THESIS

THE NUTRITIVE VALUE OF ALKALI AND MANURE TREATED CORN STOVER SILAGE

Submitted by
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION

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ABSTRACT OF THESIS

THE NUTRITIVE VALUE OF ALKALI AND MANURE TREATED CORN STOVER SILAGE

Chopped corn stover was reconstituted, treated and ensiled in 3 ply-nylon bags placed in 10 gallon plastic drums at room temperature for 30 days. The treatments were: (1) control-corn stover + water, (2) 4% NaOH, (3) 4% NH_4OH, (4) 3% NaOH + 1% NH_4OH, (5) 2% NaOH + 2% NH_4OH, (6) 35% manure + 65% corn stover on wet basis, (7) 35% manure + 4% NaOH by weight on DM basis. After 30 days the bags were opened and examined for smell and color. Sub-samples were collected for chemical analysis.

While there was a significant ($p < 0.05$) increase of crude protein and ash there was significant ($p < 0.05$) decrease of neutral detergent fiber and acid detergent fiber. There was significant ($p < 0.05$) decrease of hemicellulose and cellulose with alkali treatment, but the differences between alkali containing samples were not significant ($p > 0.05$). There was no significant ($p > 0.05$) changes in lignin content between the treatments. The *in vitro* dry matter digestibility (IVDMD) was significantly ($p < 0.05$) improved by alkali treatments and decreased by manure inclusion. Both alkali and manure treatment significantly ($p < 0.05$) improved IVDMD than manure alone. Different levels of NaOH and NH_4OH in combination did not have better results than any of the alkali separately.

The physical fermentation characteristics indicated that fermentation had taken place. The alkali treated silages had sweet "estery" smell and yellow color. The manure containing silage had butyric acid smell and dark brown color. Chemical fermentation parameters measured were pH, lactic acid and volatile fatty acids. There was a significant ($p < 0.05$) decrease of pH of alkali and waste containing silages after ensiling. There was no significant ($p > 0.05$) change of pH of post-ensiled untreated silage when compared to the pre-ensiled untreated silage. Lactic acid and propionic acid showed a significant ($p < 0.05$) decrease between the untreated and treated samples, while acetic acid and butyric acid showed significant ($p < 0.05$) increase between the untreated and treated samples.

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DEDICATION

To my mother who instilled in me a curiosity for what I don't know and an appreciation for higher education.

During her untimely death I was in the U.S.A. pursuing further education. She was a great "mama." May her soul always rest in peace.

IN APPRECIATION

To the Great Lord God Most Gracious, Most Merciful,
who gave me the health and mind to pursue such things,
to Him who makes all things possible.

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CHAPTER I

INTRODUCTION

The peculiar digestive structure and symbiotic microbes provide ruminants with the ability to convert otherwise waste agricultural by-products and cattle waste into high quality food for people. This ability is centered on rumen microbes which depend on the host animal for their growth promoting nutrients and which in turn become digested in the small intestines of the host animal to meet part of its nutrient requirement.

Energy and protein sources are the nutrients commonly limiting in the livestock feed in most parts of the world. They are also the most expensive portion of the animal's diet. This can be attributed in part, to the rising cost of energy feeds. As the demand for grain increases for both human consumption and other uses, e.g., the manufacture of gasohol, the cost of supplying energy for the animal is becoming very expensive. The Developing Nations of the Third World cannot afford to feed grain to their livestock because of the high demand for grains as part of their every day diet. It is, therefore, necessary that agricultural by-products, for example, straw, hulls, corn cobs and corn stover be physically and/or chemically processed to maximize their nutritive quality and value for livestock feed.

Cattle waste has been successfully fed to ruminants. An extensive review of the utilization of cattle waste as a feedstuff for cattle was published by Bhattacharya and Taylor (1975). There are problems encountered when feeding animal waste to ruminants. One problem is the generally poor digestibility values of these materials. This is not surprising considering that the waste consists of material already exposed to the digestive processes. Treatment of cattle waste with sodium hydroxide has been known to increase its digestibility *in vitro* (Smith *et al.,* 1970) and *in vivo* (Smith *et al.,* 1971).

Potential health hazards from feeding animal wastes have been reviewed by Fontenot and Webb (1975) and by McCasky and Anthony (1979). One of the major concerns is the transmission of potentially pathogenic bacteria from infected animals to healthy ones by feeding waste. Numerous studies have been conducted which indicate that ensiling waste with various feedstuffs, such as corn or roughages, can reduce or even eliminate potential pathogens. Ensiling has also the added benefit of enhancing palatability.

While there is ample data on the alkali treatment of low quality roughage and cattle waste, separately, there is little work incorporating both of them with alkali treatment and ensiling for some time.

The general objective of this research was, therefore, to investigate the affects of adding alkali, manure, both alkali and manure on the nutritive value of reconstituted corn stover silage. Specifically the objectives were:

1. To determine the effect of alkali on the nutritive value of corn stover silage.
2. To compare the effects of sodium hydroxide and ammonium hydroxide separately and in combination at varying levels.
3. To investigate the effect of adding manure on the nutritive value of corn stover silage.

4. To determine the effect of both alkali and manure on the nutritive value of corn stover silage.

CHAPTER II

LITERATURE REVIEW

Alkali Treatment of Low Quality Forage

Alkali treatment of low quality forage has been one of the more popular chemical agents for delignification and has been applied to a variety of materials using different methods. These materials include rice hulls (Archibald, 1924), straw (Ololade *et al.*, 1970; Singh and Jackson, 1971; Coombe *et al.*, 1979; Solaiman *et al.*, 1979; Anderson and Ralston, 1973) corn cobs (Whitney *et al.*, 1976; Kategile and Frederiksen, 1979), wood (Klopfenstein *et al.*, 1972; Mellenberger *et al.*, 1971; Wilson and Pigden, 1964), corn stover (Urio, 1977; Oji, 1977), feces (Smith *et al.*, 1970) and tropical grass (Gihad, 1979; Meissner *et al.*, 1973; Urio, 1977; Mwakatundu, 1974). Depending on the procedure used, digestibility was increased to a greater or lesser extent. Alkalinity shows a positive relationship with improved availability of carbohydrate. The increase results through improvement in the availability of insoluble residual cell wall as well as the formation of soluble matter (Van Soest *et al.*, 1974).

Chemical Composition of Roughage

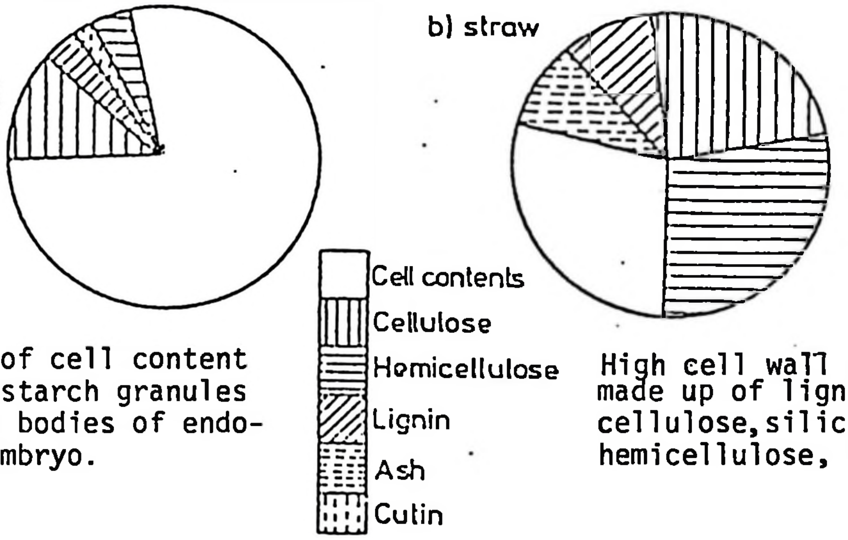
Chemical composition of roughage varies with species, maturity, location and cultural practices employed in growing the cereal crops from which these residues are obtained, but these variations have not been studied extensively (Khorat, 1974; Saleem and Jackson, 1975). Most fibrous materials such as corn stover or straw are generally characterized by a high level of cell wall contents (Jackson, 1977).

More than half of the dry matter of corn stover consists of hemicellulose, cellulose, lignin and ash. The rest is comprised of nitrogenous compounds, lipids, sugars, starch and pectin as components of the cell contents.

Figure 1 illustrates a comparison between a typical composition of barley straw with that of barley grain. The grain is characterized by high level of cell contents made up of starch granules and protein bodies of the endosperm and embryo. These contents are virtually completely digestible and most of it is available to meet nutritional requirements of the ruminant. The cell content of the straw occupies a very small portion made up of dehydrated cytoplasmic material. The energy that an animal can derive from this portion is very limited, and can hardly meet maintenance requirement of an animal.

Crude Protein

Crude protein is extremely important in forages. A well managed pasture often will provide an animal's protein needs. However, as the pasture becomes more mature the protein content declines. There is a negative correlation between protein content of a plant and its crude fiber over the period of growth. With rank pastures the protein content is very low. It will not meet the animal's protein requirement. It is, therefore, necessary to add a protein supplement to the ration of the animal to meet its needs. Since protein and energy are the most expensive nutrients of the animal's diet, the expenses of protein supplements can be reduced if non-protein nitrogen, e.g., urea is carefully added to the ration.



High level of cell content made up of starch granules and protein bodies of endosperm and embryo.

High cell wall contents made up of lignin, cellulose, silica, hemicellulose, etc.

Figure 1. Diagramatic representation of the relative compositions of barley grain and straw (Jackson, 1977).

Cell Contents

The cell contents of all feeds consist of lipids, proteins, amino acids (up to 90% of crude protein), sugars, starches, other digestible carbohydrates and water soluble matter (Van Soest, 1965), as shown in Table 1. A neutral detergent procedure has been developed (Van Soest *et al.*, 1967) that separates the dry matter of feeds very near the point where the nutritionally available, soluble constituents of cell contents can be differentiated from those constituents only partially available for animal nutrition. The neutral detergent procedure is essentially the same as the enzyme digestion procedure (Van Soest *et al.*, 1967). Van Soest (1971) has observed that regardless of whether forage is lush or rank, the cell contents consistently approach 98% digestible.

Cell Wall Contents

The cell wall contents consists mainly of fiber that is insoluble in neutral detergent. Fiber has been defined (Van Soest, 1967) as insoluble vegetable matter which is indigestible by proteolytic and diastatic enzymes and cannot be utilized by the host animal until after microbial fermentation in the digestive tract. The major portions of cell wall that are of main concern with alkali treatment are hemicellulose, cellulose, lignin and lignin bound nitrogen. This lignocellulose complex (lignin, cellulose, hemicellulose) accounts for most of the gross energy in mature forages. The usefulness of lignocellulose as a source of energy for ruminants depends on the extent and rate at which it can be degraded by rumen microorganisms.

Hemicellulose.

Hemicelluloses are defined empirically as the fraction of plant polysaccharides that cannot be extracted by water or

Table 1. Classification of fractions and components of forage.

Fraction	Components	Ruminant Nutritional Availability
	Category A	
Cell contents (soluble in neutral detergent)	Lipids Sugars, organic acids, and water-soluble matter Starch Nonprotein nitrogen Soluble protein Pectin	Virtually complete
	Category B	
Cell-wall constituents (fiber insoluble in neutral detergent)	Attached protein	Complete
Soluble in acid detergent	Hemicellulose	Partial
Insoluble in acid detergent (acid-detergent fiber)	Lignin	Indigestible
	Lignified nitrogen compounds	Indigestible
	Heat-damaged protein	Indigestible
	Keratin	Indigestible
	Silica	Indigestible

ammonium oxalate solutions but are solubilized by aqueous alkali (Clarke *et al.*, 1967). Hemicelluloses constitute a heterogeneous mixture of homo- and hetero-glycans in the cell wall of plants. They are often classified as neutral (hemicellulose A) and acidic (hemicellulose B) hemicellulose. Both hemicelluloses have been shown to have a linear B-D-(1→4)-linked xylan as the basic structure, but may contain varying amounts of other sugars such as arabinose, galactose, and uronic acids. True xylans are relatively rare in nature.

The host animal is dependent on gut microorganisms for digestion of hemicelluloses. However only strains of cellulolytic and non-cellulolytic rumen bacteria capable of growth on xylan can degrade and utilize hemicelluloses for growth (Dehority, 1968). The ability of one strain of bacteria to utilize the hemicelluloses as an energy source and the inability of a second strain, apparently similar with regard to enzymatic activity for degrading the hemicelluloses, to utilize them would thus appear to be either a function of cell wall permeability to the oligosaccharides which are produced or a lack of the intracellular enzymes required for further metabolism of these intermediate products (Dehority, 1965). Although the exact nature of the enzyme or enzymes involved in hemicellulose degradation is not known, very limited data suggests a possible similarity to the cellulose enzymes, perhaps a non-specific cleavage of the β-1,4-xylosidic linkage in the hemicelluloses.

<u>Cellulose</u>. Cellulose is one of the major components of plant cell walls and serves solely as a structural function in the living plant. It is an important ingredient of the diet of herbivores and is the most plentiful organic compound on earth.

Cellulose molecules consist of long unbranched chains of β-1, 4-linked glucose units. The β-1, 4-linkage results in each successive glucose lying in the reverse position to its neighbors, which causes the molecule to be linear and not a helix. The long molecules are bound together by van der Waals forces and cross-linking hydrogen bonds, and are, at intervals, arranged in a highly ordered three-dimensional lattices, forming crystalline micelles each containing some 100 cellulose chains. About 20 micelles are bound together into microfibrils that are 25-30 mm wide and, like micelles, probably ribbon-shaped. Some 250 microfibrils are grouped to form macrofibrils that can withstand great stress without rupturing (Clarke *et al.*, 1967).

Cellulolytic rumen bacteria produce an enzyme complex called cellulase that degrades cellulose molecules to soluble oligosaccharides and, in addition, hydrolyses 1,4 linkages of β-glucans that also contain 1,3-linkages (licherin). There are two steps involved in the degradation of cellulose. The first step is brought about by a protein (C_1) attacking the native (undegraded) cellulose which is then hydrolyzed in the second step, by another enzyme or enzyme complex (C_x), to soluble sugars with different chain lengths. These sugars can finally be hydrolyzed to glucose by cellobiase or more unspecific β-glucosidases. True celluloytic organisms are considered to produce both the C_1- and C_x-enzymes. Enzymic degradation of soluble cellulose derivatives, such as carboymethylcelluloses (CMC) or highly degraded forms of cellulose, can be brought about by C_x alone and is not considered "true" cellulolytic activity. The rumen microbes degrade cellulose by closely adhering to the plant cell walls and then releasing the enzymes on the areas of attachment (Akin, 1976).

It is this portion of cell wall that is regarded to contain potential digestible energy (PDE). By chemical treatment with an alkali some of this PDE can be made available to the animal. Donefer *et al.* (1969) reported that cellulose digestibility increased *in vitro* as NaOH treatment levels increased from 0 to 16 g/100g straw. Cellulose digestibility values ranged from 25 to 81% for the 0 and 16 g/100g straw treatment levels, respectively.

Lignin. Lignin is important as a strengthening material in developing and mature plant tissues. It is a highly complex polymer of phenylpropane derivation and is covalently linked to proteins and carbohydrates such as cellulose and hemicellulose; probably acting as a physical barrier to digestibility of these nutrients.

Lignin is a major endogenous factor affecting digestibility of forage fiber (Van Soest, 1971; Smith *et al.*, 1972). It decreases rate and (or) extent of fiber digestion. Digestibility of fiber or dry matter has been negatively related to the lignin content of forage (Van Soest, 1971; Smith *et al.*, 1972). Coombe *et al.* (1979) reported that alkali treatment of straw resulted in increased cellulose digestibility, although lignin content of treated and untreated straws was similar. Several other studies have also found no reduction in lignin content of straw following NaOH treatments (Ololade *et al.*, 1970; Saxena *et al.*, 1971; Huffman *et al.*, 1971). Opposite results were reported by Chandra and Jackson (1971) and also later by Anderson and Ralston (1973).

Cattle Waste

Composition. The nutrient composition of cattle wastes used in refeeding experiments is highly variable. Diets, animals, housing facilities and how the waste is handled following collection may vary among experiments.

Smith *et al.* (1971) collected and dried waste from dairy cattle fed equal portions (dry basis) of alfalfa hay, corn silage and concentrates. Analysis of the cell wall fractions showed neutral detergent fiber (NDF), cellulose, hemicellulose, lignin, ash and nitrogen contents of 64, 25, 51, 15, 16 and 2%, respectively. Waste containing sawdust bedding had higher NDF, cellulose and lignin contents. Yokayama *et al.* (1978) reported values for the composition of undried waste from a steer fed corn silage and soybean meal which were very similar to those reported above by Smith *et al.* (1971).

The composition of waste from steers fed a diet containing approximately 50% roughage was determined by Lucas *et al.* (1975). After drying, the NDF, cellulose, hemicellulose and lignin contents were 70.9, 30.3, 26.1 and 9.4% on dry basis, respectively. Analysis for crude protein, ether extract, crude fiber and ash indicated levels of 13.2, 2.8, 31.4 and 5.4% on dry basis, respectively.

Schake *et al.* (1977) collected fresh waste from finishing cattle fed high concentrate rations. The excrement containing feces, urine and hair was used to reconstitute sorghum grain. Some of the waste was passed over a vibrating screen system and the high fiber excrement was collected. The fresh waste and high fiber excrement contained 15.7 and 35.1% dry matter; 21.5, 12.8% crude protein; 7.4, 1.0% ether extract; 22.7, 36.8% crude fiber; 1.6 and 5.7% ash, respectively.

Johnson *et al.* (1975) found that the fibrous fraction separated from dairy manure using a vibrating screen technique contained 72% cell walls, 46% acid detergent fiber, 29% cellulose and 10% lignin. Crude protein of the material was 6.9% (dry basis).

Waste from heifers fed 79% ground shelled corn, 20% bermuda-grass pellets and 1% urea had dry matter, crude protein, ether extract, crude fiber, ash and nitrogen free extract (NFE) values of 20.1, 12.5, 3.5, 18.4, 6.7 and 58.9%, respectively (Newton *et al.,* 1977).

Waste from cattle housed on concrete floors and fed a cracked corn, grass-legume hay, soybean meal diet was analyzed by Lamm *et al.* (1979). The waste, which included urine, contained 23% dry matter and 17.2% crude protein, 3.2% either extract, 23.0% crude fiber, 8.6% ash and 50.0% NFE on a dry basis. These values are similar to those reported by Braman (1975) for cattle fed a cracked corn based diet. Waste from cattle fed on all-roughage diet contained 25.2% dry matter and 13.6% crude protein, 1.6% ether extract, 27.9% crude fiber, 14.6% ash and 42.3% NFE on a dry basis (Braman, 1975).

Digestibility studies. Smith *et al.* (1971) fed pelleted cattle waste to sheep as the sole dietary ingredient. Dry matter and cell wall digestibilities were found to be 16.6 and 15.4%, respectively. Crude protein digestibility was 24.4% and the digestible energy was 763 kcal/kg of dry matter.

McClure *et al.* (1975) fed diets contained either whole shelled corn or crimped corn alone or with 9.1 kg of corn silage per head per day. The waste from animals fed these four diets were collected, dried and used in diets fed to sheep. The sheep diets were 1) control-corn silage 2) 55% control + 45% waste from the whole shelled corn fed animals,

3) 55% control + 45% waste from the whole shelled corn plus silage fed animals, 4) 55% control + 45% waste from the crimped corn fed animals, 5) 55% control + 45% waste from the crimped corn plus silage fed animals and 6) 94% of a mixture of wastes from the whole shelled and crimped corn fed animals plus 5% molasses and 1% trace-mineralized salt. Dry matter digestibilities for rations 1 through 6 were 80.2, 59.8, 53.1, 60.9, 52.4 and 40.3%, respectively.

Tinnimit *et al.* (1972) utilized waste from lactating dairy cows or finishing steers as protein supplements for sheep. Waste from cows fed a corn silage and concentrate diet was dried and fed as 39 or 44% of the diets of sheep. Digestibility values for the waste-containing diets were compared to those for a control diet using soybean meal as a protein source. Dry matter, organic matter, cell wall and nitrogen digestibilities were all lower in the waste-containing diets. Nitrogen retention (g/day) was significantly lower for the waste-containing diet when feed intake was not restricted. When waste from steers was included as 31.5% of the diet dry matter apparent digestibility of organic matter, cell walls and nitrogen was reduced.

With the current high cost and projected increases in the costs of energy, drying of waste prior to feeding is becoming economically infeasible. An alternative method of waste handling is ensiling. Cattle waste ensiled with grass hay in a ratio of 57 parts waste to 43 parts hay (wet basis) was termed "wastelage" by Anthony (1966). The term "wastelage" is often used to refer to cattle waste ensiled with dry materials such as hays or crop residues.

Digestibility studies were conducted with steers to compare dried and fermented waste diets (Newton *et al.*, 1977). The control diet consisted of 79% ground shelled corn, 20% bermudagrass pellets and 1% urea. Waste from animals fed this diet was mixed with the control diet in a 40:60 ratio, wet basis. One half of the mixture was dried and the other half was ensiled. Dry matter, crude fiber, ether extract and NFE digestibilities for the control, wastelage and dried waste diets were 76.1, 42.5, 69.6, 82.1; 73.7, 41.2, 68.2, 81.7 and 72.1, 40.7, 64.9, and 80.3%, respectively. Digestibility values of the fermented waste, calculated by difference, revealed an improvement in dry matter and nitrogen digestibility compared to the dried waste.

Cattle waste and chopped grass-legume hay were mixed in a 60:40 ratio (wet basis) by Harpster *et al.* (1978) and ensiled. Metabolism trials were conducted with sheep. Diets fed were 1) control, 2) 50% wastelage + 50% high moisture corn, 3) 100% wastelage, 4) 100% corn silage, 5) 60% wastelage + 40% high moisture corn and 6) corn silage plus soybean meal. Intake, dry matter, organic matter and digestibilities were significantly lower for the 100% wastelege. Digestibility of the 50% wastelege diets was not significantly different from the corn silage diet but both had higher digestibilities than the 60% wastelage diet. Crude protein digestibilities for the wastelage diets were not different but were lower than the soybean meal supplemented corn silage. Nitrogen retention was reduced in animals fed wastelege. Digestible energy values for diets 1 through 6 were 3.55, 3.05, 2.24, 3.18, 2.84 and 3.26 Mcal/kg dry matter, respectively.

Lamm *et al.* (1979) ensiled a mixture of 60% cattle waste and 40% grass-legume hay (wet basis). Digestibility values of dry matter, organic matter, crude protein, ether extract, crude fiber and NFE were 54.6, 56.1, 63.8, 55.6, 59.0 and 51.1%, respectively, when the wastelage was fed to sheep as the sole dietary ingredient. Treatment of the wastelage with 4% NaOH (dry basis) prior to ensiling increased dry matter, organic matter, crude fiber and NFE digestibilities but decreased crude protein and ether extract digestibilities.

Diets containing 50% basal ingredients composed of grass hay, ground corn and soybean meal) and 50% wastelage on dry basis were fed in a lamb metabolism study (Cornman, 1979). The wastelages were made with waste collected from cattle fed a high concentrate diet and ground rye straw ensiled in the following ratios: 40:60, 50:50, 60:40 and 70:30 (wet basis). Calculated digestibilities of the fermented portion of the diets ranged from 32.8% for the 40:60 wastelage to 37.8% for the 70:30 wastelage. Differences were not significant.

Feeding studies. Anthony and Nix (1972) fed washed fecal residue and a mixture of corn, soybean meal and molasses in a 60:40 ratio (wet basis) to yearling steers. Steers gained 1.54 kg/day in the 54-day trial.

Anthony (1967) reported ewes were maintained for a year when fed a cattle waste-Coastal Bermudagrass hay silage. Ewes fed the silage remained in good physical condition, lambed normally and consumed less feed per day than ewes fed hay.

Anthony (1968) mixed cattle manure and either Coastal Bermudagrass hay or Johnsongrass hay in a 57:43 ratio (wet basis) and ensiled the mixtures. Two feeding trials using yearling steers were conducted. The diets fed were: 1) control - a full feed of a balanced high-concentrate diet, 2) corn silage fed *ad libitum* plus 1.82 kg ground ear corn and .455 kg protein supplement or 3) diet 2 except wastelage was substituted for corn silage. Cattle fed wastelage diets gained faster than cattle fed the corn silage diet in both trials.

Wastelage containing 57 parts manure and 43 parts Coastal Bermudagrass hay was examined by Bandel and Anthony (1969). Wastelage and whole corn were mixed in the following ratios prior to feeding: 1) 1:4, 2) 2:3, 3) 2:3 (ground corn replaced whole corn) and 4) 3:2 on wet basis. A conventional steer finishing diet was also fed. Daily gains during a 56-day trial were .94, 1.05, 1.19 and .72 kg for diets 1 through 4, respectively, and 1.09 kg for the conventional diet. Feed per unit gain were 4.91 for the conventional diet and 3.46, 3.96, 5.42 and 6.43 for diets 1 through 4, respectively.

Beef steers were fed either a concentrate control diet, autoclaved cattle waste or washed cattle waste in a 60:40 ratio with the control or a diet consisting of corn silage, ground ear corn and urea for 126 days (Anthony, 1970). Daily gains for cattle fed the control and autoclaved manure diets were 1.24 and 1.23 kg, respectively. These gains were significantly higher than those for cattle fed the washed manure or corn silage-ground ear corn diets. In a second trial untreated waste was used in place of the washed manure. Daily gains (kg) and feed dry matter per unit gain values were 1.2, 9.2; 1.0, 8.5 and .99, 8.8 for the control, untreated and autoclaved manure diets, respectively.

A 112-day feeding trial was conducted by Newton *et al.* (1977). Heifers were fed either a control diet of ground shelled corn, bermudagrass pellets and urea or a wastelage diet consisting of 40% waste (collected from the control heifers) and 60% control. Daily gains, daily dry matter intake and feed efficiency were similar among treatments.

Anthony (1971) examined the potential use of manure in finishing rations for steers. Either manure or wastelage (57% waste, 43% ground grass hay) were substituted for 40% of a corn grain basal control diet during a 102-day feeding trial. Carcass data were collected on the steers at slaughter. No significant differences were observed in daily gain, although addition of supplemental protein (cottonseed meal) resulted in a slight increase in daily gain. Feed cost per kilogram of gain was reduced in the waste and wastelage containing diets, compared to the control. Feed efficiency was 10.7 kg for the manure-containing diet and 7.37 kg for the control. Carcass data were similar for the cattle fed all diets.

Wastelage containing 60% fresh cattle waste and 40% chopped hay (wet basis) was fed to steers as 0, 40, 50 or 75% of the total diet for 183 days (Harpster *et al.*, 1978). Dry matter intake was highest for cattle fed the 40% waste diet and decreased with increasing waste levels. Intake was lowest for the 0% waste treatment. Daily gains decreased with increasing waste level, although values for the 40% waste group were not significantly different from those of the control treatment. Dry matter per unit of gain increased as the level of waste increased. Only minor differences in carcass quality were noted between steers fed the control and the 40 and 50% wastelage diets. When 75% wastelage was fed quality grade was significantly lower.

Schake *et al.* (1977) used beef cattle waste to reconstitute sorghum grain. When waste to grain ratios were either 1:3.1 or 1:1.6, intake by heifers was similar to those fed a control diet. When the waste to grain ratio was 1:1, consumption was drastically reduced. Mature pregnant cows were fed a high-fiber waste at levels of 39.0, 60.5, 74.5 or 86.5% (wet basis) of a sorghum-based diet. Dry matter intake was highest for the 39.0% waste diet and tended to decrease with increasing waste levels. Cows fed the diet containing 86.5% waste maintained their weight, while cows fed the other waste-containing diets gained between 1.08 and 1.10 kg per day.

Bollar *et al.* (1974) fed ewes pelleted alfalfa-waste diets containing 0, 50, or 75% beef feedlot manure for 30 days prior to breeding. No apparent differences in ovulation rate or pregnancy rate occurred due to feeding the waste diets. Ewes fed the waste diets for a total of 130 days exhibited lower body weight gains, compared to ewes fed the 0% waste diet. However, due to large variations, the differences were not significant.

Silage containing 27% cattle waste, 38% whole plant corn silage, 20% corn, 10% cobs and 2% cane molasses on dry basis was fed to steers at two levels (Vetter and Burroughs, 1974). Waste made up 12.2 and 16.5% of the diet dry matter at the two different levels. Daily gains were 1.04 and 1.14 kg per day for the low and high levels, compared to .62 kg per day for steers fed the basal diet composed of whole-plant corn silage.

In Vitro Dry Matter Digestibility (IVDMD)

Methods using rumen inoculum *in vitro* have been developed to study the digestibility of forages in the laboratory with a close approximation as possible to animal digestion. They offer a quick and inexpensive method of determining the amout of bacterial digestion and the nutritional quality of the forages in the laboratory (Denham, 1965; Campbell, 1973).

High correlations have been demonstrated between digestibility coefficients determined in *in vitro* and corresponding factors obtained with cattle or sheep in conventional digestibility trials (Shelton and Reid, 1960). Tilley *et al.* (1960) found closest agreement between the *in vivo* and *in vitro* dry matter digestibility with feeds of relatively low digestibility (below 60%) and of low protein contents; those feeds with higher protein contents had digestibility figures as much as 10% lower than corresponding *in vivo* figures.

Voracheck (1966) and Bowden and Church (1962) reported significant correlations between *in vitro* and *in vivo* digestibility of crude protein, and concluded that within trial variations of dry matter digestibility for all substrates was generally small. Many reservations have been posed to the effects of the source and nature of the inoculum on the IVDMD results obtained. Warner (1946) believed that it was very essential to have the steer from which the inoculum was taken to be on the same type of diet as the substrates being tested by the *in vitro* methods. However, Quicke *et al.* (1968) reported the digestibility of cellulose *in vitro* to be the same irrespective of the forage fed to the steer used for inoculum collection.

Berger (1979) reported that the *in vitro* dry matter digestibility of corn cobs treated with 4% NaOH on dry matter basis was 5-12% higher than *in vivo* dry matter digestibility. The low *in vivo* DMD findings can be attributed to the adverse effects of NaOH on rumen fermentation. The increased rate of passage and decreased rate of ruminal fiber digestion may also explain the differences observed between *in vitro* and *in vivo* values.

Mechanisms of Alkali Action

(i) Acetylation of hemicellulose residues: Some evidence has been obtained that the hemicelluloses are esterified with acetic acid and that the acetyl groups impede the digestion of hemicellulose (Morris and Bacon, 1976). The acetylated residues seem to inhibit fermentation (Morris and Bacon, 1977). Tarkow and Feist (1969) showed that there was an increase in acetate due to alkali treatment of stover. They stated that addition of alkali results in hydrolytic liberation as acetic acid of acetyl groups attached to xylan chains in the polysaccharide units of cell walls. Sodium hydroxide probably hydrolyses such ester linkages which would also contribute to the higher digestibility of alkali-treated roughage.

(ii) Cellulose: Cellulose swells when treated with alkali (Whistler and Tong, 1970). The alkali reduces the strength of intermolecular hydrogen bonds which bind cellulose molecules together, thus preventing swelling. Cellulose fibers within the cell wall matrix may be physically restrained from swelling and alkali treatment probably removes these restraints to some extent. Swollen cellulose should be more easily penetrated by rumen fluid enzymes and this would account for the greater digestibility of cellulose of treated roughages.

(iii) Lignin carbohydrate linkages: Studies have shown that lignin which is a complex polymer of phenyl propane units is covalently bound to both cellulose and hemicellulose fractions (Morrison, 1974). These linkages are understood to be alkali labile ester bonds which are hydrolysed by alkali treatment separating hemicellulose and cellulose from lignin (Morrison and Bacon, 1977). The hydrolysis of these bonds improve digestibility of roughage as a result of an increase (1) in the solubility of hemicellulose, (2) in the availability of both hemicellulose and cellulose in the cell wall for fermentation, (3) in the solubility of lignin of young plants. With mature plants the formation of cross-linkages and lignin polymer prevents fermentation by physical exclusion of enzymes (Hartley and Jones, 1976). None of the effects have been quantified, therefore much speculation exists as the true inhibitory effect of lignin.

Methods of Treatment

Methods of treatment of crop residue vary a lot depending on how much a farmer is willing to invest and expected returns (profit) that will be obtained from such operations. Small-scale treatments can be done on the individual farm. They are simple and equipment costs vary too. These costs vary from a few dollars, U.S., for a garden sprinkling can and a hay fork to several thousands for an automatic pressure sprinkler system. Different methods of treatments have different effectiveness due to uniformity and through mixing of alkali with crop alternative residue. Large scale operations are still under trial in countries like Norway, Denmark and Great Britain.

The alkali treatment methods may be classified as follows:

A. Wet Methods
    1. Beckmann (NaOH)
    2. Modified Beckmann (Torgrimsby) (NaOH)
B. Dry Methods
    1. Industrial process (NaOH)
    2. Farm scale treatment
        a) Daily treatment (NaOH, $Ca(OH)_2$, NH_3)

b) Bulk treatment
    (i) followed by stacking (NaOH)
    (ii) followed by ensiling (NaOH, $Ca(OH)_2$)
    (iii) of stacks under plastic sheet (NH_3)

Wet method. The Beckmann method of alkali treatment consists of soaking corn stover in dilute alkali solutions for 24 hours and then washing it with clean water. Although this method is very effective it has some disadvantages. The high water requirement, high dry-matter losses and environmental pollution has made industrilization of stover treatment by this method practically prohibitive. Modified Beckmann method still faces the same problems as the Beckmann method, but the problems have been reduced to some extent.

Dry method. The development of dry chemical methods of corn stover treatment was also approached from the point of view of improving the Beckmann method. The improvement was that the treated stover is not washed. Consequently only as much sodium hydroxide can be used as will not unduly disturb the animal's system. This level of NaOH has been found to be about 4-5 kg/100 kg stover (Jackson, 1978). Thus, while the problems of dry matter loss and environmental pollution are solved by the dry method, the benefit from the use of a high alkali: stover ratio (i.e., a large increase in digestibility) had to be foregone. By applying heat and pressure some of this loss can be recovered. A very great advantage of the dry method is that it can be industrialized.

Industrial process. A simple process-flow diagram of a corn stover processing factory is given in Figure 2. It is a composite of the designs of the several commercial plants under trial. The capacity of these plants is 4-5 tons of stover treatment per hour. Stover is delivered to the plant as bales which are unloaded onto a concrete apron. They are then pushed by a tractor with a front-mounted loader onto a conveyer leading to a tub grinder, or lifted and placed directly into the grinder. Bale strings (sisal or plastic) are not removed but are processed with the stover. From the tub grinder, the stover is elevated to an intermediate holding bin. This bin acts as a buffer to even out variations in rate of intake. An automatic switch stops the intake conveyor when this bin fills to a certain level, the conveyor is switched on when the level falls. Stover chopped by hammer mill is blown into a cyclone and from there it passes into the alkali treater. The band weigher regulates the rate of addition of the alkali solution, when the rate of application is 10-15 liter of a 30-45% solution of NaOH per 100 kg stover. From the treater, the stover is conveyed to the pellet mill. Pelleting increases the density of the stover from about 50 to 500 kg/m^2. It also causes heating (due to friction) of the stover to about 90^{o}C.

Bulk treatment followed by ensiling. The results of several experiments (Oji *et al.*, 1977; Coombe *et al.*, 1979) have shown that corn stover treated with NaOH solution and then ensiled can be stored up to one year without damage. There is no microbial fermentation after a period of about one month of ensilment, the product remains stable due to its low pH. Wilkinson and Santillana (1978b) reported that long-term storage of alkali-treated straw by ensiling has little effect on composition or on nutritive value compared to short-term. The temperature of the ensiled mass rises during the fermentation process (Greenhalgh *et al.*, 1978), but probably not high enough due to

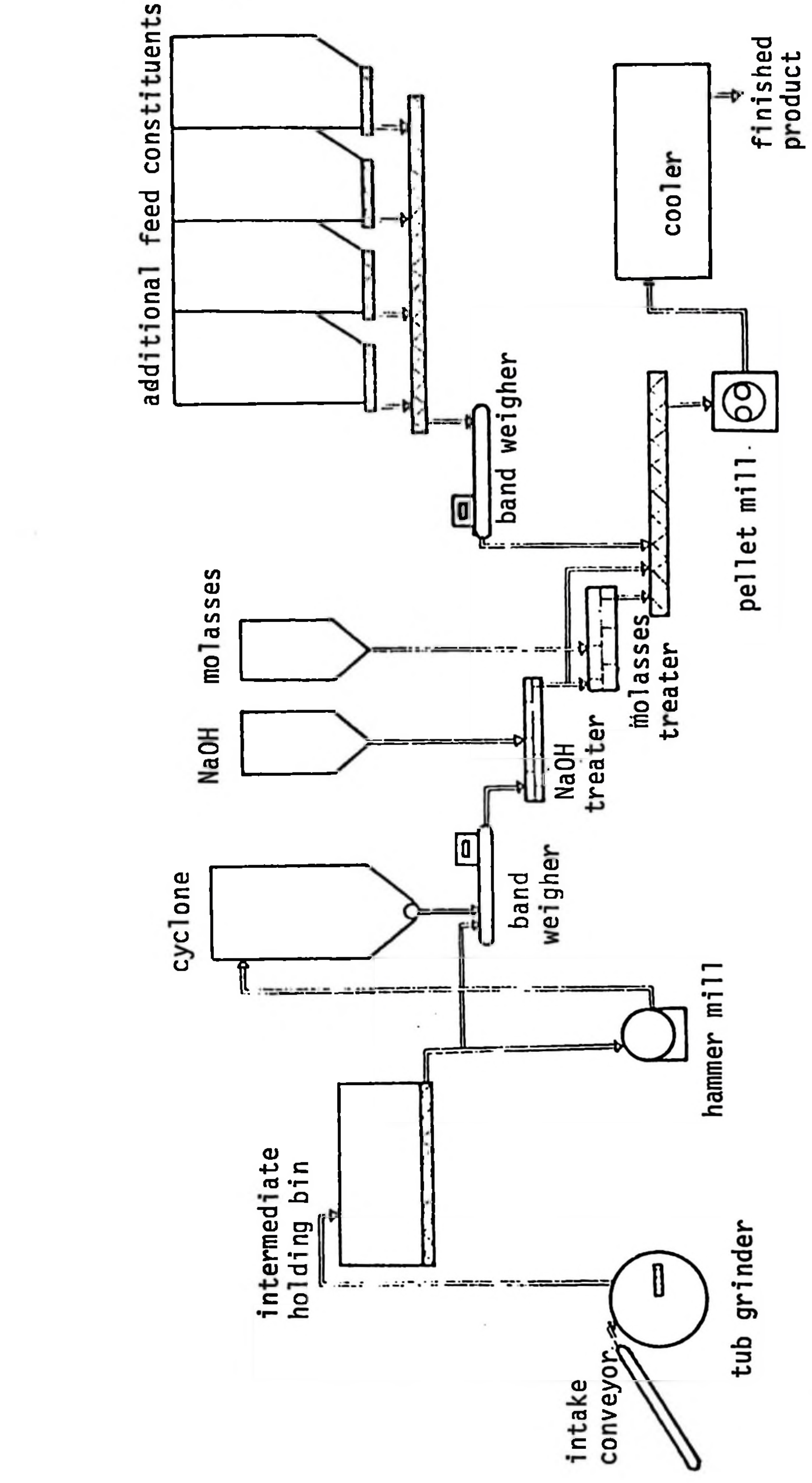


Figure 2. Process flow diagram of stover treatment by the industrial process.

the water content of the stover, to increase the effectiveness of the alkali and kill some strains of microorganisms.

Ensiling process. The ensiling process refers to changes which take place when forage is stored in a silo in the absence of air (Yamamoto, 1976), and the product of this process is silage. Barnett (1954) describes silage fermentation as a process which preserves the material by achieving a sufficient concentration of lactic acid to inhibit other forms of microbial activity. The ensiling process involves both aerobic and anaerobic fermentations and usually requires two to three weeks. The ensiled mass continues to respire consuming the oxygen of the silage-entrapped air and produce carbon dioxide and water. During this time anaerobic yeasts and molds thrive and multiply. The temperature may rise to 100°F or higher. When all the available oxygen has been consumed, araerobic bacteria (mainly lactobacillus) multiply and simultaneously yeasts and molds die. These bacteria promote production of acids preventing decomposition. They convert the available carbohydrates to lactic acids and volatile fatty acids (VFA's). Geasler (1970) and Hawkins (1969) reported a significant positive correlation between soluble carbohydrate content and organic acid content of corn silage. They reported that increasing maturity of the corn plant significantly reduced soluble carbohydrate content of silage and significantly reduced lactic acid content of silage. Protein is broken down into ammonia, amino acids, amides and amines. As the fermentation continues the acids accumulate and pH is reduced to a point where further bacteria and enzyme action is inhibited. This inactivation and/or killing of the enzyme and bacteria marks the completion of the silage making process and under such conditions the silage is preserved as long as air is excluded from the silo.

Fermentation characteristics. Irrespective of the type of crop ensiled, successful ensilage is accompanied by the formation of both steam volatile and steam non-volatile acids (Barnett, 1954). The silage quality generally refers to the success of the fermentation and not the feeding value of the silage. However, there is a positive correlation between silage quality and nutritional value of the silage (McCullough, 1978), since silage fermentation results in the use of highly digestible nutrients to support fermentation. Fermentation characteristics that usually determine silage quality can be both physical and chemical.

Physical characteristics. Physical characteristics of silage has been used as an aid to the estimation of silage quality. A considerable amount of information as to the quality and general characteristics of silage may be obtained by consideration of its color and smell. Good silage has light brown or yellow color and a pleasant "estery" smell (Barnett, 1954).

Chemical characteristics. The physical characteristics — smell and color, alone is not enough measure to determine the extent of fermentation. Other chemical components that are usually measured, to determine the quality of a silage are pH, actic acid, VFA's, dry matter and ammonia nitrogen in percent total nitrogen. The first three of these variables are discussed below.

The pH of silage: The pH (negative logarithm of the hydrogen-ion concentration) of silage is one measure of good quality. Watson and Nash (1960) showed that a pH is a satisfactory index of the course of the fermentation process. According to Yamamoto (1976) a pH of less than 4.5 is indicative of a desirable silage fermentation. Turner (1968) gave a pH of 4.2 or below to be an indication of good quality silage. However, ensiling of roughages after alkali treatment elevates the pH at first, due to the alkali treatment, but decreases after the ensiling. The decrease is associated with the formation of organic acids (Filpot *et al.*, 1976). Mowat (1971) noted that ensiling of maize stover or barley straw after treatment with 6% NaOH reduced pH from 9-10 to 7-7.5. Such a reduction in pH may be of consequence when treated straw comprises a large proportion of the diet of ruminants, since Rexen *et al.* (1975) noted that neutralization of up to pH of 7 increased voluntary intake and organic matter digestibility of a diet containing concentrates and straw treated with 5% NaOH.

The importance of pH as the best single factor for estimating quality in silage has been stressed by many researchers. It is now, not looked upon in quite as favorable a light because in the first place, silage which has, technically speaking, been well made may have a low feeding value, and secondly, overheated silage of known low feeding value is usually characterized by low pH. Also, the much critized butyric acid is frequently found in silage of pH lower than 4.2 (Barnett, 1954).

Organic acids. The process of silage making, except in acidified cases, is dependent upon a successful lactic acid fermentation. The importance of the formation of lactic acid in the successful production of good quality silage is well known (Barnett, 1954; Wilkinson, 1976).

Lactic acid: Lactic acid is produced during the fermentation of green forage from the breakdown of carbohydrate under conditions of anaerobic respiration in silage. Adequate amounts of fermentable carbohydrate must be present for the survival of lactic acid-producing organisms. According to Barnett (1954), the reaction may be presented by the following equations:

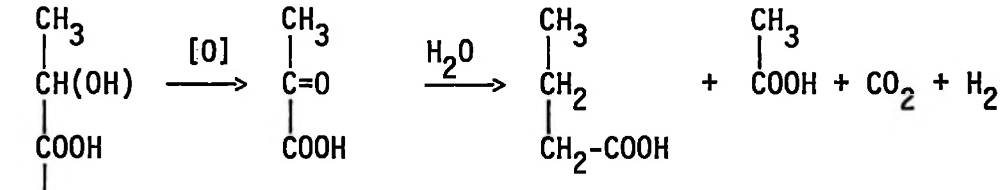
Disaccharide or Hexose
↓
+ $2(H_3PO_4)$
↓
Hexose diphosphate
↓
2 Triosephosphate + acetaldehyde or pyruvic acid
↓
2 Phosphoglycerate
↓
2 Pyruvic acid + $2(H_3PO_4)$
↓
2 Lactic acid

Lactic acid is a stronger acid than any of the fatty acids, and exerts a dominating effect on pH.

Knight *et al.*, (1977) found lactic acid levels of 2.37, 4.68 and 7.47% of the dry matter after 10 days ensiling in silages containing 20, 40, 60% manure respectively. When cattle waste was ensiled with ground rye straw in ratios of 30:70 up to 70:30 on wet basis, lactic acid levels were found to increase from 1.65 to 4.16% of the dry matter (Cornman, 1979). Silage containing 60% manure, 40% straw on dry basis, contained 4.79% lactic acid (Harpster *et al.*, 1978).

Volatile fatty acids. Volatile fatty acids include acetic, propionic, butyric, isobutyric, valeric and isovaleric. The first three are briefly discussed below.

Acetic acid: Acetic acid is looked upon as a normal constituent of good quality silage and many organisms can produce it (Barnett, 1954). Acetic acid can be formed from lactic acid. The organisms, *Clostridium Butyricum* which occurs with *Clostridium Welchii* in soil and in grass is a saccharolytic bacteria, capable of breaking down pyruvic acid chiefly to butyric and acetic acids. Pyruvic acid crops up in a number of metabolic processes and is readily derived from lactic acid by oxidation (McCoy *et al.*, 1930).



$$\begin{array}{c} CH_3 \\ | \\ CH(OH) \\ | \\ COOH \end{array} \xrightarrow{[O]} \begin{array}{c} CH_3 \\ | \\ C{=}O \\ | \\ COOH \end{array} \xrightarrow{H_2O} \begin{array}{c} CH_3 \\ | \\ CH_2 \\ | \\ CH_2\text{-}COOH \end{array} + \begin{array}{c} CH_3 \\ | \\ COOH \end{array} + CO_2 + H_2$$

Lactic acid — Pyruvic acid (3 moles) — Butyric Acid — Acetic acid

Wilkinson *et al.* (1978) reported that there was an increase of acetate with increasing level of NaOH when straw is treated with this alkali and ensiled for three months. The same results were obtained by Tarkow and Feist (1969). Aines (1980) reported that silage containing 35% manure and 65% straw had 1.86% acetic acid for the untreated and 3.10% acetic acid for the 4% NaOH treated samples.

Propionic acid: The presence of propionic acid becomes manifest usually after butyric acid has appeared. Whether or not there is any significance in this, nobody knows. Propionic acid is produced as the result of the activity of organisms of the group *Lactobacteriacae*. Fitz (1878) showed that these organisms convert lactic acid, malic acid and glucose to propionic and acetic acids.

$$3CH_3\cdot CH(OH)\cdot COOH\cdot 2CH_3 \rightarrow CH_2COOH + CH_3(COOH + CO_2 + H_2O$$

Lactic Acid — Propionic Acid — Acetic Acid

Aines (1980) reported that a silage containing 35% waste and 65% straw and .4% of dry matter was propionic acid for the 0 NaOH, and .53% of dry matter was propionic acid for the 4% NaOH.

Butyric acid: Butyric acid is produced from lactic acid together with acetic acid as shown under acetic acid. It can also be produced by direct action of saccharolytic organisms on disaccharides according to the following scheme:

$$\underset{\text{Disaccharide}}{C_{12}H_{22}O_{11}} + H_2O \rightarrow \underset{\text{Hexose}}{2H_6C_{12}O_6} \rightarrow 4H_2 + \underset{\text{Bytyric acid}}{4CO_2 + 2CH_4H_8O_2}$$

High levels of butyric acid are usually found in silage of pH lower than 4.2 and associated with damaged silage. Aines (1980) reported 1.05% butyrate for the 4% NaOH treated wastelage compared to .14% for the untreated samples.

The sum of the organic acids in the silage is termed total acid. The general scheme of the formation of fatty acids in silage is shown in Figure 3.

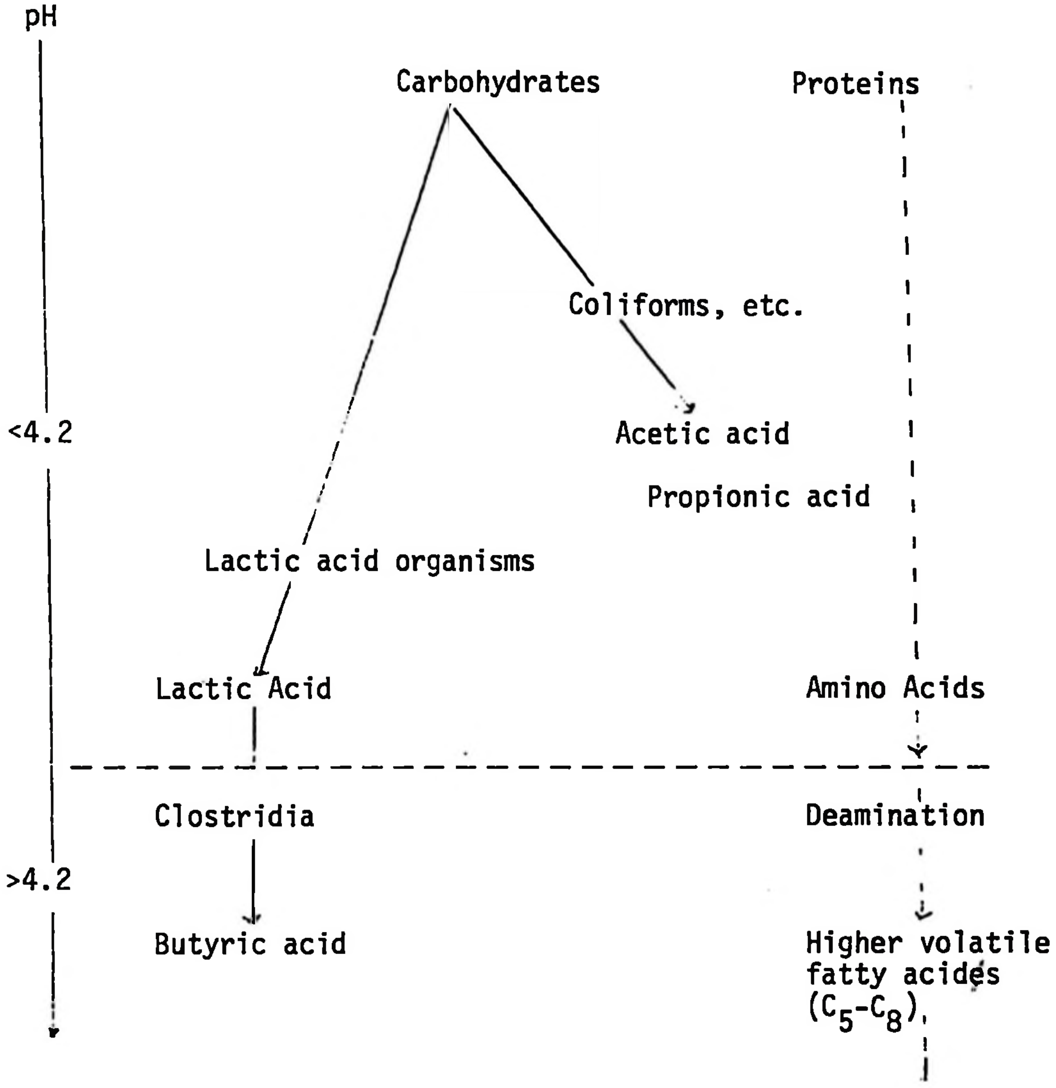


Figure 3. Barnett - General scheme of fatty acid formation in silage.

CHAPTER III

MATERIALS AND METHODS

Preparation of the Samples

After the harvest period (October) corn stover was collected from the University Farm. The stover was chopped using a silage harvester into shorter pieces that were 3-4 inches long. From the chopped sample, a subsample was randomly collected and dried in an oven at 60^oC to determine its dry matter content on natural basis according to the AOAC (1970) procedure. This sample was ground in a Wiley mill through a 1 mm screen and stored for chemical analysis. Cattle manure (faeces + urine) from beef cattle that were fed 90% corn silage, 6% alfalfa hay and 4% protein supplement was randomly collected by scrapping a solid concrete floor in a confinement from the University Feedlot. A small portion of manure was dried at 60^oC to determine dry matter on natural basis and ground using a Wiley mill through a 1 mm screen in preparation for chemical analysis.

Roughage Treatment

(1) Alkali treatment - The chopped corn stover was treated with NaOH and NH_4OH at different levels on dry matter basis and water added such that the final product after the treatments was 65% moisture. Water, alkali and corn stover were thoroughly mixed in a rotating concrete mixer. To attain maximum uniformity of the mixture, the mixing was done for 30-45 minutes per treatment. pH was measured before and after ferementation process from an effluent obtained by mixing 10 g of sample and 100 ml of distilled boiling water. The temperature was

also recorded before ensiling the mixture and after the fermentation.

The mixture as computed in Table 2, after the treatments, was compactly ensiled in 3 ply-nylon bags for 30 days. The bags were tightly tied and covered in 10 gal. plastic drums to ensure maximum absence of oxygen.

A. Levels of Alkali

1. Corn stover + water (control)
2. Corn stover + water + 4% NaOH
3. Corn stover + water + 4% NH_4OH
4. Corn stover + water + 3% NaOH + 1% NH_4OH
5. Corn stover + water + 2% NaOH + 2% NH_4OH by weight on DM basis
6. Corn stover + water + manure (65%:35% ratio of corn stover to manure on DM basis. The final product before ensiling was 45% DM).
7. Corn stover + water + manure + 4% NaOH by weight on DM basis. Final product before ensiling was 45% DM.

Table 2. Weights of the ingredients used (in kg).

	Alkali and Manure Treatments						
Item	1	2	3	4	5	6	7
Corn Stover	3.947	3.790	3.790	3.790	3.790	3.299	3.167
Manure	-	-	-	-	-	2.537	2.435
NaOH	-	.140	-	.105	.070	-	.180
NH_4OH	-	-	.241	.060	.120	-	-
Water	6.053	6.070	5.969	6.045	6.020	4.329	4.218

In Vitro Experiments

The *in vitro* dry matter digestibility was determined from a 96-hour incubation in rumen inoculum according to Mellenberger *et al.* (1970) as described below.

Rumen contents were collected by a vacuum pump from rumenally fistulated cows fed alfalfa hay, approximately 4 hours after feeding. The contents were squeezed through four layers of cheese cloth into a thermally insulated jug. The atmosphere in the jug was replaced with CO_2 for 3-5 minutes to maintain anaerobiosis.

McDougall saliva (1948) was prepared, the composition of which is presented in Table 3, and maintained at 39^oC and pH adjusted to 6.9 by bubbling CO_2 through the buffer. An inoculum (25 ml) that was a mixture of one part rumen fluid to three parts buffer was added into preheated (39^oC) tubes, each containing 0.3 g of air dry substrate. All the tubes were then flushed with CO_2 and sealed with a cap. The tubes were incubated in a water bath at 39^oC for 96 hours, and then frozen to kill the microbes. Blanks containing inoculum and buffer solutions were run in triplicate and treated identical to sample tubes throughout the digestion process.

Table 3. Composition of buffer solution (McDougall's Saliva).

Item	Grams/liter	Item	Grams/liter
$NaHCO_3$	9.80	$MgSO_4$	0.12
Na_2HPO_4	3.71	$CaCl_2$	0.04
KCl	0.57	Urea	0.015
NaCl	0.47		

After 2 days, the tubes were thawed for 1 hour and centrifuged for 20 minutes at 5,000 r.p.m.; supernatant was decanted and oven dried at

$100^{o}C$ for 24 hours. The IVDMD% was calculated from the expression:

$$\% \text{ IVDMD} = \frac{\text{initial dry weight} - (\text{final dry weight} - \text{blank weight})}{\text{initial dry weight}} \times 100.$$

Chemical Analysis

All samples before and after fermentation process were analyzed for chemical composition. DM, ash and crude protein (% N x 6.25) were determined by AOAC (1975) methods. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) analysis were determined according to the procedure of Goering and Van Soest (1979). Acid detergent lignin (ADL) and fiber-bound nitrogen (ADF-N) were also determined using the methods of Goering and Van Soest (1979).

Fermentation Parameters

Fermentation parameters that were measured included pH, lactic acid and volatile fatty acides (VFA's). The pH was determined with a glass electrode in juice squeezed from the sample after maceration with boiled distilled water. Effluents extracted from the samples were used for the determination of lactic acid (Baker and Summerson, 1971 as modified by Pennington and Sutherland, 1956). VFA's were analyzed by methods of Erwin *et al.* (1951) and were analyzed using a Varian Aerograph Series 1700 gas chromatograph.

Statistical Analysis

One way analysis of variances according to Snedecor and Cochran (1969) was used to analyze the data. The means of the treatment differences were tested using Honestly Significance Difference (HSD) according to the procedure of Tukey (1960).

CHAPTER IV

RESULTS AND DISCUSSION

Chemical Composition and Nutritive Value of Cattle Waste and Corn Stover

The proximate composition of the manure and corn stover used in this study is shown in Table 4. Dry matter content of the cattle excreta and ground corn stover was 33.24 and 90.12, respectively. The crude protein content of the cattle waste was 14.22% and that of corn stover 4.41%, dry basis. The crude protein value of cattle waste is considerably lower than that reported by Lamm *et al.* (1979), which was 17.2%. Braman (1975) reported crude protein values between 15 and 17% for waste collected from cattle fed a high concentrate diet. Albin and Sherwood (1975) reported a crude protein value of 21.6% for cattle waste. The highest crude protein value of cattle waste thus far reported is 26.89% (Cornman, 1979). The differences of crude protein values observed is a clear indication of the fact that factors like diet, housing animals and how the waste was handled can drastically affect chemical composition of cattle waste.

The crude fiber components of both cattle waste and corn stover used in this study is also shown on Table 4. The NDF (cell wall constituents) on ash-free basis of corn stover and cattle waste were 75.41% and 36.63% respectively. Aines (1980) reported NDF of 75.1% for rye straw and NDF of 45.7% and 59.6% for cattle waste that have been collected from cattle that were on high concentrate and high roughage respectively. The ADF on ash-free basis of corn stover and cattle waste were 44.06 and 26.43 respectively. Aines (1980) reported

Table 4. Composition of cattle waste and ground corn stover (% of dry matter in the sample) used in this study.

Item	Cattle Waste	Corn Stover
Dry matter,[a] %	66.4	88.67
Proximate components,[a] %		
Crude Protein	14.22	4.41
Ash	22.04	7.73
Cell wall fractions,[a] %		
Neutral Detergent Fiber	36.63	75.41
Acid Detergent Fiber	26.43	53.91
Acid Detergent Insoluble Nitrogen	31.44	44.06
Hemicellulose	10.20	21.50
Cellulose	19.06	46.43
Lignin	7.37	7.48
Digestibility,[a] %		
In vitro Dry Matter Digestibility	25.07	36.68

[a] Each value represents the mean of two samples.

values of 46.1% ADF for rye straw and that of 22.5% and 32.9% ADF for high concentrate and high roughage waste sources, respectively. The *in vitro* dry matter digestibility was 25.07% for the manure and 36.68% for the corn stover. The low IVDMD for cattle waste reflects the fact this feed ingredient has once undergone the digestion process.

The pH of the manure and stover prior to ensiling was 5.44 and 7.7 respectively. The low pH of the manure indicates that the waste had undergone some fermentation between when the waste was collected and the time it was thoroughly mixed and sampled. Knight *et al.* (1977) reported that pH of fresh cattle manure to be between 6.9 and 7.2. Moore and Anthony (1970) reported a value of 6.2 and Corman (1979) found a value of 5.5 for the pH of waste from cattle fed a high concentrate diet.

Composition and Nutritive Value of Silage

Physical characteristics. After ensiling for a month, the odor of all silages indicated that fermentation had taken place. The silages that contained alkali had a sweet "estery" smell. The silage that contained 35% cattle waste had a strong pungent smell while the one that had 4% NaOH and manure had a butyric acid smell.

When the bags were examined for mold, the alkali treated silages had more surface covered with mold than the untreated silages. Silages containing manure had even greater surfaces covered with molds. The alkali treated silages had yellow color and the one that contained manure had dark brown color. The temperature of the pre-ensiled material was 24°C. After ensiling for a month the temperature had risen to 32°C.

Chemical Characteristics

Crude protein. The mean crude protein (CP) content of the alkali treated corn stover silages used in this study is shown on Table 5. There were significant ($p < 0.05$) differences in the CP content between the treatments. The 4% NH_4OH had a greater CP content of 6.16%. This could be due to the fact that the nitrogen in the ammonium hydroxide, during the fermentation process, had been incorporated by microorganisms to synthesize microbial protein. There was an increase of CP from 4.63% for stover + water to 4.74% for 4% NaOH treated stover, and to 6.16% for 4% NH_4OH. There was no significant ($p < 0.05$) differences between 3% NaOH + 1% NH_4OH and 2% NaOH + $2NH_4OH$ when compared to the control (stover + water). Wilkinson *et al.* (1978) reported that there was a decrease of CP when alkali-treated barley straw was ensiled for 90 days. Braman and Abe (1977) reported no decrease in CP levels when wheat straw was treated with 4% NaOH. Pirie *et al.* (1978) reported a slight increase of CP when barley straw was treated with 4% NaOH.

The mean CP content of corn stover + water, manure + stover (wastelage), manure + stover treated with 4% NaOH is shown on Table 6. There was a significant ($p < 0.05$) increase in CP due to manure treatment. Although there was a change in CP of wastelage after treatment with 4% NaOH, it was not significant ($p > 0.05$). Aines (1980) reported a CP of 7.9% for a diet composed of 30% manure and 70% rye straw after ensiling for 90 days. When treated with 4% NaOH the CP increased to 9.8%.

Ash. The ash content of untreated, treated, and ensiled corn stover is shown in Table 5. The ash content of corn stover as collected from the farm was 7.73%. When ensiled with water it was

Table 5. Composition and fermentation parameters of alkali-treated corn stover silage (% of dry matter at 105°C).

Item	Stover + Water	4% NaOH	4% NH_4OH	3% NaOH + 1% NH_4OH	2% NaOH + 2% NH_4OH
Dry Matter[a], %					
60°C	33.71	35.93	34.95	34.43	37.84
105°C	30.82	32.54	31.65	30.99	33.99
Proximate Components[a], %					
Crude protein	4.63^{b}	5.74^{b}	7.16^{c}	4.88^{b}	4.89^{b}
Ash	8.12^{b}	12.07^{c}	11.61^{c}	10.98^{c}	10.47^{c}
Cell Wall Fractions[a], %					
Neutral detergent fiber	71.24^{b}	61.78^{c}	62.94^{c}	66.62^{c}	69.83^{b}
Acid detergent fiber	51.12^{b}	45.86^{c}	43.27^{c}	50.22^{b}	51.27^{b}
Acid detergent insoluble nitrogen	42.83^{b}	43.91^{bc}	43.82^{bc}	44.27^{c}	45.16^{c}
Hemicellulose	20.12^{b}	15.93^{c}	19.67^{bc}	16.4^{c}	18.56^{c}
Cellulose	43.71^{b}	38.77^{c}	35.43^{c}	53.11^{b}	44.04^{b}
Lignin	7.41	7.09	7.04	7.11	7.23
Digestibility[a], %					
In vitro dry matter digestibility					
Unadjusted for alkali addition	45.48^{b}	51.78^{bc}	60.78^{c}	48.61^{bc}	46.68^{b}
Adjusted for alkali addition	45.48	49.98	58.98	46.81	44.88
Fermentation Parameters[a]					
pH	6.19^{b}	7.87^{c}	7.77^{c}	7.49^{c}	7.00^{c}
Lactic Acid	1.20^{b}	0.26^{c}	0.13^{c}	0.15^{c}	0.13^{c}
Volatile Fatty Acids					
Acetic Acid	1.65^{b}	3.13^{c}	3.19^{c}	3.10^{c}	2.75^{c}
Propionic Acid	0.67^{b}	0.34^{c}	0.37^{c}	0.31^{c}	0.27^{c}
Butyric Acid	0.05^{b}	0.21^{c}	0.18^{c}	0.13^{c}	0.14^{c}

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[a] Each value represents the mean of two samples.

[bc] Means in same column not containing a common superscript letter differ significantly ($p < 0.05$).

8.12% and on treatment with 4 NaOH it was 12.07%. The 4% NH_4OH treated stover had higher ash content of 11.61% than the stover ensiled with water. There were significant ($p < 0.05$) increases between the untreated and treated samples but no significant ($p > 0.05$) change among treated samples. While NaOH-treated samples had ash content values which were almost twice that in the untreated materials, the NH_4OH-treated samples had ash content values just slightly higher than those for the untreated samples. The increase in ash was due to the addition of sodium salt (Ward, 1981). Adeleye (1974) observed lower gross energy values of the treated samples and explained that the decrease in energy was the result of an increase in ash due to alkali treatment. The ash content of manure-containing silages was higher than silages that had no manure (Table 6). This can be attributed to the high ash content of cattle excreta.

Cell Wall Constituents

Hemicellulose. The hemicellulose content in a plant makes up a fairly large portion of the NDF. Hemicellulose is one part of the cell-wall constituents which can be partially utilized by a ruminant through attack by microbial enzymes. Most of the hemicellulose can be made available by alkali treatment or other processes. The hemicellulose content is usually estimated by substraction of the ADF from NDF.

Hemicellulose of ensiled, untreated and alkali-treated corn stover is given in Table 5. That of wastelage and 4% NaOH-treated wastelage is shown in Table 6. There were significant ($p < 0.05$) differences of hemicellulose between treatments. There was a significant ($p < 0.05$) decrease of hemicellulose of untreated corn stover silage when compared to 4% NaOH, 3% NaOH + 1% NH_4OH, and 2% NaOH + 2% NH_4OH. Although there

Table 6. Composition of wastelage after ensiling with 4% NaOH (% of dry matter in the sample at 105°C).

Item	Stover + Water	Manure + Stover	Manure + Stover + 4% NaOH
Dry Matter			
60°C	33.71	38.79	39.75
105°C	30.82	36.07	35.87
Proximate Components,[a] %			
Crude Protein	4.63^{b}	7.62^{c}	8.25^{c}
Ash	8.12^{b}	16.47^{c}	10.64^{c}
Cell Wall Fractions[a], %			
Neutral Detergent Fiber	71.24^{b}	58.66^{c}	50.56^{c}
Acid Detergent Fiber	51.12^{b}	42.76^{c}	38.22^{c}
Acid Detergent Insoluble Nitrogen	42.83	41.28	39.80
Hemicellulose	20.12^{b}	15.90^{c}	12.34^{c}
Cellulose	43.71^{b}	34.94^{c}	31.10^{c}
Lignin	7.41	7.78	7.12
Digestibility[a], %			
In vitro dry matter digestibility			
Unadjusted for alkali addition	45.48^{b}	36.66^{c}	50.89^{b}
Adjusted for alkali addition	45.48^{b}	36.66^{c}	49.09^{b}
Fermentation Parameters[a]			
pH	6.19^{b}	5.71^{c}	5.35^{c}
Lactic acid	1.20^{b}	$.87^{bc}$	0.11^{c}
Volatile Fatty Acids			
Acetic acid	1.65^{b}	3.34^{c}	3.86^{c}
Propionic acid	0.67^{b}	0.35^{c}	0.58^{b}
Butyric acid	0.05^{b}	0.26^{c}	0.28^{c}

[a] Each value represents the mean of two samples.

[bc] Means in same column not containing a common superscript letter differ significantly ($p < 0.05$).

was a slight decrease with 4% NH_4OH treated corn stover silage it was not significant ($p > 0.05$). The hemicellulose of wastelage and 4% NaOH treated wastelage was 15.90% and 12.34%, respectively. These results agree with that of Aines (1980) who reported 4-5% decrease when wastelage was treated with 4% NaOH.

Olodate *et al.* (1970) showed that hemicellulose solubilatization was enhanced by alkali treatment of roughage. The labile bonds of the hemicellulose fraction of the cell wall constituents undergo hydrolysis when treated with alkali (Feist *et al.*, 1970). However, Sneddon *et al.* (1981) reported there were no changes in hemicellulose concentration when sunflower silage was treated with NaOH.

Cellulose. The cellulose content of corn stover treated with alkali is shown on Table 5 and that of wastelage, untreated and treated with 4% NaOH is also shown on Table 6. Cellulose contents were estimated as ADF minus lignin. There was significant ($p < 0.05$) differences of cellulose contents between treatments. There was a significant ($p < 0.05$) decrease between the untreated and 4% NaOH and 4% NH_4OH treated silage. There were no significant ($p > 0.05$) differences between 3% NaOH + 1% NH_4OH and 2% NaOH + 2% NH_4OH treated silages when compared to corn stover + water only. Cellulose of manure + stover was 37.98% and that of 4% NaOH treated manures + stover was 31.10. The decrease due to alkali treatment has been thought to result from breakage of bonds between cellulose and lignin, and swelling of cellulose fibers within the cell wall matrix (Wilkinson, 1978).thereby allowing microbial enzymatic breakdown.

Lignin. The lignin content of corn stover treated with alkali, cattle manure, both alkali and manure is shown in Tables 5 and 6. There were no significant ($p > 0.05$) differences of lignin content between the treatments. Although there was a slight decrease of lignin due to alkali treatment, it was not significant ($p > 0.05$). The results obtained both from alkali and/or manure treatment of corn silage indicate that there was no effect on lignin content.

Lignin is a chemical entity of plants and is listed as one of the factors affecting forage digestibility. According to Colburn *et al.* (1968) and Van Soest *et al.* (1967) lignin increases with maturity in a plant, and this lignification process renders cellulose and hemicellulose less digestible by an animal. The results obtained from this study agree with those reported by Ololade *et al.* (1970) and Berger *et al.* (1979), but disagree with those reported by Chandra *et al.* (1971) and Anderson and Ralston (1973).

In vitro dry matter digestibility. *In vitro* dry matter digestibility (IVDMD) is a measurement of the utilization by ruminants of the total chemical constituents in plant material. There is little doubt, however, that the most useful single measure of the nutritive value of roughage is the percentage digestibility of the dry matter. According to Walker (1958) the IVDMD value gives more information than any other single estimator by itself. Several factors influence IVDMD, one of the most important being the percentage of certain chemical components present within a forage.

The IVDMD of alkali-treated corn stover silage is shown on Table 5, and that of untreated and treated wastelage with 4% NaOH is shown on Table 6. There were significant ($p < 0.05$) differences between treatment.

The increased IVDMD from 45.5% for the untreated to 51.8% for the 4% NaOH and to 6018 for the 4% NH_4OH treated materials were significant ($p < 0.05$).

1% NH_4OH and 2% NaOH + 2% NH_4OH, though had a slight increase when compared to the control, the increase was not significant ($p > 0.05$). The 4% NH_4OH treated corn stover silage had the highest IVDMD of 60.78% and 2% NaOH + 2% NH_4OH had the lowest reading of 46.68%. The IVDMD of stover and manure was 36.66% and that of 4% NaOH treated wastelage was 50.89%. From these results the inclusion of manure seems to lower the IVDMD. This should not seem strange, since manure had once undergone digestive process breakdown. Alkali treatment of wastelage seems to improve IVDMD, the increase is still lower compared to 4% NaOH and 4% NH_4OH treated corn stover silage.

Corman (1979) reported that a wastelage containing 60% rye straw and 40% waste had IVDMD of 31.93%. Braman and Abe (1977) reported *in vitro* dry matter digestibility of wheat straw to be 27.2%. Lamm *et al.* (1979) reported an IVDMD of 46.7% for wastelage containing 60% cattle waste, collected from cattle fed a 70% concentrate diet, and 40% ground grass-legume hay on wet basis. The IVDMD values observed in the literature and those found in this study were low. The low IVDMD of all the silages are a reflection of the low digestibility of corn stover and cattle waste.

Fermentation Parameters

pH of the silages. The pH of the pre-ensiled and post-ensiled materials is shown on Table 7. The pH of the pre-ensiled materials was greatly increased by addition of alkali. There were no significant ($p > 0.05$) differences of pre- and post-ensiled pH readings of alkali containing samples. The pH values of alkali containing silages ranged from 9.01 to 10.46. The highest pH noted in the literature is 11.4 reported by Greenhalgh *et al.* (1978). After one month of ensiling the pH of alkali containing silage had dropped between 5.71 and 7.87. The fall in pH can be attributed to the increase in population of those microorganisms that produce organic acids. There are a number of types of Bacillus which show optimal growth at pH 9-11 (Ohata *et al.*, 1975) and other strains at a low pH of 4-5 (Beck, 1974). Such a reduction in pH may be of consequence then treated straw comprises a large proportion of the diet of ruminants, since Rexen *et al.* (1975) noted that neutralization to pH 7 increased voluntary intake and OMD of a diet containing concentrates and straw treated with 5% NaOH.

The pH of silages that did not contain alkali was relatively low. There was little change of pH of post-ensiled untreated silage when compared to the pre-ensiled untreated silage. The silage that contained manure but no alkali had dropped from 6.30 to 5.71. This change in pH was greater than that of untreated stover without manure. Possibly the addition of manure resulted better fermentation.

Table 7. pH readings before and after ensiling for 30 days.

Item	[1] pH_1 (at 0 day)	[1] pH_2 (after 30 days)
Stover + water (control)	6.29	6.19
Stover + 4% NaOH	10.46	7.87
Stover + 4% NH_4OH	9.98	7.77
Stover + 3% NaOH + 1% NH_4OH	9.46	7.49
Stover + 2% NaOH + 2% NH_4OH	9.01	7.00
Stover + manure (control)	6.30	5.71
Stover + manure + 4% NaOH	9.79	6.35

[1] Each value represents the mean of two samples.

Lactic acid. Since the pH of the treated silage remained elevated, this was detrimental to the lactic acid production. Woolford (1972) indicated that species such as *Streptococcus faecalis* produce lactic acid between pH 6.5 and 5.0 and that species such as *Lactobacillus plantarum* produce lactic acid at pH 5.0 and below. Lactic acid content of alkali-treated corn stover silage is shown in Table 5 and that of untreated and treated wastelage is shown in Table 6. Lactic acid production of untreated corn stover silage was the highest and significantly ($p < 0.05$) different from other treatments. Lactic acid values of alkali containing silages were very low and not significantly ($p > 0.05$) different from each other. Lactic acid of untreated wastelage was also low, but higher than that of 4% NaOH treated wastelage. These low lactic acid values are a clear reflection of how high pH and limited fermentable carbohydrate can depress lactic acid production.

Lamm *et al.* (1979) reported lactic acid values of 3.16% for untreated and 1.68% for treated wastelage composed of 60% manure and 40% grass-legume hay on wet basis. Their values have lower pH than those found in this study. This could be due to the high percentage of manure used, the source of manure does not seem to affect lactic acid production. Aines (1980) reported lactic acid value of .8% when wastelage from high roughage waste source constitute 50% manure and 50% rye straw, and 6.1% when wastelage was from high concentrate waste source.

Volatile fatty acid. VFA's that were of main concern in this study were acetic, propionic and butyric acids. The values of these acids for alkali-treated corn stover silage is shown in Table 5 and that of untreated and 4% NaOH treated wastelage is shown in Table 6.

Acetic acid: The acetic acid value of untreated corn stover silage was significantly ($p < 0.05$) lower from the alkali treated silages. There were no significant ($p > 0.05$) differences between the treatments of alkali containing silages. The acetic acid values of alkali containing silages were higher than the untreated silage. This agrees with the statement of Tarkow and Feist (1969) that alkali treatment results in hydrolysis of hemicellulose thereby liberating acetyl groups. Acetic acid of untreated wastelage was slightly lower than that of 4% NaOH treated and significantly ($p < 0.05$) different to that of untreated silage. Lamm *et al.* (1979) reported acetic acid values of 1.90% for untreated and 3.81 for 4% NaOH treated wastelage containing 60% manure and 40% grass-legume hay on wet basis.

Propionic acid: Propionic acid values of the untreated silages were higher than those of the treated samples. This was significantly different from other silages that contained alkali. There were no significant ($p > 0.05$) difference between treatments that contained alkali. Lamm *et al.* (1979) reported propionic acid values of 0.44% for untreated and .36% for 4% NaOH treated wastelage composed of 60% manure and 40% grass-legume hay.

Butyric acid: Butyric acid production was lower for the untreated silage than treated ones and significantly ($p < 0.05$) different from those values. The manure containing silage had higher values of butyric acid when compared to the silages that do not contain manure, but there were no significant ($p > 0.05$) differences among manure containing treatments. Lamm *et al.* (1979) reported values of 0.06% butyric acid for untreated and .21% for treated wastelage.

CHAPTER V

SUMMARY AND CONCLUSION

The objective of this study was to evaluate the effects of addition of manure, alkali, both manure and alkali, and to compare the effects of sodium hydroxide and ammonium hydroxide separately and in combination at varying levels of each, on the nutritive value of reconstituted corn stover silage.

Chopped corn stover and water with and without feedlot manure and with and without 4% sodium or ammonium alkali was ensiled at room temperature for 30 days. The materials before and after treatment were analyzed for dry matter, crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin and *in vitro* dry matter digestibility (IVDMD). Fermentation was assessed by determining pH, lactic acid levels and volatile fatty acids. Alakli treatment significantly reduced HDF and ADF content of corn stover ensilage. The reduction was even greater when corn stover was ensiled and treated with alkali and manure. After the fermentation process, there was an increase in crude protein, but this was only significant at 4% NH_4OH and on manure inclusion. Alkali treatment improved IVDMD values. These were highest with 4% NH_4OH treatment. Manure inclusion lowered the IVDMD values substantially. Silages that contained manure had pungent smell of butyric acid; the rest exhibited desirable fermentation as measured by the parameters used. Alkali treatment resulted in increased acetic and butyric acids. Butyric acid values were elevated by manure addition. Propionic acid levels were decreased by alkali treatment and unaffected by manure addition.

Ensiling treated corn stover with alkali and manure has desirable effects in improving its nutritive quality. The resulting product "wastelage" can be used as a feed for ruminants, especially when relatively high quality forages are scarce. However, assessment of technical and economic feasibility needs further research. Again, methods applicable to small-scale livestock producer needs to be evaluated.

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APPENDIX

Table A1. Weights of ingredients used on as is basis.

	Ingredient	%	% dm	kg dm	% H_2O	kg H_2O	10 kg batch
1. Stover + H_2O	Stover	39.47	88.67	35	11.33	4.47	3.947
	Water	60.53	0	0	100.00	60.53	6.053
	Total	100.00		35.00		65.00	10.000
2. 4% NaOH	NaOH	1.4	100.00	1.4	0	0	.140
	Stover	37.89	88.67	33.6	11.33	4.3	3.790
	Water	60.7	-	-	100.00	60.7	6.070
	Total	100.00		35.0		65.00	10.000
% NaOH of dm = $\frac{1.4}{35}$ = 4%							
3. 4% NH_4OH	NH_4OH	2.41	58.00	1.40	42.00	1.01	.241
	Stover	37.90	88.67	33.60	11.33	4.29	3.790
	Water	59.69	-	-	100.00	59.69	5.969
	Total	100.00		35.00		64.99	10.000
% NH_4OH of dm = 2.41 x .58 = $\frac{1.4}{35}$ = 4%							
4. 3% NaOH + 1% NH_4OH	NaOH	1.05	100.00	1.05	-	-	.105
	NH_4OH	.60	58.00	.35	42.00	.25	.060
	Stover	37.90	88.67	33.60	11.33	4.29	3.790
	Water	60.45	-	-	100.00	60.45	6.045
	Total	100.00		35.00		64.99	10.000
% NaOH of dm = $\frac{1.05}{35}$ = 3.0%							
% NH_4OH of dm = .60 x .58 = $\frac{.35}{35}$ = 1.0%							

Table A1. (continued) Weights of ingredients used on as is basis.

	Ingredient	%	% dm	kg dm	% H_2O	kg H_2O	10 kg batch
5. 2% NaOH + 2% NH_4OH	NaOH	0.70	100.00	.70	-	-	.070
	NH_4OH	1.20	58.00	.70	42.00	.50	4.29
	Stover	37.90	88.67	33.60	11.33	4.29	3.790
	Total	100.00		35.00		64.99	10.000
% NaOH of dm = $\frac{.7}{35}$ = $\underline{\underline{2.0\%}}$							
% NH_4OH of dm = 1.2 x .58 = $\frac{.7}{35}$ = $\underline{\underline{2.0\%}}$							
6. Feedlot manure:Corn Stover (35:65 ratio on DM basis) DM = 45% H_2O = 55%	Manure	23.72	66.40	15.75	33.60	7.97	2.537
	Stover	32.99	88.67	29.25	11.33	3.74	3.299
	Water	43.29	-	-	100.00	43.29	4.329
	Total	100.00		45.00		55.00	10.000
% manure of dm = $\frac{15.75}{45.00}$ = $\underline{\underline{35\%}}$							
% corn stover of dm = $\frac{29.25}{45}$ = $\underline{\underline{65\%}}$							
7. Feedlot manure + C.S. + 4% NaOH DM 45% H_2O 55%	NaOH	1.80	100.00	1.80	0	0	.180
	Manure	22.77	66.40	15.12	33.4	7.61	2.435
	Stover	31.67	88.67	28.08	11.33	3.59	3.167
	Water	43.76	-	-	100.00	43.76	4.218
	Total	100.00		45.00		55.00	10.000

Table A1. (continued) Weights of ingredients used on as is basis.

Ingredient	%	% dm	kg dm	% H_2O	kg H_2O	10 kg batch
$\therefore$ NaOH - $\frac{1.8}{45}$ = 4% dm						
manure - $\frac{15.12}{45}$ = 33.6						
stover - $\frac{28.08}{45}$ = 62.4						

Table B1. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Dry Matter

Source of Variation	DF	SS	MS	F	Signif. of F
Total	16	131868.25			
Mean	1	131845.24	131845.24		
Corr. Total	15	23.01397	1.5342646		
Treatments	7	21.90507	3.1293	22.57486	.00011 S*
Residual	8	1.10890	0.13861		

*Significant at 5% level.

Table B2. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Crude Protein

Source of Variation	DF	SS	MS	F	Signif. of F
Total	16	569.79979			
Mean	1	539.86522	53986522		
Corr. Total	15	29.93457	1.995638		
Treatments	7	29.28817	4.18402	51.78249	0.00001 S*
Residual	8	0.64640	0.08080	6681.50031	

*Significant at 5% level.

Table B3. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Ash

Source of Variation	DF	SS	MS	F	Signif. of F	
Total	16	2579.2366				
Mean	1	2345.22276	2345.2276			
Corr. Total	15	234.01394	15.600929			
Treatments	7	233.46819	33.35260	488.9066	.00001	S*
Residual	8	.54575				

[*] Significant at 5% level.

Table B4. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Neutral detergent fibre

Source of Variation	DF	SS	MS	F	Signif. of F	
Total	16	67019.0020				
Mean	1	66059.28040	66059.28040			
Corr. Total	15	959.7228	63.98152			
Treatments	7	958.4678	66059	421095.01356	.00001	S*
Residual	8	1.255	.15688			

[*] Significant at 5% level.

Table B5. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Acid detergent fiber

Source of Variation	DF	SS	MS	F	Signif. of F
Total	16	36420.113			
Mean	1	36045.87031	36045.87031		
Corr. Total	15	374.24339	24.949559		
Treatments	7	373.33664	53.33381	470.54916	0.00001 S*
Residual	8	.90675	.11334		

*Significant at 5% level.

Table B6. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Lignin

Source of Variation	DF	SS	MS	F	Signif. of F
Total	16	874.6914	872.02090		
Mean	1	872.02090	0.17803		
Corr. Total	15	2.67050	.17896	1.00977	.48828 NS*
Treatments	7	1.25270	.117723		
Residual	8	1.41780			

*Non-significant at 5% level.

Table B7. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: ADF-Nitrogen

Source of Variation	DF	SS	MS	F	Signif. of F
Total	16	29834.572			
Mean	1	29790.76000	279790.76000		
Corr. Total	15	43.8124	2.9208266		
Treatments	7	43.2660	6.18094	90.49697	0.00001 S*
Residual	8	.54640	.06830		

*Significant at 5% level.

Table B8. Example of analysis of variance of chemical constituents of silage.

One Way Analysis of Variance Procedure

Dependent Variable: *In vitro* dry matter digestibility

Source of Variation	DF	SS	MS	F	Signif. of F
Total	16	36355.897			
Mean	1	35454.06556	35454.06556		
Corr. Total	15	901.83214	60.122142		
Treatments	7	896.40959	128.05851	188.92737	0.00001 S*
Residual	8	5.42255	.67782		

*Significant at 5% level.

Table C1. Examples of analysis of variance of fermentation characteristics of silage.

One Way Analysis of Variance Procedure

Dependent Variable: pH

Source of Variation	DF	SS	MS	F	Sign. of F
Total	16	1169.2966	1113.39006		
Mean	1	1113.39006	3.7271093		
Corr. Total	15	55.90664	7.94936	243.51848	.00001 S*
Treatments	7	55.64549	.03264		
Residual	8	.26115			

*Significant at 5% level.

Table C2. Examples of analysis of variance of fermentation characteristics of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Lactic acid

Source of Variation	DF	SS	MS	F	Signif. of F
Total	16	4.69299			
Mean	1	2.05922	2.05922		
Corr. Total	15	2.63377	0.17558		
Treatments	7	2.63237	.37605	2148.87755	0.00001 S*
Residual	8	8.0014	.00018		

*Significant at 5% level.

Table C3. Examples of analysis of variance of fermentation characteristics of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Acetic acid

Source of Variation	DF	SS	MS	F	Signif. of F	
Total	16	132.0315				
Mean	1	110.61781	110.61781			
Corr. Total	15	21.41369	1.4275793			
Treatments	7	21.38754	3.05536	934.71920	0.00001	S*
Residual	8	0.02615	.00327			

*Significant at 5% level.

Table C4. Examples of analysis of variance of fermentation characteristics of silage.

One Way Analysis of Variance Procedure

Dependent Variable: Propionic acid

Source of Variation	DF	SS	MS	F	Signif. of F	
Total	16	2.6722				
Mean	1	2.10250	2.10250			
Corr. Total	15	0.5697	0.03798			
Treatments	7	.56840	.08120	499.69321	.00001	S*
Residual	8	0.00130	.00016			

*Significant at 5% level.