nitrogen retention was expressed as either a percent of intake or as a percent of digested, ration three was definitely superior. Ration two also caused a larger proportion of the digested nitrogen to be retained in lambs than did the control ration.

The data presented by Singh and Jackson (1971) showed a considerably higher nitrogen retention as a percent of intake for alkali treated wheat straw fed to cattle. Lambs fed NaOH-treated corn cobs (Koers, Klopfenstein and Woods, 1969) retained more nitrogen with every level of treatment. Both species and substrate specificity were probably responsible for these deviations from the ryegrass straw data.

Energy Balance

Untreated straw supported the highest level of digestible energy per g of DM intake, a level that was statistically significant ($P < .05$) over the treated rations (Table 25). This was attributed to the larger energy intake and the proportionally smaller fecal energy excretion for lambs consuming this ration. Furthermore, ration three supported significantly ($P < .05$) more digestible energy than ration two. This was a reflection of the lower feed energy concentration and a larger daily fecal energy output for the latter. Utilization of the gross energy of ration two was not as complete as for the other two rations.

Lamb Performance

Ration three markedly ($P < .01$) reduced average daily gain below that supported by rations one and two. However, two lambs of this treatment failed to gain, and this badly skewed the data. It was not known whether this was actual failure to gain or weighing error. Even without these two values, ration three supported statistically significant (P < .01) inferior performance. The untreated straw based ration promoted slightly greater gains than ration two, but this difference was not significant. The superiority (P < .01) of ration two in gain above ration three did not fit the remainder of the data and would cause one to believe weighing error as the cause of poor gain shown for ration three. These data can only serve as guidelines for the gains that treated straw would support under feed lot conditions since a digestion crate was far from a normal environment.

Sodium and Potassium Balances

The results from sodium and potassium balance trials were inconsistent and variable. Interpretation was difficult to make, and no definite conclusions could be drawn about the effect of NaOH-treated straw consumption on body sodium and potassium status. Evidently, sodium residue levels on the treated straw were not high enough to cause any particular upset in sodium-potassium equilibrium. The absence of any observable detrimental effects and the positive potassium balances tended to confirm this.

Heifer Feeding Trials

The results of trial one are shown in Table 26. The alfalfa-urea-mustard containing ration promoted the highest gains and feed efficiency, but there were no significant differences among rations. The urea-barley ration ranked second on the basis of gain and feed efficiency and was followed by the cottonseed meal ration. The difference in gain and feed efficiency was linked to variations in intake.

Table 26. Animal performance. Feeding Trial 1 (Leached Ryegrass Hay).[a]

Rations	1	2	3
Initial wt., kg	239.1	232.3	246.8
Final wt., kg	324.5	305.9	330.9
Total gain, kg	85.4	73.6	84.1
Daily gain, kg	0.80	0.69	0.79
Daily feed intake, kg	6.8	5.7	6.6
Feed/gain, kg	7.7	9.2	8.7

[a] See Table 3 for ingredients and chemical composition of the ration.

For trial 2 there was a lack of statistical significance for average daily gain among treatments (Table 27). A discrepancy between calculated NFE composition used in formulating the rations and actual NFE content of the rations based on chemical analysis probably accounted for the lack of significance. NFE levels among rations were not wide enough to cause marked gain differences as a result of soluble carbohydrate-urea interactions. The highest and most efficient gain was recorded for the ration containing 1.3% urea and 7.5% wheat, and the 1.3% urea and 10% wheat ration followed closely. This superiority was related to greater amount of feed consumption for these two rations. The markedly inferior ration of the trial was for the ration containing 1.8% urea and 5.0% wheat. Although feed intake was the lowest of any rations, the relatively poor gain and feed efficiency indicated that 5.0% wheat did not supply enough readily available carbohydrate for the rumen microbes to efficiently utilize the nitrogen from urea. Thus, there was not enough nitrogen being presented to the host animal to support higher gains. 1.8% urea was a higher level of non-protein nitrogen than is usually recommended, especially for high roughage rations. However, no detrimental side effects were noted.

Generally lower and less efficient gains were noted for rations of Trial 2 when compared to the performance supported by the rations of Trial 1. This implied that wheat and/or urea at these levels of supplementation were not as effective as the supplements employed for Trial 1. Data for Trial 3 was highly variable for animals within treatment, so that no statistically significant differences in gain were detected among rations (Table 28). Ration six, that contained whey and a variety of other ingredients to supply needed protein, promoted the most superior gains which were related, in part, to greater feed intake. Rations (one and five) containing molasses produced slower gains than when whey replaced it (Rations two and six) as the only variable ration ingredient. It should also be pointed out that the lowest gain and the

Table 27. Animal performance. Feeding Trial 2.[a]

Rations	1	2	3	4	5	6
No. Heifers	5	5	5	5	5	5
Initial Wt., kg	236.4	237.7	237.3	230.5	230.5	231.8
Final Wt., kg	287.3	310.9	299.1	272.3	277.7	289.5
Total Gain, kg	50.9	73.2	61.8	41.8	47.2	57.7
Daily Gain, kg	0.46	0.66	0.56	0.38	0.54	0.52
Daily Feed Intake, kg	6.7	7.1	6.9	6.2	6.2	6.7
Feed/Gain, kg	12.8	10.8	12.3	16.3	11.4	12.8

[a] See Table 4 for ingredients and chemical composition of rations.

Table 28. Animal performance. Feeding Trial 3.[a]

Rations	1	2	3	4	5	6
No. Heifers	5	5	5	5	5	5
Initial Wt., kg	237.3	234.1	230.9	228.2	225.0	232.7
Final Wt., kg	296.8	301.8	296.8	287.3	285.5	306.8
Total gain, kg	59.5	67.7	65.9	59.1	60.5	74.1
Daily gain, kg	0.60	0.69	0.67	0.61	0.62	0.76
Daily Feed Intake, kg	7.6	7.4	6.9	7.4	7.3	8.1
Feed/Gain, kg	12.5	10.8	10.3	12.3	11.9	10.8

[a] See Table 5 for ingredients and chemical composition of rations.

highest feed requirement per kg of gain occurred for the ration (one) containing 1.8% urea. Therefore, the differences in performance seemed to be attributable to the urea level employed. The alfalfa-ryegrass straw pellets gave inconsistent gains and feed efficiency, which was related in part to differences in feed intake (Rations three and four).

Results from these feeding trials were not conclusive, and further experimentation is needed. But these trials did illustrate that ryegrass straw was economically supplemented with deficient nutrients so that feeding value was improved to a level that promoted gains of from 0.38 kg to 0.80 kg per day. Traditionally, gains from straw rations supplemented with plant protein sources, such as soybean oil meal, have been superior to those where a non-protein nitrogen source was used (Saxena _et al._, 1971; Hasimoglu, Klopfenstein and Doane, 1969; and Klopfenstein _et al._, 1970). Our data did not necessarily refute this, but they did demonstrate that urea was more successfully included in high roughage rations as a cheap nitrogen source than was previously thought. Respectable gains for growing cattle can be obtained, but the level of urea used is critical.

Even with a successful method for increasing the availability of straw cellulose, supplementation will be required. Intake is largely controlled by rumen turnover rate, which in turn is dependent upon the rate of fermentation. The latter is a function of the numbers and kinds of rumen microbes. Like all other living organisms, bacteria and protozoa have nutrient requirements. Consequently the provision of an optimum environment to promote microbial proliferation becomes the first step towards improving the feeding value of straw. Enriching the straw with protein, minerals and soluble carbohydrates supples the microorganisms with required nutrients so that numbers expand rapidly. Subsequently, rumen fermentation rates, rumen turnover times and intake will increase. With an increase in rumen fermentation rates and feed consumption, there will be a greater quantity of microbial by-products available for utilization by the host animal. Since a majority of the energy and protein used by a ruminant are from this source, this means that performance improvements should be a direct result over and above native straw. With the importance of supplementation noted, it should be apparent that wide-spread usage of by-product, low quality roughages such as straw, depends to a great extent on the economy and practicability of alternative supplementation programs. Additional growth and metabolism trials need to be conducted to learn about the comparative advantages and disadvantages of a variety of potential feed ingredients.

Since all straws are bulky, some physical alteration will be required to ensure consumption at levels that will support both maintenance and growth. Pelleting provides a denser, less bulky feed in which there is less wastage and sorting. It also provides a convenient medium by which the supplemental nutrients can be included in the ration. However, it does add to the cost of the end product.

Feeding Trial Digestion Studies

To add to the completeness of the performance data collected from ryegrass straw supplemented feeding trials, digestion trials were conducted on three of the rations from Trial 3. Rations four, five and six of the digestion trials corresponded to rations one, two and three of feeding Trial 3. Cattle served as the experimental animals for the feeding trials while sheep were used in the digestion trials. The direct exchange of sheep and cattle data has been debatable among researchers. It was the opinion of the author that some information on digestibility, nitrogen retention and energy utilization of untreated, supplemented ryegrass straw rations, even though it was with a different species, was better than none.

Daily DM intake and apparent digestibility are shown in Table 29. The former was not significantly different among rations even though lambs consumed slightly more of ration six. The significantly ($P < .05$) lower digestibility of the CP of ration six was most likely due to less complete digestion of the plant protein supplied by alfalfa. The hemicellulose fraction of the cell wall was significantly ($P < .05$) more digestible in ration six than it was in the other two rations. Possibly this reflected hemicellulose being more available from alfalfa, whose cell wall was less lignified than that for a mature forage, such as ryegrass straw. It should be pointed out that apparent digestibilities

Table 29. Voluntary dry matter intake and apparent digestibility for ryegrass straw based rations fed to sheep.

Ration[a]	4	5	6
Daily Dry Matter Intake, g/kg Body Weight	36.2	36.6	37.2
Apparent Digestibility, %			
Straw	36.4	38.7	36.9
Dry matter	47.5	50.4	49.1
Organic Matter	47.2	51.7	49.6
Energy	46.2	45.8	46.5
Crude Protein	67.1^b	67.3^b	61.5^c
Ash	24.1	32.0	35.6
Acid Detergent Fiber	33.7	35.3	35.9
Hemicullulose	51.2^b	50.7^b	57.9^c
Cellulose	41.1	42.3	44.8
Cell Wall Constituents	39.9	41.0	43.2
Cell Contents	61.0	63.9	58.9

[a] See Tables 6 and 7 for ingredients and chemical composition of rations.

[b, c] Means in the same line bearing different superscripts are significantly ($P < .05$) different.

of straw, DM and OM were slightly higher, though not significant, for ration five than for the other two. Perhaps the lactose of whey was exerting a stimulatory effect. The higher ash content of alfalfa was evidently favorably influencing rumen microbes as ADF, CWC and cellulose digestibility was slightly higher for ration six than in rations four and five. Other investigators (Burroughs et al., 1950; Swift et al., 1951; and Chappel et al., 1955) have demonstrated an increase in the digestibility of low quality roughages after alfalfa ash was added. There was essentially no difference in energy utilization. The cell contents of ration six were less available than this fraction for the other rations. However, the variability within treatments was too large for both cell contents and ash, for any statistical significance to develop.

The nitrogen intake was slightly lower for ration six primarily because of the smaller amount of CP that got mixed into the ration (Table 30). Urea containing rations (four and five) predisposed sheep to excrete slightly more nitrogen via the urine than for the alfalfa containing ration (six). The latter had the largest proportion of nitrogen voided through the feces. Daily nitrogen retention was slightly in favor of the whey containing ration five, which corresponded with its higher DM, OM and CP digestibilities. If nitrogen retention was expressed either as a percent of intake or a percent of digested, ration five was still superior. However, ration five had the lowest

Table 30. Nitrogen balance, energy utilization, and animal performance for ryegrass straw based rations fed to sheep.

Ration[a]	4	5	6
Daily Nitrogen Balance, g			
Nitrogen Intake	33.1	33.2	31.5
Nitrogen in Feces	11.3	10.8	12.0
Nitrogen in Urine	15.8	15.2	13.2
Nitrogen Retained	6.1	7.1	6.2
Percent of Intake	18.5	21.5	19.7
Percent of Digested	28.0	32.6	31.8
Partition of Energy, Kcal/day			
Energy Intake	6924.2	6637.6	6911.8
Fecal Energy	3730.4	3601.5	3693.3
Digestible Energy	3193.8	3036.1	3218.5
Digestible Energy, Kcal/g DM Intake	1.901	1.824	1.914
Animal Performance			
Average Daily Gain, g/day	115.0	128.6	163.4

[a] See Tables 6 and 7 for ingredients and chemical composition of rations.

amount of digestible energy per g of DM intake. This was a result of a smaller energy intake and a lower level of digestibility than for the other two rations. Rations four and six were not too different in energy utilization as was shown by their digestion coefficients. Animal performance data was too highly variable to be significant among rations or to draw conclusions from.

These digestion trials furnish information that was not previously available. The data were not different enough to draw conclusions and recommendations from. More research is needed.

SUMMARY

There were several objectives for this investigation. The relative effects of soaking annual ryegrass straw in solutions of NaOH, KOH, NH_4OH and $NaCHO_2$ of varying concentrations on in vitro DDM were studied. In addition, the effects of feeding unwashed NaOH-soaked straw on animal health, feed intake, water consumption, urine excretion and pH, apparent digestibility, nitrogen and energy utilization and sodium and potassium balances were examined. Finally, performance, digestion and metabolism data were collected on untreated straw.

Spraying a two percent NaOH solution on straw did not significantly improve DDM while soaking at the same level produced a significant ($P < .01$) increase. There was no significant difference among particle sizes or treatment times for straw soaked in two percent NaOH. Two, four, six or eight percent levels of either NaOH or KOH solutions significantly ($P < .01$) enhanced DDM. No significant improvement was noted above the eight percent level. $NaCHO_2$ significantly ($P < .01$) increased DDM above native straw, but higher treatment levels were necessary to achieve an equal magnitude of improvement than for NaOH. NH_4OH treatment produced variable results which could not be consistently repeated, but the CP content of treated straw was consistently increased. This was in contrast to

NaOH soaking, which significantly ($P < .01$) degraded CP, ADF and ADL with each increase in level. All treatment combinations also produced significant ($P < .01$) CWC declines below native straw. Straw treated on a solution basis was significantly ($P < .01$) higher in DDM than that treated on a dry matter basis. However, treated straw DDM was significantly ($P < .01$) greater in either case than that recorded for untreated straw. Draining off of the NaOH effluent prior to drying significantly ($P < .01$) reduced DDM. There was a trend for water soaking to depress DDM, but significance was not reached until samples were drained prior to drying.

No detrimental effects were noted when lambs consumed unwashed NaOH-soaked straw. Daily DM intake per kg of body weight was significantly ($P < .05$) reduced for treated straw when compared to untreated. Increased water consumption and urinary excretion ($P < .01$) were evident when straw soaked in a one percent NaOH solution (ration three) was fed. Urine pH for sheep consuming straw treated on an eight percent dry matter basis (ration two) was significantly ($P < .05$) reduced below that recorded for urine from sheep fed the other two rations. However, none of the pH's were outside the normal range for ruminants. Treatment two significantly ($P < .05$) reduced apparent digestibilities for straw, DM, OM, energy, CP, ash and cell contents below that for the other two treatments. Treatment three significantly ($P < .05$) increased straw, ash, ADF, hemicellulose and CWC apparent digestibilities when compared to untreated straw (ration one). The digestibility of CP was significantly ($P < .01$) greater in the untreated straw ration.

All sheep were in a positive nitrogen balance for the duration of the trials. There was no significant difference in nitrogen balance for lambs fed rations one and three. However, nitrogen retention for lambs receiving ration two was significantly ($P < .05$) depressed below the quantity retained by lambs on the other two rations. Ration three was clearly superior in terms of either percent nitrogen intake or percent of digested nitrogen. Untreated straw supported a statistically ($P < .05$) higher level of digestible energy per g DM intake than did either of the treated straw rations. Utilization of the gross energy of ration two was significantly ($P < .05$) less than that from the other two rations. Ration three supported lower average daily gains than the other two rations ($P < .01$).

No definite conclusions can be drawn from the sodium and potassium balances. Evidently, sodium residue levels were not large enough to cause any problems as there were no observable side effects and potassium excretion was not increased.

A series of feeding trials demonstrated that ryegrass straw successfully comprised from 45 to 86% of a ration for growing heifers. Feeding value of the straw was improved to support gains from 0.38 kg to 0.80 kg per day by the use of a variety of feed ingredients that corrected the straw's deficiencies. Performance data suggested that the maximum level of urea that can be used in such high roughage rations was about 1.5%. Above this level gains and feed efficiency were depressed.

Digestion trial data showed that DDM for untreated, supplemented straw was from 47.5 to 50.4%. From 61.5 to 67.5% of the CP and 39.9 to 43.2% of the CWC was digestible. The CP was least digestible in the ration containing alfalfa. Nitrogen retention ranged from 6.1 to 7.1 g per day. The superior ration in this respect was ration five, which contained whey.

BIBLIOGRAPHY

Ammerman, C.B., J.L. Evans, D.C. Tomlin, L.R. Arrington and G.K. Davis. 1959. Gamma irradiation and subsequent digestion in the rumen of cellulose and various roughages. J. Anim. Sci. 18:1518. (Abstr.).

Anderson, Daniel Craig. 1969. Biochemical evaluation of silage corn varieties. M.S. Thesis, Oregon State Univ., Corvallis.

Anthony, W.B. and J.P Cunningham. 1968. Hardwood sawdust in all concentrate rations for beef cattle. J. Anim. Sci. 27:1159. (Abstr.).

A.O.A.C. 1960. Official methods of analysis. (9th ed.). Washington, D.C.

Axelsson, J. and A. Kivimae. In: Silage Fermentation, ed. by A. J. G. Barnett, New York, Academic Press, 1954. p. 23.

Bartling, R.R., T.J. Klopfenstein and Walter Woods. 1968. Animal response to high temperature, pressure treated forages. J. Anim. Sci. 27:1766. (Abstr.).

Beckman, E. 1921. Conversion of grain straw and lupins into feeds of high nutrient value. Festschrift Kaiser Wilhelm Ges. Forderung Wiss. Zehnzahrigen Jubilaum, pp. 18-26. Chem. Abstr. 16:765 (1922).

Bowden, David Merle and D.C. Church. 1962. Artificial rumen investigations. II. Correlations between in vitro and in vivo measures of digestibility and chemical components of forages. J. Dairy Sci. 45:972.

Burroughs, Wise, John Long, Paul Gerlaugh and R.M. Bethke. 1950. Cellulose digestion by rumen microorganisms as influenced by cereal grains and protein rich feeds commonly fed to cattle using an artificial rumen. J. Anim. Sci. 9:523.

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

Chappel, Charles F., Robert J. Sirny, C.K. Whitehair and Robert MacVicar. 1955. Effect of mineral supplements on digestibility of a corn cob ration by sheep. J. Anim. Sci. 14:153.

Church, D.C. 1969. Digestive physiology and nutrition of ruminants. Vol. 1. O.S.U. Bookstores, Inc., Corvallis.

Cody, R.E., Jr., J.L. Morrill and C.M. Hibbs. 1968. Evaluation of health and performance of bovines fed wood fiber as a roughage source or intake regulator. J. Dairy Sci. 51:952. (Abstr.).

Dinius, D.A., A.D. Peterson, T.A. Long and B.R. Baumgardt. 1970. Intake and digestibility by sheep of rations containing various roughage substitutes. J. Anim. Sci. 30:309.

Donefer, E. 1968. Effect of sodium hydroxide treatment on the digestibility and voluntary intake of straw. Proc. 2nd World Conf. on Anim. Prod. p. 446.

El-Sabban, F.F., T.A. Long and B.R. Baumgardt. 1971. Utilization of oak sawdust as a roughabe substitute in beef cattle finishing rations. J. Anim. Sci. 32:749.

Feist, W.C., A.J. Baker and H. Tarkow. 1970. Alkali requirements for improving digestibility of hardwoods by rumen microorganisms. J. Anim. Sci. 30:832.

Ferguson, William Swan. 1942. The digestibility of wheat straw and wheat straw pulp. Biochem. J. 36:786.

Ferguson, William Swan. 1943. The digestibility of straw pulp. J. Agric. Sci. 33:174.

Godden, William. 1920. The digestibility of straw after treatment with soda. J. Agric. Sci. 10:437.

Godden, W. 1942. Predigestion of straw. Scottish J. Agric. 23:373.

Goering, H.K. 1968. Roughage treatment. Anim. Nutr. Health 23:21.

Goering, H.K., L.W. Smith, P.J. Van Soest and C.H. Gordon. 1969. In vivo digestibility of barley straw ensiled with sodium chlorite. J. Dairy Sci. 52:935. (Abstr.).

Goering, H.K. and P.J. Van Soest. 1968. In vitro digestibility of lignified materials ensiled with sodium chlorite. J. Dairy Sci. 51:974. (Abstr.).

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analysis. Agric. Handbook 379. A.R.S., U.S.D.A., Beltsville.

Guggolz, Jack, G.M. McDonald, H.G. Walker, Jr., A.H. Brown, W.N. Garret and G.O. Kohler. 1971. Chemical treatment of agricultural wastes to improve digestibilities as livestock feed. Proc. West. Sec. Amer. Soc. Anim. Sci. 22:71.

Guggolz, Jack, R.M. Saunders, G.O. Kohler and T.J. Klopfenstein. 1971. Enzymatic evaluation of processes for improving agricultural wastes for ruminant feeds. J. Anim. Sci. 33:167.

Guggolz, J., G.O. Kohler and T.J. Klopfenstein. 1971. Composition and improvement of grass straw for ruminant nutrition. J. Anim. Sci. 33:151.

Hasimoglu, Sumer, T.J. Klopfenstein and T.H. Doane, 1969. Nitrogen source with sodium hydroxide treated wheat straw. J. Anim. Sci. 29:160. (Abstr.).

Hogan, J.P. and R.H. Weston. 1971. The utilization of alkali-treated straw by sheep. Aust. J. Agric. Res. 22:951.

Huffman, J.G., W.D. Kitts and C.R. Krishnamurti. 1971. Effects of alkali treatment and gamma irradiation on the chemical composition and in vitro rumen digestibility of certain species of wood. Can. J. Anim. Sci. 51:457.

Javed, A.H. and E. Donefer. 1970. Alkali-treated straw rations for fattening lambs. J. Anim. Sci. 31:245. (Abstr.).

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

Kehar, N.D. 1954. Effect of feeding alkali treated cereal straws on the growth of young cattle. Indian J. Vet. Sci. and Anim. Husb. 24:189.

Kinsman, D.M., D.A. Grant, A.R. Cobb and L.A. Peterson. 1969. Growth and carcass performance of sawdust-fed lambs. J. Anim. Sci. 28:875. (Abstr.).

Klopfenstein, Terry, Walter Koers, Sumer Hasimoglu and Walter Woods. 1970. Increasing crop residue use. Beef Cattle Report EC 70-218. Dept. Anim. Sci., Univ. Nebraska, Lincoln.

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

Klopfenstein, T. J., R. R. Bartling and W. R. Woods. 1967. Treatments for increasing roughage digestion. J. Anim. Sci. 26:1492. (Abstr.).

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

Koers, Walter, Walter Woods and T. J. Klopfenstein. 1970. Sodium hydroxide treatment of corn stover and cobs. J. Anim. Sci. 31:1030. (Abstr.).

Krause, Vernon, T. J. Klopfenstein and Walter Woods. 1968. Sodium hydroxide treatment of corn silage. J. Anim. Sci. 27:1167. (Abstr.).

Lampila, Martli. 1963. Experiments with alkali straw and urea. Ann. Agr. Fennia. 2:105.

McAnally, R. A. 1942. Digestion of straw by the ruminant. Biochem. J. 36:392.

McDougall, E. I. 1948. Studies on ruminant saliva. I. The composition and output of sheep's saliva. Biochem. J. 43:99.

Mellenberger, R. W., L. D. Satter, M. A. Millet and A. J. Baker. 1971. Digestion of aspen, alkali-treated aspen and aspen bark by goats. J. Anim. Sci. 32:756.

Millett, M. A., A. J. Baker, W. C. Feist, R. W. Mellenberger and L. D. Satter. 1970. Modifying wood to increase its _in vitro_ digestibility. J. Anim. Sci. 31:781.

Morrison, Frank B. 1959. Feeds and Feeding. 22nd Ed. The Morrison Publishing Co., Clinton.

Ololade, B.G. and D.N. Mowat. 1969. *In vitro* digestibility of sodium hydroxide treated straw. J. Anim. Sci. 29:167. (Abstr.).

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.

Pigden, W.J., G.I. Pritchard and D.P. Heaney. 1966. Physical and chemical methods for increasing the available energy content of forages. Proc. 10th Int. Grassl. Congr. p. 397.

Pigden, W.J. Research Coordinator (Animal Nutrition), Canada Dept. of Agric., Central Experimental Farm. Personal Communication. Ottawa, Ontario, Canada. October 24, 1969.

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

Ralston, A.T., D.C. Church and J.E. Oldfield. 1962. Effect of enzymes on digestibility of low quality roughage. J. Anim. Sci. 21:306.

Roubicek, C.B. Water metabolism. In: Animal Growth and Nutrition, ed. by E.S.E. Hafez and I.A. Dyer. Philadelphia, Lea and Febiger, 1969. p. 357-373.

Saeman, Jerome F. and Merrill A. Millett. 1952. Effect of high-energy cathode rays on cellulose. Ind. and Engr. Chem. 44:2848.

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

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

Smith, L.W., H.K. Goering and C.H. Gordon. 1970. *In vitro* digestibility of chemically treated feces. J. Anim. Sci. 31:1205.

Steel, Robert G. D. and James H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York.

Stone, E. J., H. F. Morris, Jr. and J. B. Frye, Jr. 1965. Chemical pretreatment of roughages. II. Effect of various combinations of alkali and acid on cellulose content and digestibility of bagasse. J. Dairy Sci. 48:815. (Abstr.).

Stone, E. J., R. E. Girouard, Jr. and J. B. Frye, Jr. 1965. Chemical pretreatment of roughages. I. The effect of alkali and enzymes on cellulose content of bagasse. J. Dairy Sci. 48:814. (Abstr.).

Sullivan, J. T. and T. V. Hershberger. 1959. Effect of chlorine dioxide on lignin content and cellulose digestibility of forages. Science 130: 1352.

Swift, R. W., R. L. Cowan, G. P. Barron, K. H. Maddy and E. C. Grose. 1951. The effect of alfalfa ash upon roughage digestion in sheep. J. Anim. Sci. 10:434.

Van Soest, P. J. and L. H. P. Jones. 1968. Effect of silica in forages upon digestibility. J. Dairy Sci. 51: 1644.

Williamson, Grahame. 1941. The effect of Beckman's treatment by sodium hydroxide on the digestibility and feeding value of barley straw for horses. J. Agric. Sci. 31:488.

Wilson, R. K. and J. O. O'Shea. 1964. In vitro production of volatile fatty acids and dry matter digestibility of wheat straw as affected by alkali treatment. Irish J. Agric. Res. 3:245.

Wilson, R. K. and W. J. Pigden. 1964. Effect of sodium hydroxide treatment on the utilization of wheat straw and poplar wood by rumen microorganisms. Can. J. Anim. Sci. 44: 122.

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