To the Graduate Council:

I am submitting herewith a thesis written by Bertil Gunnar Johnson, III entitled "Effect of Fermentation Aids During the Fermentation Process in Experimental Silos and During Aerobic Deterioration of Corn Silage." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

Karl M. Barth
K. M. Barth, Major Professor

We have read this thesis
and recommend its acceptance:

J. B. McLaren

M. J. Montgomery

Accepted for the Council:

Lee Minkel
The Graduate School

EFFECT OF FERMENTATION AIDS DURING THE FERMENTATION PROCESS IN EXPERIMENTAL SILOS AND DURING AEROBIC DETERIORATION OF CORN SILAGE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Bertil Gunnar Johnson, III

December 1983

ACKNOWLEDGMENTS

The author wishes to express his appreciation and gratitude to the following people who have contributed to the completion of this course of study and to the preparation of this manuscript:

To his major professor, Dr. K. M. Barth, for his guidance, assistance, and patience throughout this course of study and the completion of this manuscript.

To Dr. J. B. McLaren for serving as a member of the graduate committee and for providing classroom instruction about statistical analyses.

To Dr. M. J. Montgomery for serving as a member of the graduate committee and for reviewing this manuscript.

To Victor L. Fulgoni, III for his assistance in collecting data, statistical analyses, and friendship.

To the lab personnel, especially Jenny Hafley, for their assistance in analyzing data.

To his lovely wife, Tina, for her love, encouragement, and assistance throughout this course of study and the completion of this manuscript.

And finally, the author wishes to dedicate this manuscript in memory of his grandfather, the late James Paul Snow, who as a farmer in Portland, Tennessee, was instrumental in the author's decision to pursue a career in the science and art dealing with the prevention, cure, or alleviation of disease and injury to animals.

ABSTRACT

Objectives of this research were to study the effect of microbial and chemical fermentation aids during the fermentation process in experimental silos and during aerobic deterioration in feed bunks of corn silage. Specific parameters studied were: lactic acid and other volatile fatty acids, dry matter, crude protein, neutral detergent solubles, neutral detergent fiber, acid detergent fiber-nitrogen, pH, and temperature at various sampling times. The four experimental corn silage treatments were: (1) an untreated control silage; (2) treated with Silabac, a live Lactobacillus plantarum and acidophilus preparation; (3) treated with Culbac, a killed Lactobacillus preparation; and (4) treated with Crop Cure, sodium diacetate. Chopped whole corn plants (28.8% dry matter), treated or untreated, were placed in 205 liter (55 gallon) steel drums lined with polyethylene bags. During the ensiling period, silage samples were collected on days, 0, 1, 3, 6, 18, 27, and 36 and temperatures of the ensiling mass were recorded continuously during this period. On day 36 of the ensiling period, silages were placed in open bunks to study changes during aerobic deterioration. Samples were taken at 0, 12, 24, 36, 48, and 60 hours and temperatures were also recorded during the period. All samples taken during the ensiling process were analyzed for volatile fatty acids and other nutrients, and pH. Silage samples taken during aerobic deterioration were analyzed for pH and various nutrients.

Lactic acid production was higher in all treated silages when compared to the control silage on all sampling days, but was significantly higher ($P<.05$) on days 3 and 27 during the ensiling period. There were no significant differences ($P>.05$) in acetic, propionic, and isobutyric acids due to treatment. However, acetic acid concentration of the Culbac and Crop Cure treated silage was higher than the control and Silabac treated silage at the end of the ensiling period. Final pH of all treatments during the ensiling period was below 4.0 and was not significantly different ($P>.05$) due to treatment. Changes in dry matter, crude protein, and neutral detergent solubles during the ensiling period were not significantly different ($P>.05$) due to fermentation aids. There were no significant differences ($P>.05$) in neutral detergent fiber and acid detergent fiber-nitrogen due to treatment. Temperatures recorded during the ensiling period were similar for all treatments and were not significantly different ($P>.05$) due to treatment. Temperature in the control silage changed from 24.4 C at the beginning of the ensiling period to 30.1 C by the third day to 20.2 C at the end of the study (44 days).

During aerobic deterioration, the pH of treated and untreated corn silage were similar, except at hour 48 when the pH of the Crop Cure treated corn silage was significantly higher ($P<.05$) than that of all other silages. The pH of the control changed from 3.82 at the beginning of aerobic deterioration to 6.36

by the end of the study (60 hours). There were no significant differences (P>.05) in dry matter content and neutral detergent solubles due to treatment during aerobic deterioration. Crude protein on a percent dry matter basis was significantly lower (P<.05) in the Culbac and Crop Cure treated corn silage compared to the control and silabac treated corn silage at 24 hours during aerobic deterioration. However, at 36 hours the crude protein content of the Crop Cure and Silabac treated corn silage was significantly lower (P<.05) than the control and Culbac treated corn silage. There were no significant differences (P>.05) in neutral detergent fiber and acid detergent fiber-nitrogen due to treatment. In all silages, acid detergent fiber-nitrogen increased during aerobic deterioration by approximately 30%. Temperatures recorded during aerobic deterioration were not significantly different (P>.05) due to treatment. The temperature of the control silage increased from 20.6 C at the beginning of aerobic deterioration to 39.2 C at the end of the study (60 hours).

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	REVIEW OF LITERATURE	3
	Silage Fermentation	3
	Factors Affecting Silage Quality	10
	Silage Additives	16
	Aerobic Deterioration of Silage After Ensiling	23
	Experimental Silos	27
III.	EXPERIMENTAL PROCEDURE	32
	Plant Material Used for Ensiling	32
	Temperature Changes During Fermentation	33
	Nutrient Composition and pH Changes During Fermentation	34
	Effect of Aerobic Deterioration	38
	Statistical Analysis	39
IV.	RESULTS AND DISCUSSION	40
	Silage Composition During the Ensiling Period	40
	Temperature Changes During the Ensiling Period	48
	Silage Composition During Aerobic Deterioration After Ensiling	52
	Temperature Changes During Aerobic Deterioration After Ensiling	56
V.	SUMMARY	60
LITERATURE CITED		64
VITA		73

LIST OF TABLES

TABLE		PAGE
1.	Lactic, Acetic, Propionic, and Isobutyric Acids (μM/g silage wet wt.) of Corn Silage During the Ensiling Period as Affected by Fermentation Additives	41
2.	pH Level of Corn Silage During the Ensiling Period as Affected by Fermentation Additives	45
3.	Dry Matter, Neutral Detergent Solubles, and Crude Protein Content of Corn Silage During the Ensiling Period as Affected by Fermentation Additives	47
4.	Hemicellulose, Cellulose, Lignin, and Acid Detergent Fiber-Nitrogen Content of Corn Silage During the Ensiling Period as Affected by Fermentation Additives	49
5.	Temperature (°C) Changes of Corn Silage During the Ensiling Period as Affected by Fermentation Additives	50
6.	pH Level of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives	53
7.	Dry Matter, Neutral Detergent Solubles, and Crude Protein Content of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives	55
8.	Hemicellulose, Cellulose, Lignin, and Acid Detergent Fiber-Nitrogen Content of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives	57
9.	Temperature (°C) Changes of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives	58

CHAPTER I

INTRODUCTION

Most forage crops cannot always be utilized as feed at time of harvesting. It is important then to have some means of preservation thereby enabling the storage of the crop material for later use when the fresh harvested forage is not available.

One important way of crop preservation is a process known as ensiling. According to Webster (1957) ensiling is defined as the "process of preserving fodder in a silo." A more detailed definition of ensiling according to Barnett (1954) would be "the feedstuff resulting from the anaerobic preservation of moist forage or other feedstuffs by the formation and/or addition of acids." Silage is the end produce of fermentation of forage crops. In order to preserve important nutrients of the crop, it is vital to maintain anerobic conditions, and avoid oxidative activities by aerobic microorganisms.

Corn is the crop most utilized for silage making in the United States. The success of corn as a silage crop is mainly due to the relatively high levels of soluble sugars and starches that provide a favorable substrate for microbial production of organic acids.

Basically, the objective of fermentation is the production of lactic acid by lactic acid producing bacteria which results in lowering the pH of the silage, thereby halting all forms of

microbial activity. Successful crop preservation may not always be the end result. With this in mind, there are ways other than good management to enhance ensiling characteristics and quality of the ensiling material, and that is with the use of commercial silage fermentation aids.

In this study, 208 liter (55 gallon) steel drums were used as experimental silos to study the effect of several microbial and chemical fermentation aids during the ensiling process and during aerobic deterioration after ensiling. Effects of fermentation aids on changes in levels of various volatile fatty acids and other nitrients, pH, and changes in temperature were determined.

CHAPTER II

REVIEW OF LITERATURE

I. SILAGE FERMENTATION

Crops for Silage

Silage can be produced from many different crops. Several crops are grown for the sole purpose of making silage but others are ensiled because they are surplus to immediate requirements. According to McDonald (1981), the characteristics of an ideal crop for preservation as silage are that it should contain adequate levels of water-soluble carbohydrates, it should have a relatively low beffering capacity, it should have a dry matter (DM) content in the fresh crop above 200 g kg^{-1}, and it should possess a physical structure which will allow it to compact readily in the silo. Several crops do not meet these requirements and such materials may require pretreatments, such as field wilting, fine chopping, or the use of additives.

According to the USDA Agricultural Statistics (1980), approximately 150 million tons of silage were produced annually in the United States. Of this amount, 115 million tons were corn silage, 9 million tons were sorghum silage, and the remaining 21 million tons consisted of grasses, legumes, and miscellaneous herbaceous materials.

Good quality corn silage is a very palatable product with a moderate to high content of digestible energy. According to Church (1977), except for sugar cane, the highest yields of digestible nutrients per unit of land can be harvested from this crop, since the ratio of bushels of grain per ton of silage increases with yield. Also, the whole corn plant can be easily handled mechanically at a convenient time of the year.

Sorghum silage is lower in nutritive value than corn silage. This is usually due to the lower digestibility and lower sugar content of the stalk. However, Church (1977) stated that when the seeds have been partially broken, then the nutritive value of the sorghum silage is similar to that of corn silage, if the grain content is comparable.

Grain sorghums for silage production should be selected on the basis of time needed for maturity and the ability to produce grain. According to Barnett (1954), sorghums should be harvested when the major portion of the seeds reach the soft dough stage. Danley and Vetter (1973) reported that sorghum silage was significantly lower in total digestible nutrients and digestible energy, but there was no difference between sorghum and corn silage in digestible crude protein.

Hay-crop silages in the United States which consist mainly of grasses and/or legumes are very popular for ensiling particularly in areas where weather makes hay harvest difficult. McDonald (1981) stated that although species of grasses such as perennial

ryegrass (Holium perenne), timothy (Phleum pratease), orchard grass (Dactylis glomerata), and the fescues (Festuca spp.) may be grown singly as silage crops, it is quite common to find mixed species of both grasses and legumes being used.

According to Bath et al. (1978) alfalfa and grass mixtures are very popular as silage crops. The nutritional value of alfalfa-grass silage is excellent due to its high protein and mineral contents. However, fresh-cut green chop is usually high in moisture, and therefore if the forage is not wilted before ensiling, seepage from silos may be a problem.

Grasses tend to be low in water soluble carbohydrates which are important as the substrate for lactic acid bacteria in the production of lactic acid. This low level of water-soluble carbohydrates has sometimes been corrected by the addition of molasses which is high in water soluble carbohydrates. The available carbohydrates will increase lactic acid and thereby lower pH (Carpintero et al., 1969; Watson and Nash, 1960).

Legumes have always been considered an important group of crops grown for feeding livestock due to their nitrogen-fixing properties and their high level of protein. Some common legumes are red clover, white clover, and alfalfa. According to McDonald (1981), most legumes were once regarded as being unsuitable for ensiling as the fermentation was basically dominated by clostridia, leading to a butyrate-type silage. The reason for this problem

has been attributed to three factors. First, they are highly buffered, second they tend to have low water soluble carbohydrates, and third they are often of low dry matter content. The disadvantages of using legumes as a silage product has somewhat been overcome by pretreatments such as wilting and the use of fermentation additives (Carpintero et al., 1969).

A wide variety of other herbaceous material are used to make silage. Waste from canneries processing food crops such as green beans, sweet corn, green peas, beet tops, and cull potatoes, have been used successfully in areas where they are available. Residues of this type are difficult to use on a fresh basis because of the difficulty in the availability of daily supply and/or because they are available for only short periods of time (Church, 1977; Barth and Gelaye, 1979).

Ensiling Process

Ensiling is basically a method of crop preservation. Barnett (1954) stated that the fundamental principle underlying all attempts at the conservation of any crop is the desire to preserve the material at its optimum stage of growth for utilization at those seasons when the fresh crop itself is not available. If forages are not preserved they either putrify or compost and most of all nutritive value is lost. Two methods of preservation are drying (hay making) and ensiling. Traditionally hay making has long been the main process of preserving forage. It was not until the latter part of the nineteenth century that interest in silage making as a

conservation technique became widespread. Hay making requires delaying harvest until a mature stage of plant growth of relatively high dry matter content was achieved. This usually means that the product would be of low nutritional value. Any attempts to harvest crops at an earlier stage of maturity resulted in the decomposition of the crop due to the high moisture content and the microbical activity that would occur under these conditions. But, preserving crops by natural fermentation would result in a decreased need to harvest plants at a more mature (higher dry matter content) stage and permit harvesting crops that were higher in nutritional value.

The ensiling process is a destructive method, and therefore no silage produced can be expected to have a feeding value greater than the material ensiled. It is, therefore, essential to minimize the nutrient losses of the ensiled material during ensiling and to produce silage that is adequate in meeting an animal's nutritional needs. In order to minimize nutrient losses it is necessary to achieve and maintain anaerobic conditions, thereby restricting the destructive process of aerobic microorganisms and oxidative enzymes on plant material (Whittenbury et al., 1967).

Nutrient preservation in silages is basically the result of fermentation of soluble carbohydrates by lactobacillus and/or other lactic acid producing bacteria. Wood (1961) divided the lactic acid producing bacteria into two types: (1) homofermentative lactic acid bacteria, and (2) heterofermentative lactic acid

bacteria. The homofermentative organisms are utilized in the fermentation of either glucose or fructose by way of the glycolytic pathway to form two pyruvate molecules which are subsequently reduced to two moles of lactic acid.

Heterofermentative organisms can produce a number of products depending upon the type of sugar that is fermented (Edwards and McDonald, 1978). Both glucose and fructose fermentation basically follows the hexose monophosphate pathway of glyceraldehyde-3-phosphate and acetyl phosphate. The glyceraldehyde is later oxidized to pyruvate which is then reduced to lactate as in the homolactic pathway (McDonald, 1981).

Of the various organic acids that are generally present in herbage, malic acid and citric acid are two of the most important and are known to be rapidly metabolized in ensiled herbage (Playne et al., 1967). The fermentation of citrate and malate by lactic acid bacteria results in the production of pyruvate which can follow one of several pathways. Some of the products that are formed are 2,3-Butanediol, ethanol acetoin, lactates, acetates, formates, carbon dioxide, or alkaline released cations. At low pH, it was shown that lactate was the major product, but as pH increased, acetate and formate increased and above pH of seven, no lactate was formed (Campbell and Gunsalus, 1944; Gunsalus and Campbell, 1944).

Lactic acid bacteria are virtually non-proteolytic microorganisms and they have limited powers of amino acid synthesis,

but some nitrogenous components are involved in the fermentation process (Beck, 1978). The ability of the lactic acid bacteria to ferment amino acids also appears to be restricted and it is thought that only two, serine and arginine, are extensively attacked by some, but not all, of the lactic acid producing organisms (Bradey, 1966). The end products resulting from the fermentation of arginine by lactic acid bacteria are ornithine, ammonia, and carbon dioxide and serine is degraded to acetoin, ammonia, and carbon dioxide (Oginsky and Gehrig, 1953).

MacPherson and Violante (1961) reported that some amino acids may be broken down by lactic acid bacteria, but the extent may be dependent upon the pH level. In a later study by Whittenbury et al. (1967) it was reported that some lactic acid bacteria did attack arginine and serine, these being deaminated and decarboxylated to ornithine and acetoin, respectively.

Even when the anaerobic conditions are met, the stored material is still subjected to spoilage by the anaerobic clostridia. According to Buchana and Gibbons (1974) and Beck (1978), clostridia are defined as gram-positive, spore-forming, rod shaped bacteria that grow under anaerobic conditions and ferment sugars, organic acids and proteins.

Clostridia occurs not only in silage but also in feces and in the soil. It was originally postulated that the alimentary tract was the main habitat of these organisms and that their presence in soil and other materials was due to fecal contamination.

It is now postulated that the primary habitat is the soil and that their presence in the tract is through infestion of soil-contaminated vegetable foods (McDonald, 1981; Wilson and Miles, 1975). It is now considered that the contamination of silage with clostridia is probably the result of soil contamination (Allen and Harrison, 1937; Gibson, 1965; Gibson et al., 1958).

Clostridia are able to utilize the soluble carbohydrates and lactic acid as an energy source in which pyruvate and crotonyl coenzyme A are intermediates to produce butyric acid, carbon dioxide, and hydrogen as end products (Edwards and McDonald, 1978). As a result of the formation of butyrate from the breakdown of lactic acid, and the fact that the former is the weaker acid, the pH of the mass rises and provides a favorable medium for the growth of clostridia (Whittenbury, 1968).

Clostridial silages have been characterized as having a high pH, high water soluble nitrogen content, and high volatile nitrogen content, usually more than 20% of total nitrogen (McDonald and Edwards, 1976).

II. FACTORS AFFECTING SILAGE QUALITY

Stages of Plant Maturity

In selection of crops for optimum stage of maturity for the preservation of silage, they should have a soluble carbohydrate content of 6-8% (dry basis), a relatively low buffered capacity, and a dry matter content (on a fresh crop basis) of 25-35% (Church and Pond, 1974).

Chamberlain et al. (1978) stated that the harvestable corn plant yield tended to decrease as maturity increased. The quantity of green plant material (expressed on the basis of dry matter per acre) tended to increase from the late milk stage through the early and late dough stages, and later decreased at the mealy endosperm stage. Average daily gains of heifers fed silage that was harvested in the late milk and early and late dough stages were similar and significantly higher than the heifers fed the mealy endosperm stage of silage. Average daily intakes decreased with increased maturity of the plant material ensiled. Intake of the mealy endosperm silage was significantly less when compared to the intake of the other three stages. These results suggest that the optimum time to cut whole corn plant for feeding beef heifers as silage is between the early dough and late milk stage of maturity. After that stage, beef production per acre decreases.

Ohshima and McDonald (1978) reported in a study on the composition of whole corn crop that was planted at different plant densities. Results indicated that with increasing plant density there was a marked increase in the dry matter content and starch and decreases in water soluble carbohydrates and buffering capacity. Church (1977) has shown that the effect of stage of maturity on nutritive value of corn silage results in a significant increase in dry matter content from the soft dough to the glazed and frosted stage. Also, there was an increase in nitrogen free extract as the corn plant matures.

Moisture Content

Moisture content is probably the single most important factor affecting the quality of silage. According to Bolsen (1981), silage with a moisture content of above 74 to 76% can produce seepage, clostridial fermentations and butyric acid, high fermentation and storage losses, and reduced silage intake by cattle.

Gordon (1967) stated that one can reduce average moisture content by: (1) wilting; (2) inclusion of a high dry matter additive; and (3) allowing further maturation of the crop. The third method is generally unattractive due to the lowering of the feed value of the more matured forage.

According to Bolsen (1981), silage that contains a moisture level below 50% results in problems such as: (1) elimination of air because of poor compacting; (2) achieving sufficient fermentation to lower pH level and preventing mold and spoilage.

Size of Cutting

Crops, when chopped too coarsely, present two major problems: (1) more air will be entrapped when the crop is ensiled; and (2) generally cattle will tend to refuse silage that is large in size. Bolsen (1981) indicated that the length of cut of corn silage should be in the vicinity of .6 to 1.3 cm, but this will vary with the crop, power requirement, and tonnage per hour.

pH

The buffer capacity of plants, or their ability to resist change in pH level, is an important factor affecting the quality of silage. In early stages of the ensiling period, that which consists of the period in the field and the initial period in the silo, there seems to be little change in pH. For example, Carpintero et al. (1979) reported in an experimental study, that samples of herbage were subjected to a rapid wilt for six hours in a forced-air cupboard at room temperature, a natural wilt for 48 hours in the field under good weather conditions, a moist wilt for 48 hours under high relative humidity, and a moist wilt for 144 hours under similar conditions. Results indicated that there were no significant changes in the pH in any of the treatments.

After the initial period from field to the first few hours in the silo, anaerobic conditions are presumed to dominate. Lactic acid bacteria tend to grow very rapidly on the released plant juices resulting in a decrease in pH. Moon et al. (1981) reported that corn silage reached a minimum pH of 3.6 after two days and remained constant throughout the remainder of the ensiling period. McDonald (1981) stated that although there has been no direct measurements of respiration rates in silos, there is evidence that respiration rate declines as pH falls.

Virtanen (1938) found that at pH 3.5 respiration was only about 20% of the normal and that a pH of 3 or under resulted in the inhibition of plant cell respiration. Virtanen (1947) also

found that the action of clostridia and coliforms were inhibited below a pH of 4.

Temperature

In the early stages of the ensiling period most biosynthetic reactions that are still occurring in the harvested plants are limited and it is assumed that virtully all the energy in the oxidized glucose is converted into heat. This results in a temperature increase of the mass and is due to aerobic respiration that is still occurring in the harvested plant (McDonald, 1981).

McDonald (1973) stated that upright silos containing a mixture of air and grasses in the proportion of 2:1, that had been rapidly filled and well sealed, results only in a small increase (2.3 C) in temperature during the early stage of the ensiling process. However, gordon et al. (1961) and Langston et al. (1958) found that a considerable amount of aerobic respiration and oxidation with subsequent heat production occurs in many silos resulting in temperature increases of 30 to 50 C.

Generally, it can be concluded that high temperatures should be avoided if at all possible (Wieringa, 1960). It has been shown that temperature levels in the ensiling mass can have a marked influence on the growth of clostridia. The optimum temperature for the growth of most clostridia organisms is 37 C (Ohyama et al., 1973). In a study using one ton capacity silos McDonald et al. (1980) demonstrated that with ensiled grass of low dry matter

content (152 g kg^{-1}), increasing the temperature to 42 C resulted in a clostridial fermentation, whereas in similar material kept at 20 C a lactic acid fermentation occurred. High temperature should be avoided for another reason. Protein digestibility has been found to be reduced in the presence of oxygen at high temperatures, thereby decreasing nutritive value (Bratzler et al., 1960). The cause of reduced protein digestibility is accepted as being due to the Maillard reaction. The Maillard reaction refers to the condensation reaction of carboxyl groups obtained from reducing sugars with amino groups of protein (Darrah et al., 1977). Temperature control is very important and in most cases high temperatures can be controlled by adequate packing techniques employed at the time of ensilage, rapid sealing, and rapid removal of the material from the silo during feeding.

Type of Storage

The type of silo can and will alter the effect on silage quality. Bolsen (1982) indicated it is not uncommon for silage losses to be as high as 40% in value from the time the crop is cut until it is fed. Bolsen (1980) reported the following guidelines that can be followed as to the amount of dry matter loss for type of structure utilized: (1) oxygen limiting silo would be expectant of a 3 to 8% loss; (2) concrete upright silo would be expectant of a 5 to 15% loss; (3) trench type storage would be expectant of a 12 to 25% loss, and (4) open stack would be expectant of a 20 to 40% loss.

III. SILAGE ADDITIVES

Various types of commercial additives have been marketed for improving the fermentation process of corn and other forage silages. Bolsen (1978) defined aids to silage fermentation as those products that either: (1) supply acids for direct acidification; (2) supply readily fermentable carbohydrates required by lactic acid producing microorganisms; or (3) supply lactic acid producing microorganisms (living or killed).

Acids for Direct Acidification

Organic and mineral acids are available as commercial aids in the preservation of grains and forages. The most commonly utilized organic acids are: (1) formic; (2) propionic; (3) acetic. The mineral acids include such acids as hydrochloric and sulfuric acids. The main purpose of the addition of acids to silage is to lower the pH so that undesirable microbial activity is reduced or completely stopped.

Organic Acids

Formic acid. The utilization of formic acid as a silage additive was originally advocated by Dirks in 1926 (McDonald, 1981). But it was not until 1966, with the development of an apparatus that could be attached to a harvesting machine which could spray the acid directly onto the forage immediately after cutting, that use of formic acid as a commercial silage additive became widespread.

Britt et al. (1975) reported that lactic acid concentrations of corn silage were decreased by the addition of .5 and 1% formic acid, which suggests an inhibition of microbial activity. However, with the addition of 2% formic acid, there was total inhibition of lactic acid producing microorganisms.

Waldo et al. (1971) compared both direct-cut alfalfa and sudan-sorghum hybrid ensiled as untreated or treated with a .5% solution of formic acid. Dry matter recovery was higher for the forages treated with formic acid than for those of untreated perennial ryegrasses with .2% formic acid and reported lower temperatures during the ensiling than in untreated grasses.

Propionic acid. The action of propionic acid has been of special interest because it has been shown to inhibit fungal growth and heating (Britt et al., 1975). Huber and Soejono (1976) reported that propionic acid treatment of high dry matter silage resulted in a cooler fermentation more resistant to fungal growth and spoilage than for untreated silages. Leaver (1975) reported that propionic acid treatment of corn silage resulted in less dry matter loss during ensiling by 8% when compared to that of untreated silage. Gross and Beck (1970) reported that fresh corn crop treated with propionic acid at greater than .4% under aerobic conditions, reduced the early rise in temperature, prevented a drop in lactic acid and pH, and prevented spoilage.

Acetic acid. Huber et al. (1972) reported that acetic acid treatment of silages with dry matter (34-39%) slightly increased silage intake of dairy cows. Byers et al. (1982) reported acetic acid addition to corn silage resulted in inhibiting fermentation, since it decreased production of lactic acid and ethanol by 18 and 30% and reduced wet matter and energy losses by 18 and 67%.

Overall, the use of propionic acid over formic and acetic acid as a silage additive is suggested as being more desirable in terms of recovery of silage nutrients and animal performance (Huber and Soejono, 1976).

Mineral Acids

The proposal to utilize mineral acids as silage additives as a means of silage preservation dates back to 1885. However it was not until the late 1920's when Virtanen developed a method of preserving crops with the use of mineral acids that farmers widely accepted and utilized acidification of crops for silage making (Watson and Nash, 1960).

Virtanen's (1938) main objective of crop preservation was to determine the amount of mineral acid needed to reduce the pH of silage to a level at which plant and microbial enzymes would be inhibited. But in order to cause this, Virtanen found that the pH of the silage had to be reduced to 3.0. But this low pH resulted in silage that was unacceptable to animals. Through further investigation, Virtanen finally discovered that silage

at a pH of 3.6 was sufficiently low to considerably reduce plant respiration and microbial activity but was still palatable and readily accepted by ruminant animals.

Mineral acids as silage additives are not widely utilized because of their corrosive nature on metal silos and equipment for loading, mixing, unloading, and hauling of the acid treated silage.

Readily Fermentable Carbohydrates

Fermentable carbohydrates are the main source of nutrients utilized by microoraganisms. Materials high in fermentable carbohydrates have been added to silage crops in order to increase the supply of available substrate for the growth of lactic acid producing microorganisms.

Such crops as legumes, which are low in soluble carbohydrates, have been aided with the addition of readily fermentable carbohydrates. Various materials which have been utilized as additives include grains, sugars, and molasses.

Grains such as corn, oats, milo, and barley have been used as additives in an attempt to improve both the fermentation quality and the nutritional value of silages. The aim of these additions was to add dry matter so as to decrease the effect of excess moisture and to add readily fermentable carbohydrates to influence fermentation (Ely, 1978).

Corn has been added to ensiling material in various forms. Autrey et al. (1947) added 45 kg of hominy corn feed per ton to

alfalfa, brome grass-ladino clover, and orchard grass-ladino clover silages and found that hominy feed was as effective as 27 kg per ton of molasses on producing an acceptable fermentation and a desirable pH. Allen and Porter (1954) stated that with the addition of 45 kg per ton ground corn to alfalfa bromegrass silage resulted in increased lactic acid and total acids.

Ground oats (63.5 kg per ton) was added to grass and legumes (Archibald, 1953) with a slight increase in acidity. Owens and Senel (1963) added crushed milo to first cut early bloom alfalfa in the laboratory with no change in pH when compared to early bloom alfalfa ensiled by itself. Mutdock et al. (1955) added 45.4 kg of barley meal per ton to alfalfa-timothy that was effective in the preserving of the crop but no better than wilting, acid, or molasses on preserving the crop.

Ohyama et al. (1975) have shown that the addition of glucose to ryegrass resulted in a silage that had a pH of 3.7 and a lactic acid content of 20 g kg^{-1} when compared with the untreated silage which had a pH of 5.7 and contained no lactic acid.

Weise (1967) reported that by adding a 1% sucrose solution to herbage containing 15-16% dry matter resulted in an initial increase in lactic acid producing bateria when compared to untreated herbage. Also, increases in pH and butyric acid producing organisms were less for silage with the sugar treatment.

Molasses has been utilized as a source of readily fermentable carbohydrates for microorganisms in silage making for many years

(McDonald, 1981). According to Archibald (1953) the addition of molasses to alfalfa will increase dry matter, lower pH, and increase organic acids. Molasses not only adds available readily fermentable carbohydrates for the microorganisms in the silage but also increases the palatability of the silage.

Microbial Inoculants

Nutrient composition of forages has been preserved by fermentation with varying success. The overall objective of fermentation is to produce lactic acid by bacteria in sufficient quantities to lower pH of silage to stability (Watson and Nash, 1960). It is important then that the lactic-acid-producing microorganisms established themselves and reach optimum numbers rapidly because until they do, undesirable anaerobes will be active (McCullough, 1977).

It has been generally assumed that sufficient population levels of lactobacilli are naturally present in fresh herbage (Burghardi et al., 1980). However Stirling (1953) and Anderson (1956) reported that the number of lactobacillus organisms on fresh forages may sometimes be extremely low, resulting in a possible need for the addition of the lactobacillus organisms.

There are various types of Lactobacillus species utilized as silage additives, including Lactobacillus acidophilus Lactobacullus bulgaricus, Lactobacillus brevis, and Lactobacillus plantarum. Beck (1978) summarized several studies that found that

Lactobacillus plantarum was an effective additive that considerably improved silage quality and decreased silage spoilage loss.

Ely et al. (1981) reported that the addition of Lactobacillus plantarum to alfalfa and wheat silages resulted in a lower pH, higher lactic acid content, and a greater recovery of dry matter and crude protein. However, Moon (1981) reported that the addition of a mixture of Lactobacillus adidophilus and yeast (Candida sp.) resulted in similar lactic acid bacteria populations and pH in both the control and the inoculated silages. Alli and Baker (1982) reported that the incorporation of a Lactobacillus plantarum culture to chopped whole plant corn increased rate of lactic acid production 70% when compared to a control over a 48 hour fermentation period.

O'Leary and Bull (1977) found that addition of Lactobacillus microorganisms caused a more rapid decrease in pH and readily available carbohydrates concurrently with a more rapid increase in lactic acid during the early fermentation period of ensiling, when compared to control silage. However, Burghardi et al. (1977) could not detect significant changes in pH and lactic acid concentrations of corn silage due to the level or type of several Lactobacillus microorganisms.

Bolsen (1976) ensiled whole-plant corn (dented) at 37% DM in 23 metric ton capacity concrete silos. Silage treatments were an untreated control and Lactobacillus, A . oryzea and B. subtilis cultures. Lactobacillus, A. oryzea and B. subtilis treatment preserved 87.5% of the silage dry matter compared to 80.9% for the untreated

control. Yearling steers fed treated silage gained non-significantly faster and more efficiently than those fed the control silage. Dry matter digestibility was 64% for the Lactobacillus, A. oryzea and B. subtilis treated silage and 63% for the control silage.

Burghardi et al. (1977) ensiled whole-plant corn (about 29% DM) in upright concrete silos with and without Lactobacillus, A. oryzea and B. subtilis cultures. Steers fed the control and Lactobacillus, A. oryzea and B. subtilis treated silages had similar gains and efficiencies of gain. Dry matter, energy, and protein digestion coefficients were not affected by silage treatment.

IV. AEROBIC DETERIORATION OF SILAGE AFTER ENSILING

During the utilization period (bunklife) silage is exposed for varying amounts of time to atmospheric oxygen. During this period deterioration of silage is due mainly to microorganisms which are active under aerobic conditions.

Ohyama and Hara (1975) reported that the deterioration process of silage is due mainly to that of lactic-acid-assimilating yeasts and fungi such as species of Candida, Hansenula, Pichia, and Endonycopsis. These yeasts can assimilate lactic acid rapidly resulting in temperature and pH increases in the deteriorating silage.

The aerobic deterioration process has often been referred to as "secondary fermentation" or "after-fermentation," but these

terms are inappropriate as fermentation is an anaerobic process while deterioration of this nature is considered aerobic (McDonald, 1981).

There is considerable variation among different silages in the rates at which deterioration occurs. Some silages show temperature rises a few hours after exposure to air, while other silages remain stable in the presence of oxygen for several days. For example, Moon et al. (1980) reported that early deterioration of wheat silage differed greatly from that of alfalfa and corn silages because of very high butyric acid concentrations and little lactic acid present in the wheat silage. Growth of yeasts and molds was rapid in the wheat silage resulting in temperature increases and the disappearance of lactic acid.

Microbiology of Aerobic Deterioration After Ensiling

The importance of yeasts in the deterioration of silage on exposure to air was first reported by Beck and Gross (1964) who concluded that the stability of silages was dependant upon yeast populations. Beck (1975) in a later study found that after the initiation of aerobic deterioration by yeasts, a second microflora was built up consisting of proteolytic bacteria, streptomyces, and molds.

According to McDonald (1981) the presence of yeasts in silage is not considered desirable because under aerobic conditions,

yeasts respire in a manner similar to that of higher plants. Respiration occurs in the mitochondria that contain enzymes of the citric acid cycle and an organized electron-transport system. This may result in the complete oxidation of any remaining sugars by yeasts, yielding carbon dioxide and water. In addition to hexose sugars, some yeasts are known to utilize polysaccharides (starch) and organic acids (lactic, acetic, citric).

Moon et al. (1980) showed that protein availability in alfalfa silages inoculated with Lactobacillus acidophilus and a Candida spp. resulted in large losses of protein in the early stages of aerobic deterioration after ensiling. Deterioration of protein continued during the feeding period as concentrations of isovaleric, isobutyric, and other acids increased.

Ohyama et al. (1975) reported that aerobic deterioration after ensiling of silages by yeast and fungi can be prevented or retarded in some instances by organic acids and other end products of a nonlactate fermentation. In a later study, Crawshaw et al. (1980) found that silages treated with propionic acid were associated with smaller changes in pH and restricted carbon dioxide production during aerobic deterioration after ensiling and there was virtually no bacterial or mold proliferation through still considerable increases in number of yeasts.

Molds also play an important role in the aerobic deterioration of silage after ensiling and have been found to be of particular importance in grass silage (Ohyama et al., 1977). The presence

of molds in silage according to McDonald (1981) is undesirable since they break down not only sugars and lactic acid, but also hydrolyse and metabolize cellulose and other cell wall components. Furthermore, certain molds produce substances (mycotoxins) which are harmful to animals.

Biochemical Changes During Aerobic Deterioration

Water soluble carbohydrates, lactic acid, and acetic acid are the main sources of energy for aerobic microorganisms involved in silage deterioration. The oxidation of these nutrients results in the release of carbon dioxide, water, and heat. According to McDonald (1981), silages in which fermentation in the silo has been restructed by the use of chemical additives or by excessive wilting, glucose and fructose will be the main energy sources, whereas in untreated well-preserved silage the main product oxidized is likely to be lactic acid.

In the early stages of aerobic deterioration after ensiling, crude protein and crude fiber content tended to remain constant while in the later stages crude fiber and sometimes crude protein are decomposed (Honig and Woulford, 1980). The assimilation of lactic and acetic acids by aerobic microorganisms results in an increase in pH, which is well correlated with temperature rise (Britt et al., 1975).

Moon et al. (1980) conducted a study by preparing alfalfa and corn silages with a live bacterial inoculum, Lactobacillus

acidophilus, and yeast, Candida spp. This was done to determine the effect of these organisms on silage quality during aerobic deterioration after ensiling. In all instances where the silages were inoculated, the pH and temperature increases were significantly different than in the control silages. These higher increases were attributed to the rapid increases in yeast and mold flora which oxidized lactic and volatile acids resulting in increased temperature and pH. It was concluded that aerobic deterioration of silage is significantly affected by the addition of Lactobacillus acidophilus and Candida spp.

V. EXPERIMENTAL SILOS

The products of the ensiling process are the result of many influences working together. Experimentally, the effects of individual influences are difficult and sometimes impossible to trace when utilizing large field silos. But, with the aid of experimental silos such effects might be more readily determined where conditions could be more readily controlled (Perkins and Pratt, 1951).

The purposes of the experimental silo are manifold. First of all, it is more economical with less time and labor to conduct silage research in smaller experimental silos than using the larger commercial field silos. Their use enables the researcher to be able to utilize adequate replications which make analysis of results by statistical methods more meaningful. Sampling of the material

being ensiled is another advantage when utilizing experimental silos, because according to Parker (1978) it is difficult to extract a meaningful sample during the course of fermentation in a large silo without having the microbial environment altered at that point, and adjacent areas are no longer representative of the typical fermentation. But the utilization of smaller amounts of substrate in experimental silos permits removal of the entire contents and results in more uniformity of the material.

El Hag et al. (1982b) stated that under optimal conditions, experimental silos will provide an environment that produces silage of excellent quality and permits the investigation of chemical and microbiological changes during fermentation. However, according to Parker (1978) experimental silos do not always offer the field characteristics of heat flow and heat accumulation, hydrostatic pressure and packing as found in the large field silos and therefore, concern must be taken when interpreting the results obtained when utilizing the smaller experimental silos.

The utilization of experimental silos as a tool for silage research has been reviewed by several workers (Barnett, 1954; Otis et al., 1959; Perkins and Pratt, 1951). The most widely used type of experimental silo, according to McDonald (1981), is the test-tube with a capacity normally ranging from 50 g to 250 g. The test-tube is normally fitted with some type of a sealing device which permits the escape of gases but prevents the introduction of air. Sealing devices may either be a rubber stopper carrying a

valve of mercury supported on a sintered glass disc (Gibson et al., 1958) or a simple glass fermentation trap that is filled with water (McDonald and Henderson, 1974).

Wilson and Wilkins (1972) evaluated laboratory ensiling techniques by comparing 18 grasses and 8 legumes in test-tube silos with a capacity of 100 g of fresh herbage with the same crops ensiled in polyethylene bags holding one ton of fresh material. Measurements made on silages from the test-tube silos were highly correlated with those from the polyethylene bags. McDonald (1981) confirmed the above findings, although in some instances fermentations in laboratory silos may be atypical, and frequently high in acetate content, unless precautions are taken to ensure that the herbage contains normal levels of lactic acid producing bacteria or inoculating the herbage with these organisms prior to ensiling.

Another type of experimental silo is the steel drum. Leask and Daynard (1973) utilized 23-liter (5.1 gal.) drums lined with 2-mil polyethylene bags in a laboratory experiment. The silos were designed so that the material being ensiled could be compacted with various amounts of pressure by placing cement blocks on a plywood disc on top of the silage. The purpose for applying these different pressures was to look at the relationship between vertical pressure and silage depth. Results indicate that with airtight conditions, pressure is less important than commonly assumed in producing high-quality silage.

El Hag et al. (1982) developed an experimental silo to study the variables affecting the ensiling process, such as moisture, temperature, density, light, and additives. The experimental silo was made out of plexiglass, had a capacity of 250 g of forage material and contained four major parts. These included: a gas tight cylinder, a threaded cap fitted with a steel torque bolt, a round compacting piston that fits inside the cylinder, and a stainless steel gas-collecting tube. The experimental silo was able to simulate farm silos and produce high quality silages. The smaller amounts of substrate also permitted closer control of the ensiling process and more uniformity of composition of the starting material.

Virtanen (1938) developed an experimental silo by using a porcelain container capable of holding 20 kg of silage. The bottom of the silo was fitted with an internal slotted wooden platform to allow for the collection of seepage. The unit was sealed by cementing on a porcelain lid. This was done to limit oxygen in the silo. The internal top of the unit was a wooden cover with a dish containing concentrated potassium hydroxide so that carbon dioxide could be determined by back titrating of the carbonate formed. This type of unit allowed Virtanen to investigate respiration losses, dry matter losses, and carbon dioxide production.

Another type of experimental silo designed for measuring losses during the ensiling period was developed by McDonald and

Attwood (1958). The unit consisted of four silos, each constructed of steel and having a height of 1.8 meters and a diameter of 1.2 meters, with a capacity of approximately one ton. Each silo had seven sampling parts and ten thermocouples, and was suspended for the purpose of weighing. The weighing apparatus was designed to counterbalance the whole load and to measure the actual weight loss.

CHAPTER III

EXPERIMENTAL PROCEDURE

In this study, research was conducted at The University of Tennessee, Knoxville to determine the effects of several microbial and chemical fermentation additives on changes in temperature, moisture content, nutrient composition, pH, lactic acid levels, and other volatile fatty acids during the ensiling of whole corn plants. Also, changes in temperature, moisture content, pH, and nutrient composition were determined during aerobic deterioration after ensiling.

The four experimental treatments were evaluated and they were as follows: (1) control, untreated corn silage; (2) Silabac[1], treated corn silage; (3) Culbac[2], treated corn silage; and (4) Crop Cure[3], treated corn silage.

I. PLANT MATERIAL USED FOR ENSILING

Whole corn plants (3147 Pioneer variety), grown at the University of Tennessee dairy farm, were harvested by a Fox Forage Harvester. The corn, harvested in August 1981, was in the early

---

[1]Pioneer H-bred International, Inc., Des Moines, Iowa.

[2]TransAgra Corporation, Memphis, Tennessee.

[3]Domain Industries, Inc., New Richmond, Wisconsin.

dent stage of maturity and contained 28.8% dry matter (DM). Corn plants were chopped into approximately 6.4-12.7 mm long pieces, blown into a wagon and immediately transported to Brehm Animal Science Building. The green chop was immediately unloaded and placed temporarily in 208 liter (55) gallon steel drums lined with plastic and stored in a cooler at 4.4 C to minimize fermentation activity prior to the addition of the fermentation additives. The green chop was removed from the cooler and placed in a Marion Mixer, model number 2030, with a speed of 60 rpm and mixed for approximately two minutes, during which time one of the three fermentation aids was added as uniformly as possible by broadcasting it on top of the green chop at the rate of one pound per ton of wet green chop, as recommended by the manufacturers.

II. TEMPERATURE CHANGES DURING FERMENTATION

One hundred kg of green chop untreated or treated with one of the three fermentation aids was placed in a 208 liter steel drum that was lined with two polyethylene bags that measured 96.5 cm by 162.6 cm and had a thickness of 4 mils. This procedure was repeated eight times such that there were two drums for each of the four treatments. The 100 kg of green chop was manually placed in the experimental silos and compacted. Care was taken to pack the green chop to exclude as much air as possible.

During the placement of the green chop in the experimental silos, a thermocouple was placed in the center of the mass in each

experimental silo. This was accomplished by punching a small hole in the top of the polyethylene bag and threading the wire containing the thermocouple through the hole. Tape was then placed around the small hole to prevent air seepage. The material containing the thermocouple was then sealed by tying the polyethylene bags at the top and placing a metal lid on each steel drum. A Brown Potentiometer was utilized to record temperature changes during the fermentation period on an hourly basis for the first 36 hours, followed by recording of temperature every 24 hours for 7 days, followed by temperature recordings every 72 hours until the end of the experiment which lasted 47 days.

III. NUTRIENT COMPOSITION AND pH CHANGES DURING FERMENTATION

Conduct of Experiment

Changes in pH, proximate constituents, cell wall constituents, acid-detergent fiber-nitrogen, and volatile fatty acids at various fermentation times were measured. Therefore, 20 kg samples of green chop containing one of the four treatments were placed in a small polyethylene bag, sealed, and placed in a 208 liter steel drum. This procedure was repeated 10 times for two replications of each treatment. Thus there were four drums per treatment of five individual bags each. The ten-bag system for each replication of each treatment allowed the removal of a sample on various sampling days without interruption of the ensiling process. The 20 kg samples

were removed from the silos on days 0, .5, 1, 2, 3, 6, 9, 18, 27, and 36. The samples were immediately frozen for later analyses.

Proximate and Van Soest Analyses

Moisture content of the frozen silage samples taken during the ensiling period was determined in a two-step method. The first step required that a weighed frozen silage sample be dried at 60 C for 72 hours, removed from the drying oven, allowed to air equilibrate for 72 hours and weighed. Air-equilibrated dry matter was then calculated. To prepare for the second step, the dried sample was ground through a 1 mm mesh screen of a Wiley mill, a 2 gram portion of the sample was placed in a 100 C drying oven for 24 hours and residual dry matter was calculated. Total dry matter was then calculated.

Total nitrogen content was determined on the air-equilibrated dry matter samples by the Kjeldahl procedure according to AOAC (1975) methods. Neutral detergent fiber and acid-detergent fiber nitrogen was determined on the air-equilibrated dry matter samples according to Van Soest (1970). Acid-detergent fiber and lignin were determined by procedure outlined in the AOAC (1975).

Lactic Acid

Lactic acid concentrations were determined on wet silage samples by the Barker and Summerson (1941) colorimetric method as modified by Pennington and Sutherland (1956). Duplicate 5 gram samples of frozen macerated corn silage were placed in 250 ml

beakers. Then 100 ml of boiling distilled water was added to each beaker and allowed to cool for five minutes. The solutions were then mechanically shaken for five minutes during which time .5 gram of solid calcium hydroxide was added to each solution. The solutions were then filtered through Whatman (541) hard filter paper and the first 20 ml of filtrate were discarded. Of the remaining filtrate, one 2 ml sample was taken from each solution and diluted to 10 ml with distilled water. One ml of each solution was pipetted into a 25 ml glass stoppered bottle and 8 ml of distilled water, 1 ml .80 copper sulfate, and 1 gram of calcium hydroxide were added, respectively. The bottles were stoppered, shaken for 20 minutes in a mechanical shaker, the contents were filtered, the first 2 ml were discarded, and the remaining filtrates were collected in small test tubes. A 1 ml sample was pipetted from each filtrate and placed in a 20 ml tube where 9 ml of ice cold concentrated sulfuric acid was added dropwise. The tubes were stoppered and placed in a boiling water bath for five minutes, then allowed to cool to room temperature. After cooling, .05 ml of .16 M $CuSo_4$ and .1 ml of p-hydroxydiphenyl reagent were added to the filtrates and the tubes were placed in an ice bath. Next, the tubes were placed in boiling water for 90 seconds and returned to the ice bath for 5 minutes and allowed to warm to room temperature. The concentration of lactic acid was determined using Bausch and Lomb Spectronic 21 spectro photometer at 5200 Å.

Other Volatile Acids

Other volatile fatty acids were determined by gas-liquid chromatography using the Bendix Series 2600 Laboratory Gas Chromatograph. Preparation of corn silage for volatile fatty acid analyses was conducted by procedures described by El Hag et al. (1982). Ten grams of silage material was weighed out and 100 ml of a mixture of distilled water and thymol (1 gram of thymol per liter of distilled water) was added to the sample and shaken for two hours on a wrist-action mechanical shaker at room temperature. The extract was filtered through three layers of cheesecloth and centrifuged at 5,000 rpm for five minutes. Four ml of the water extract was acidified with 1 ml of 25% metaphosphoric acid. The acidified solution was centrifuged at 10,000 rpm for 10 minutes and the supernatant was analyzed for volatile fatty acids by gas-liquid chromatography.

pH

The pH of the frozen silage samples was determined with Fisher model 520 digital pH meter equipped with an external glass electrode. A 25 gram frozen sample was macerated in a Waring blender (model number 1120 and a speed of 21,000 rpm) with 250 ml of deionized water for three minutes. The silage and water mixture was then placed in a 400 ml glass beaker and the pH was determined by the immersion of the electrode into the mixture.

IV. EFFECT OF AEROBIC DETERIORATION

In this study, corn silage from the fermentation experiment was placed in eight open wooden bunks that measured 48 x 56 x 48 cm in size and were contained in an overall bunk that measured 4 meters by 56 cm overall. This experiment was conducted to study aerobic deterioration during bunklife.

After opening the polyethylene bags at the end of silage fermentation, the top 20 kg of corn silage was removed and discarded. This was done in order to remove any molds or other contaminants that might alter aerobic deterioration characteristics. The remaining 80 kg of silage in each silo was then utilized in four separate bunklife studies. In each bunklife study, 20 kg of silage was removed from each lab silo and placed in the open wooden bunk. Each bunklife study lasted 60 hours and ran sequentially.

Before the silage samples were placed into the wooden bunks, each was thoroughly mixed by hand for approximately two minutes to simulate conditions during unloading of silos. After the silage was placed in the bunks, thermocouples were placed in the center of the silage samples and temperature was recorded at two hour intervals in bunklife study one, two, three, and four. Samples for bunklife studies three and four were collected at 0, 12, 24, 36, 48, and 60 hours and frozen for later analysis which consisted of the determination of moisture content, total nitrogen content

according to procedures outlined in AOAC (1975), neutral detergent fiber and acid-detergent fiber-nitrogen according to procedures by Van Soest (1970), and acid-detergent fiber and lignin by procedures outlined in the AOAC (1975).

V. STATISTICAL ANALYSES

Significance of treatment effects on various parameters was determined by an analysis of variance and a Duncan multiple range test as described by Barr et al. (1976).

CHAPTER IV

RESULTS AND DISCUSSION

I. SILAGE COMPOSITION DURING THE ENSILING PERIOD

The effect of corn silage fermentation aids on lactic, acetic, propionic, and isobutyric acids at various sampling times during the ensiling period is presented in Table 1. The volatile fatty acid values for each treatment are presented as the means of four replications (two true replications per two experimental silos per treatment).

Lactic acid concentration was higher in all treated silages compared to the control silage on all sampling days, but was significantly higher ($P<.05$) only on days 3 and 27 during the ensiling period. The rate of lactic acid formation (Figure 1) was greatest by the third day of fermentation in all treated silages, approximately a 100% increase compared to the control, and continued to increase slightly throughout the ensiling period.

Alli and Baker (1982) reported that the addition of Lactobacillus plantarum cultures to chopped whole corn plant (.4 kg laboratory silo) increased the rate of lactic acid production by 70% compared to a control over two day fermentation. However, Moon et al. (1981) reported that lactic acid bacteria populations in corn silage treated with a commercial silage additive Silabac (containing Lactobacillus acidophilius and candida spp.) were similar to those of the silage.

TABLE 1. Lactic, Acetic, Propionic, and Isobutyric Acids (μM/g silage wet wt.) of Corn Silage During the Ensiling Period as Affected by Fermentation Additives

Treatment	Days of fermentation 0	1	3	6	18	27
	----------Lactic----------					
Control	---[a]	40.0[c]	47.4[c]	---[b]	190.2[c]	194.8[c]
Silabac	---[a]	81.0[c]	149.3[d]	---[b]	232.5[c]	219.3[cd]
Culbac	---[a]	74.1[c]	166.7[d]	---[b]	236.1[c]	245.5[de]
Crop Cure	---[a]	72.3[c]	175.2[d]	---[b]	227.3[c]	272.1[e]
	----------Acetic----------					
Control	17.8	30.0	27.8	38.3	36.3	37.1
Silabac	14.1	29.3	31.1	40.8	38.2	33.2
Culbac	13.4	28.9	28.7	38.8	46.8	45.3
Crop Cure	15.0	25.4	28.7	38.8	43.4	48.7
	----------Propionic----------					
Control	5.91	4.68	1.72	2.69	2.41	3.23
Silabac	4.95	4.81	1.79	2.41	2.75	2.68
Culbac	4.74	3.78	2.13	2.06	2.89	3.91
Crop Cure	5.78	4.06	1.65	2.61	3.30	3.71
	----------Isobutyric----------					
Control	1.03	1.24	.83	.96	1.03	1.17
Silabac	.89	1.44	.89	.89	1.03	1.03
Culbac	.96	1.31	.96	.89	1.10	1.17
Crop Cure	1.10	1.17	.89	.89	1.03	1.03
	----------A/P[f]----------					
Control	3.01	6.42	16.15	14.23	15.06	11.50
Silabac	2.85	6.09	17.40	16.95	13.90	12.39
Culbac	2.83	7.66	13.49	18.85	16.20	11.36
Crop Cure	2.59	6.25	17.42	14.88	13.15	13.14

[a]Lactic acid concentrations were too low to be detected.

[b]Lactic acid concentrations were not determined for day 6.

[c,d,e]Means in the same column with different superscript letters are significantly different ($P<.05$).

[f]Acetic to propionic acid ratio.

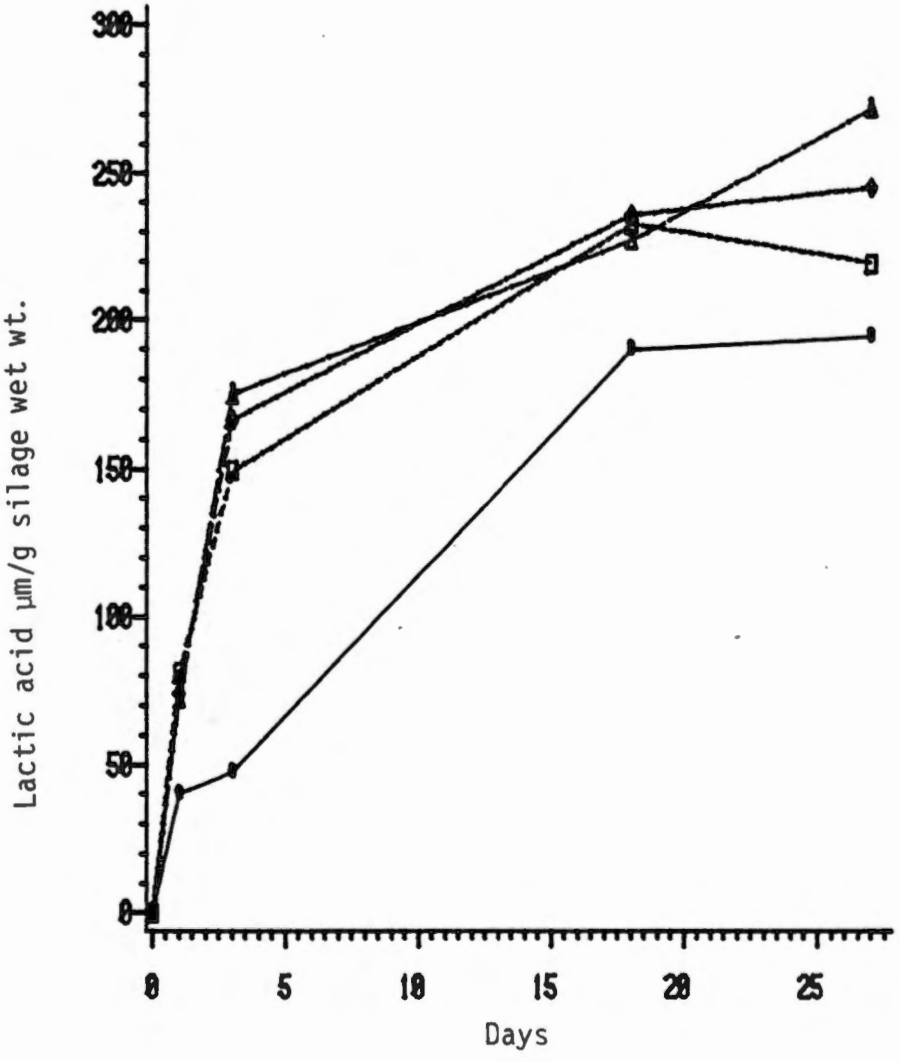

FIGURE 1. Effect of commercial aids to silage fermentation on lactic acid concentration of corn silage. Control •____•; Silabac □-----□; Culbac ◇-----◇; Crop Cure Δ ----- Δ.

The increased production of lactic acid lowers pH of the silage which stabilizes the mass so that no more fermentation occurs which results in better protection of the digestible nutrients. Lactic acid alone retains some fermentable energy for rumen organisms.

There were no significant differences ($P>.05$) in acetic, propionic, and isobutyric acids due to treatment. This agrees with results obtained by Burghardi et al. (1980) which reported that acetic acid content of corn silage was not influenced by the additive Lactobacillus acidophilus, Lactobacillus bulgaricus, or Lactobacillus brevis. Also, El Hag et al. (1982a) reported that there were no differences in acetic and propionic acid content of corn silage treated with either a bacterial inoculum containing a mixture of Lactobacillus acidophilus, streptococcus cremoris, Lactobacillus plantarum, and streptococcus diacelylactus or an air-dried live bacterial culture containing Lactobacillus and Toruloposis spp.

The mean acetic acid concentration of the treated silages and the acetic acid concentration of the control silage was similar. There was approximately a 100% increase in the amount of acetic acid during the first day of ensiling in all silages. Acetic acid concentration continued to increase in all treated silages, but there was a slight decrease in the amount of acetic

acid in the control silage on day 3. The values for acetic acid after day 3 continued to fluctuate with small increases and decreases throughout the remainder of the ensiling period.

The mean propionic acid concentration of the treated silages and in the control silage was similar. The control silage at the beginning of the ensiling period had a propionic acid concentration of 5.91 μM/g silage wet wt. and decreased 75% by day 3. However, throughout the remaining ensiling period there were slight increases in propionic acid in all treated silages and the control silage.

The mean isobutyric acid concentration of the treated silages and that of the control silage was similar. Isobutyric acid increased slightly in all treatments during the first day of fermentation, but later decreased slightly by day 3, with slight increases by the end of the ensiling period.

Final pH of all treatments (Table 2) was below 4.4 which indicated good fermentation (Van Soest, 1982). There were no significant differences ($P>.05$) in pH due to treatment. This agrees with results obtained by Moon et al. (1981) where the additive Silabac (containing Lactobacillus acidophilus and candida spp.) had no significant effect on the pH of corn silage.

Values of pH were similar between the treated corn silages and control, and changed from 5.5 at ensiling time to 3.8 at the end of the ensiling period. Alli and Baker (1982) reported a similar pH of 3.7 of corn silage treated with Lactobacillus plantarum after one week of ensiling in a 205 liter steel drum

TABLE 2. pH Level of Corn Silage During the Ensiling Period as Affected by Fermentation Additives[a]

Treatment	Days of fermentation					
	0	1	3	6	18	27
Control	5.50	4.36	3.82	3.81	3.88	3.84
Silabac	5.52	4.34	3.88	3.85	3.89	3.87
Culbac	5.51	4.37	3.84	3.86	3.85	3.87
Crop Cure	5.56	4.35	3.83	3.83	3.84	3.84

[a]There were no significant differences in pH due to treatment (P>.05).

(55 gal.). Also, they reported only small differences in pH between the treated corn silage and control silage.

The pH of the corn silage treatments reached a minimum at 3.8 by day 3 and remained this low throughout the remainder of the ensiling period. This agrees with results obtained by Moon et al. (1981) which reported that the pH of corn silage reached a minimum of 3.6 after 2 days of fermentation and remained constant throughout the remaining ensiling period.

Changes in dry matter, crude protein, and neutral detergent solubles of the treated silages and control are summarized in Table 3. There were no significant differences ($P>.05$) in any of these parameters due to treatment.

The dry matter percentages of the treated silages and the control were similar. Dry matter percent of the control silage was 28.8% at the beginning of the ensiling period and decreased to 27.2% by day 27.

Neutral detergent solubles on a dry matter basis changed from 45.4% for the control silage at the beginning of the ensiling period to 44.6% at the end of the ensiling period which lasted 27 days. The neutral detergent solubles for the treated silages and the cell solubles for the control silage were similar throughout the ensiling period.

Crude protein content on a dry matter basis was similar in the treated silages and the control silage. On a dry matter basis, the crude protein content of the treated silages at the end of the experimental ensiling period was nearly identical at 10.7% for

TABLE 3. Dry Matter, Neutral Detergent Solubles, and Crude Protein Content of Corn Silage During the Ensiling Period as Affected by Fermentation Additives[a]

Treatment	Days of fermentation					
	0	1	3	6	18	27
	----------Dry Matter, % ----------					
Control	28.8	29.1	27.6	29.3	28.2	27.2
Silabac	28.6	28.9	27.8	28.7	28.0	28.3
Culbac	28.1	28.6	29.0	27.0	27.1	27.2
Crop Cure	29.6	28.6	29.2	29.7	28.8	28.6
	--------Neutral Detergent Solubles, %DMB----------					
Control	45.4	42.5	41.9	45.8	42.8	44.6
Silabac	45.5	45.4	44.8	44.0	44.3	43.8
Culbac	43.9	43.4	44.5	45.7	42.8	44.7
Crop Cure	44.1	42.3	44.9	46.4	46.9	43.7
	----------Crude Protein, %DMB----------					
Control	10.7	10.2	10.6	10.0	11.3	10.5
Silabac	10.8	11.1	10.3	10.2	10.5	11.0
Culbac	10.5	10.1	10.8	10.8	11.1	11.2
Crop Cure	10.2	11.1	10.6	10.6	10.2	9.9

[a]There were no significant differences in any of the parameters due to treatment ($P>.05$).

control, 10.8% for Silabac, 10.6% for Culbac, and 10.9% for Crop Cure. These crude protein percentages are higher than the average crude protein value for corn silage reported by the NRC (1976). These high values for crude protein may be due to an extremely low yield of grain in relationship to stalk. El Hag et al. (1982a) reported that crude protein content averaged 9.6% for treated silage and there were no significant differences between control and treated silages.

Changes in neutral detergent fiber (hemicellulose, cellulose, and lignin) and acid detergent fiber-nitrogen of the treated silages and control silage are summarized in Table 4. There were no significant differences ($P>.05$) in hemicellulose, cellulose, lignin, and acid detergent fiber-nitrogen content due to silage treatment. Burghardi et al. (1980) also reported that the cell wall constituents were not significantly affected by the additives Lactobacillus bulgaricus, Lactobacillus acidophilus, and Lactobacillus brevis. Cell wall constituents on a dry matter basis were 48.7% for control corn silage, 51.8% for Lactobacillus brevis treated corn silage, and 43.4% for Lactobacillus bulgaricus treated corn silage.

II. TEMPERATURE CHANGES DURING THE ENSILING PERIOD

Temperatures recorded during the ensiling period are shown in Table 5. There were no significant differences ($P>.05$) in temperature due to treatment. Temperatures were very similar for all treatments throughout the ensiling period. The beginning

TABLE 4. Hemicellulose, Cellulose, Lignin, and Acid Detergent Fiber-Nitrogen Content of Corn Silage During the Ensiling Period as Affected by Fermentation Additives[a]

Treatment	Days of fermentation 0	1	3	6	18	27
	----------Hemicellulose, %DMB----------					
Control	26.3	29.4	30.4	24.6	26.3	24.4
Silabac	26.6	27.2	28.0	26.1	26.6	27.7
Culbac	27.0	26.0	27.7	20.6	25.6	25.0
Crop Cure	28.8	28.8	28.3	25.7	23.8	28.3
	----------Cellulose, %DMB----------					
Control	24.9	25.0	24.6	26.1	27.3	27.5
Silabac	24.5	24.3	24.0	26.6	26.0	25.5
Culbac	25.6	26.2	24.7	29.6	27.9	27.0
Crop Cure	22.9	25.8	23.7	24.7	25.8	25.0
	----------Lignin, %DMB----------					
Control	3.4	3.1	3.0	3.5	3.6	3.6
Silabac	3.4	3.1	3.2	3.3	3.2	3.1
Culbac	3.5	3.5	3.2	4.1	3.6	3.4
Crop Cure	3.2	3.1	3.1	3.2	3.4	3.0
	---- Acid detergent fiber-nitrogen % total N[b]------					
Control	12.2	15.3	14.1	13.2	11.6	14.6
Silabac	12.1	14.3	13.1	12.0	12.3	15.1
Culbac	13.1	12.8	13.0	14.1	14.6	14.7
Crop Cure	11.8	13.1	12.8	15.4	13.1	14.3

[a]There were no significant differences in any of the parameters due to treatment ($P>.05$).

[b]Dry matter basis.

TABLE 5. Temperature (°C) Changes of Corn Silage During the Ensiling Period as Affected by Fermentation Additives[a]

Time of fermentation, day	Ambient temperature	Treatment			
		Control	Silabac	Culbac	Crop Cure
0	26.4	24.4	24.6	23.9	23.7
.25	31.7	26.8	26.9	26.4	26.3
.5	30.0	28.4	28.5	27.8	27.8
.75	26.1	28.8	29.0	28.4	28.2
1	26.1	29.4	29.7	29.1	28.8
2	25.6	30.8	31.0	30.9	30.5
3	27.2	30.1	31.3	31.1	31.1
4	26.1	30.6	30.8	30.6	30.7
5	25.6	29.9	29.9	29.9	30.3
6	25.6	28.6	28.6	28.7	28.9
7	26.7	28.6	28.7	28.7	28.7
8	25.6	28.3	28.4	28.5	28.6
14	26.7	27.8	27.5	27.5	27.5
20	22.8	24.2	23.9	24.2	24.2
26	21.2	20.8	20.7	20.9	21.0
32	23.3	20.9	20.7	21.1	21.2
38	18.4	21.5	21.4	21.8	22.1

[a]There were no significant differences in temperature due to treatment ($P>.05$).

temperature for the control silage was 24.4 C which increased to its highest point of 30.8 C by the second day of fermentation. For the next 42 days the temperature decreased to 20.2 C by day 44.

Britt et al. (1975) reported similar temperature changes of corn silage treated with organic acids (formic, propionic, and acetic) during fermentation in 200 liter steel drums (55 gal.) with no differences due to treatment. One explanation for the lack of heating might be due to the successful exclusion of oxygen in the laboratory silos. Also, any changes in the small silage mass might have been overshadowed by changes in ambient temperature.

The highest temperature in the control and treated silages occurred during the third day of fermentation (30.1 C for control, 31.3 C for silabac, 31.1 C for culbac, and 31.1 C for crop cure). According to McDonald (1981) the optimum temperature for growth of most Lactobacillus species is about 30 C which would indicate that the temperatures reached in this experiment were acceptable for the growth of lactic acid bacteria. However, McDonald (1981) further stated that at temperatures of 37 C and above there usually is an increase in the number of clostridia. This increase in clostridial numbers results in a degradation of lactic acid to acetic, butyric acid, and carbon dioxide and extensive deamination and decarboxylation of amino acids which decreases nutritive value of the silages. ADF-N production also is believed to increase above certain temperatures during the ensiling process. However, it is not well understood above which temperatures this increase occurs.

III. SILAGE COMPOSITION DURING AEROBIC DETERIORATION AFTER ENSILING

The effect of silage fermentation aids on pH at various sampling times during aerobic deterioration in the bunk-life study is presented in Table 6. The pH values for each treatment are presented as the mean of two duplicate values (two replications per bunk per treatment).

The mean pH of the treated silages and the pH of the control silage was similar, except at hour 48 when the pH of the Crop Cure treated corn silage was significantly higher ($P<.05$) than that of all other silages. The pH of all the corn silages changed little during the first 24 hours of exposure to air. However, some increase occurred after 36 hours, but at 48 and 60 hours of exposure to air the increases in pH were massive. Moon et al. (1980) reported similar pH readings at the beginning of aerobic deterioration of 3.7 for control corn silage and 3.8 for Lactobacillus acidophilus and a Candida spp. treated corn silage. However, the pH of the treated corn silage only increased to 4.5 during the first 72 hours of aerobic deterioration, but the pH of the control corn silage remained constant with a slight decrease at 72 hours indicating a more stable product. According to Britt et al. (1975) these increases in pH as a result of exposure to aerobic conditions are the result of the catabolism of lactic acid to weaker acids and carbon dioxide.

TABLE 6. pH Level of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives[a]

Treatment	Hours of aerobic deterioration					
	0.	12	24	36	48	60
Control	3.82[a]	3.78[a]	3.80[a]	3.98[a]	4.66[b]	6.36[a]
Silabac	3.86[a]	3.80[a]	3.81[a]	3.98[a]	4.47[b]	6.40[a]
Culbac	3.91[a]	3.80[a]	3.86[a]	4.04[a]	4.74[b]	6.29[a]
Crop Cure	3.85[a]	3.76[a]	3.82[a]	4.10[a]	5.01[a]	6.79[a]

[a,b]Means in the same column with different superscript letters are significantly different ($P<.05$).

Changes in dry matter, cell solubles, and crude protein of the treated and control corn silage are summarized in Table 7. There were no significant differences ($P>.05$) in dry matter content and cell solubles due to treatment, but crude protein was significantly different ($P<.05$) due to treatment at 24 and 36 hours of aerobic deterioration.

Dry matter percentages of the treated corn silages and the dry matter percentages of the control silage were similar. The dry matter percentage of the control corn silage increased from 28.4% at the beginning of aerobic deterioration to 30.6% at 60 hours.

Neutral detergent solubles on a percent dry matter basis decreased slightly during aerobic deterioration in the Culbac and Crop Cure treated corn silage and the control silage. There was a slight increase in neutral detergent solubles in the Silabac treated corn silage.

Crude protein on a percent dry matter basis was significantly different ($P<.05$) due to treatment at 24 and 36 hours during aerobic deterioration. The crude protein for the Silabac treated corn silage (9.69%) at 24 hours was significantly higher compared to the crude protein content of the Culbac treated corn silage (8.73%) and the crop cure treated corn silage (9.26%). However, at 36 hours the crude protein of the Culbac treated corn silage (10.24%) was significantly higher than the other corn silage treatments.

Moon et al. (1980) reported similar crude protein values, which were 10.0% for control corn silage and 9.7% for Lactobacillus acidophilus and a Candida spp. treated corn silage.

TABLE 7. Dry Matter, Neutral Detergent Solubles, and Crude Protein Content of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives

Treatment	Hours of aerobic deterioration					
	0	12	24	36	48	60
	----------Dry matter %----------					
Control	28.4	28.9	28.8	29.6	29.9	30.6
Silabac	28.5	29.6	28.9	29.2	29.8	30.5
Culbac	28.1	29.5	29.4	29.8	29.9	30.7
Crop Cure	28.2	28.9	28.7	28.7	30.1	30.2
	----------Cell soulbles, %DMB----------					
Control	50.4	50.1	50.7	49.7	44.8	49.1
Silabac	47.9	50.4	47.7	48.7	45.1	52.1
Culbac	54.1	48.9	49.4	50.6	47.5	48.3
Crop Cure	50.6	51.8	49.6	47.2	48.4	48.1
	----------Crude protein, %DMD----------					
Control	9.91^{a}	9.56^{a}	9.49^{ab}	9.76^{b}	9.83^{a}	10.03^{a}
Silabac	10.01^{a}	9.28^{a}	9.69^{a}	9.30^{c}	9.88^{a}	10.12^{a}
Culbac	9.54^{a}	9.78^{a}	8.73^{c}	10.24^{a}	9.77^{a}	9.87^{a}
Crop Cure	9.69^{a}	9.36^{a}	9.05^{bc}	9.26^{c}	9.51^{a}	10.04^{a}

^{a,b,c}Means in the same column with different superscripts are significantly different ($P<.05$).

Changes in neutral detergent fiber (hemicellulose, cellulose, and lignin) and acid detergent fiber-nitrogen content of the treated corn silages and control corn silage are summarized in Table 8. There were no significant differences ($P>.05$) in these parameters. due to treatment.

During the 60 hours of aerobic deterioration, there was little change in the content on a dry matter basis of the cell wall constituents. This indicates, according to McDonald (1981), that the population of molds which can hydrolyse and metabolize cellulose and other cell wall constituents had not increased in sufficient quantities.

The content of acid detergent fiber-nitrogen on a dry matter basis increased in all treated corn silages and control. The acid detergent fiber-nitrogen in the control corn silage increased from 7.96% at the initiation of aerobic deterioration to 12.23% at the end of aerobic deterioration which lasted 60 hours.

IV. TEMPERATURE CHANGES DURING AEROBIC DETERIORATION AFTER ENSILING

Temperatures recorded during aerobic deterioration are shown in Table 9. There were no significant differences ($P>.05$) in temperature due to treatment. Temperature of all treated and control corn silage increased approximately 100% during the first 48 hours and remained basically the same until termination of the aerobic deterioration experiment. The control silage temperature peaked at 41.3 C at 48 hours with a slight decrease to 39.2 C at 60 hours.

TABLE 8. Hemicellulose, Cellulose, Lignin, and Acid Detergent Fiber-Nitrogen Content of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives[a]

Treatment	Hours of acrobic deterioration					
	0	12	24	36	48	60
	----------Hemicellulose, %DMB----------					
Control	22.8	23.9	21.5	23.4	27.8	23.8
Silabac	26.5	21.9	25.0	23.5	25.7	19.2
Culbac	19.4	24.8	23.6	23.4	25.7	23.2
Crop Cure	22.1	21.7	22.2	25.3	24.3	22.3
	----------Cellulose, %DMB----------					
Control	23.5	22.5	24.5	23.9	24.3	24.0
Silabac	22.7	24.4	24.3	24.7	25.6	25.5
Culbac	23.1	23.0	23.6	23.0	23.9	25.2
Crop Cure	24.3	23.2	24.7	24.1	23.8	26.2
	----------Lignin, %DMB----------					
Control	3.27	3.55	3.35	3.13	3.11	3.21
Silabac	2.91	3.34	3.09	3.15	3.55	3.27
Culbac	3.38	3.37	3.34	3.00	2.96	3.33
Crop Cure	3.06	3.29	3.57	3.41	3.49	3.42
	-----Acid detergent fiber-nitrogen, % total N[b]-----					
Control	7.96	9.02	9.31	10.51	11.04	12.23
Silabac	7.94	7.74	8.31	10.22	11.29	11.18
Culbac	8.29	7.52	8.77	9.66	12.63	13.05
Crop Cure	9.26	8.64	9.20	10.00	13.10	12.01

[a]There were no significant differences in any of the parameters due to treatment ($P>.05$).

[b]Dry matter basis.

TABLE 9. Temperature (°C) Changes of Corn Silage During Aerobic Deterioration as Affected by Fermentation Additives[a]

Time of aerobic deterioration, hour	Ambient temperature	Treatment			
		Control	Silabac	Culbac	Crop Cure
0	22.8	20.6	20.3	20.0	19.9
4	21.9	20.6	20.1	20.3	20.3
8	21.9	21.0	20.3	20.9	20.6
12	22.3	21.9	21.1	22.0	22.0
16	21.7	24.3	23.0	24.4	24.8
20	23.1	28.2	26.8	27.3	28.1
24	22.9	27.4	26.9	29.4	28.0
28	24.8	29.8	28.4	31.3	31.8
32	21.8	35.2	33.1	33.9	37.8
36	23.9	37.7	37.2	38.6	41.1
40	22.9	38.0	40.0	41.0	41.0
44	21.8	39.1	40.9	40.6	40.5
48	24.3	41.3	39.8	39.0	39.8
52	24.4	41.3	40.7	39.1	40.1
56	24.4	40.9	40.6	39.6	41.1
60	23.7	39.2	39.0	38.4	40.6

[a]There were no significant differences in temperature due to treatment ($P>.05$).

Moon et al. (1980) reported similar increases for treated Lactobacullus acidophilus and Candida spp.) and control corn silage during the first 48 hours during aerobic deterioration. The difference between the highest temperature for the inoculation and the control silage at 48 hours was 2 C. However, Britt et al. (1975) reported that corn silage temperatures during aerobic deterioration were lower for all organic acid treatments at all levels of administration when compared to the control corn silage, but significantly so ($P<.01$) for the 2% treated corn silage.

CHAPTER V.

SUMMARY

Objectives of this research were to study the effect of microbial and chemical fermentation aids during the fermentation process in experimental silos and during aerobic deterioration in feed bunks of corn silage. Specific parameters studied were: lactic acid and other volatile fatty acids, dry matter, crude protein, neutral detergent solubles, neutral detergent fiber, acid detergent fiber-nitrogen, pH, and temperature at various sampling times. The four experimental corn silage treatments were: (1) an untreated control silage; (2) treated with Silabac, a live Lactobacillus plantarum and acidophilus preparation; (3) treated with Culbac, a killed Lactobacillus preparation; and (4) treated with Crop Cure, sodium diacetate. Chopped whole corn plants (28.8% dry matter), treated or untreated, were placed in 205 liter (55 gallon) steel drums lined with polyethylene bags. During the ensiling period, silage samples were collected on days, 0, 1, 3, 6, 18, 27, and 36 and temperatures of the ensiling mass were recorded continuously during this period. On day 36 of the ensiling period, silages were placed in open bunks to study changes during aerobic deterioration. Samples were taken at 0, 12, 24, 36, 48, and 60 hours and temperatures were also recorded during the period. All samples taken during the ensiling process were analyzed for

volatile fatty acids and other nutrients, and pH. Silage samples taken during aerobic deterioration were analyzed for pH and various nutrients.

Lactic acid production was higher in all treated silages when compared to the control silage on all sampling days, but was significantly higher ($P<.05$) on days 3 and 27 during the ensiling period. There were no significant differences ($P>.05$) in acetic, propionic, and isobutyric acids due to treatment. However, acetic acid concentration of the Culbac and Crop Cure treated silage was higher than the control and Silabac treated silage at the end of the ensiling period. Final pH of all treatments during the ensiling period was below 4.0 and was not significantly different ($P>.05$) due to treatment. Changes in dry matter, crude protein, and neutral detergent solubles during the ensiling period were not significantly different ($P>.05$) due to fermentation aids. There were no significant differences ($P>.05$) in neutral detergent fiber and acid detergent fiber-nitrogen due to treatment. Temperatures recorded during the ensiling period were similar for all treatments and were not significantly different ($P>.05$) due to treatment. Temperature in the control silage changed from 24.4 C at the beginning of the ensiling period to 30.1 C by the third day to 20.2 C at the end of the study (44 days).

During aerobic deterioration, the pH of treated and untreated corn silage were similar, except at hour 48 when the pH of the Crop Cure treated corn silage was significantly higher

($P<.05$) than that of all other silages. The pH of the control changed from 3.82 at the beginning of aerobic deterioration to 6.36 by the end of the study (60 hours). There were no significant differences ($P>.05$) in dry matter content and neutral detergent solubles due to treatment during aerobic deterioration. Crude protein on a percent dry matter basis was significantly lower ($P<.05$) in the Culbac and Crop Cure treated corn silage compared to the control and silabac treated corn silage at 24 hours during aerobic deterioration. However, at 36 hours the crude protein content of the Crop Cure and Silabac treated corn silage was significantly lower ($P<.05$) than the control and Culbac treated corn silage. There were no significant differences ($P>.05$) in neutral detergent fiber and acid detergent fiber-nitrogen due to treatment. In all silages, acid detergent fiber-nitrogen increased during aerobic deterioration by approximately 30%. Temperatures recorded during aerobic deterioration were not significantly different ($P>.05$) due to treatment. The temperature of the control silage increased from 20.6 C at the beginning of aerobic deterioration to 39.2 C at the end of the study (60 hours).

The data obtained in this study suggest that microbial and chemical additions to properly ensiled corn in experimental silos (205-liter steel drums) are of questionable value in terms of nutrient preservation. The utilization of experimental silos in research may not offer field characteristics such as heat flow and heat accumulation that occurs under normal field conditions. Also,

it is possible that the effect of microbial and chemical fermentation additives on nutrient recoviers would be greater if conditions for fermentation were not controlled as carefully.

LITERATURE CITED

LITERATURE CITED

Allen, L. A. and J. Harrison. 1937. Anaerobic spore-formers in grass silage. Ann. Appl. Biol. 24:148.

Allen, R. S. and A. R. Porter. 1954. Effect of added ground corn on the composition and palatability of stacked legume-grass silage. J. Dairy Sci. 37:658.

Alli, I. and B. E. Baker. 1982. Effects of additive on lactic acid production and water soluble carbohydrates in chopped corn and alfalfa. J. Dairy Sci. 65:1472.

Anderson, K. J. 1956. Microbiology of silage. Nature 177:96.

A.O.A.C. 1975. Methods of Analysis, Association of Official Analytical Chemists, Washington, D.C.

Autrey, K. M., C. B. Knodt and P. S. Williams. 1947. Grass and legume silage studies using 2-quart glass jars as minature silos. J. Dairy Sci. 30:775.

Archibald, J. G. 1953. Sugar and acids in grass silage. J. Dairy Sci. 26:385.

Barker, S. B. and W. H. Summerson. 1941. The coloimetric determination of lactic acid in biological material. J. Biol. Chem. 138:535.

Barnett, A. J. G. 1954. Silage Fermentation. Butterworths Scientific Publication, London.

Barr, A. J., J. H. Goodnight, J. P. Sall and J. T. Helwig. 1976. A User's Guide to SAS. SAS Institute, Raleigh, N.C.

Barth, K. M. and S. Gelaye. 1979. Nutritive value of some vegetable-waste silages for ruminants. Tennessee Farm and Home Sci. 111:8.

Bath, D. L., F. N. Dickinson, H. A. Tucker and R. D. Appleman. 1978. Dairy Cattle: Principles, Practices, Problems, Profits (2nd Ed.). Lea and Febiger, Philadelphia, PA.

Beck, T. 1975. Beeinflussung der Nachgarung durch Siliermittel. Das wirtsch eigene Futter 21:55. Cited in M. E. McCullough (Ed.) Fermentation of Silage--A Review. National Feed Ingredients Assoc., Iowa.

Beck, T. 1978. Themicro-biology of silage fermentation In: M. E. McCullough (Ed.) Fermentation of Silage--A Review. pp.61-115. National Feed Ingredients Assoc., Iowa.

Beck, T. and F. Gross. 1964. Ursachen der unterschiedlichen Haltbarkeit von Garfutter Das wirtsch. eigene Futter 10:298. Cited in: M. E. McCullough (Ed.). National Feed Ingredients Assoc., Iowa.

Bolsen, K. K. 1976. Unpublished data. Kansas State Univ., Manhattan, Kansas. Cited in: M. E. McCullough (Ed.) Fermentation of Silage--A Review. National Feed Ingredients Assoc., Iowa.

Bolsen, K. K. 1978. The use of aids to fermentation in silage production. In: M. E. McCullough (Ed.) Fermentation of Silage--A Review. pp.181-199. National Feed Ingredients Assoc., Iowa.

Bolsen, K. K. 1980. Silage additives. Feedlot Management 22(8):19.

Bolsen, K. K. 1981. How to manage silage. Simmental Shield 12(1):133.

Bolsen, K. K. 1982. Secrets of making quality silage. Beef 19(1):36.

Brady, C. J. 1966. The redistribution of nitrogen in silage by lactic-acid-producting bacteria. Australian J. Biol. Sci. 19:123.

Bratzler, J. W., E. Keck, Jr. and R. R. Yoerger. 1960. Effect of temperature on the nutritive value of artificially dried hay. J. Anim. Sci. 19:1186.

Britt, D. G., J. T. Huber and A. L. Rogers. 1975. Fungal growth and acid production during fermentation and refermentation of organic acid-treated corn silages. J. Dairy Sci. 58:532.

Buchanan, R. E. and N. E. Gibbons. 1974. Bergey's Manual of Determinative Bacteriology. Williams and Wilkins Co., Baltimore, MD.

Burghardi, S. R., R. D. Goodrich and J. C. Meiske. 1977. Evaluation of corn silage treated with a silage additive. Minn. Cattle Feeders Rpt. B-231.

Burghardi, S. R., R. D. Goodrich and J. C. Meiske. 1980. Evaluation of corn silage treated with microbial additives. J. Anim. Sci. 50:729.

Byers, F. M., R. D. Goodrich and J. C. Meiske. 1982. Influence of acetic acid, lactic acid and ethanol on the fermentation of corn silage. J. Anim. Sci. 54:640.

Campbell, J. J. R. and I. C. Gunsalus. 1944. Citric acid fermentation by streptococci and lactobacilli. J. Bacteriol. 48:71.

Carpintero, M. C., A. J. Holding and P. McDonald. 1969. Fermentation studies on lucerne. J. Sci. Food Agr. 20:677.

Carpintero, M. C., A. R. Henderson and P. McDonald. 1979. The effect of some pre-treatments on proteolysis during the ensiling of herbage. Grass and Forage Sci. 34:311.

Chamberlain, C. C., K. M. Barth and F. A. Fribourg. 1978. Corn silage maturity and beef heifer performance. University of Tennessee Agricultural Experiment Station Bull. No. 583.

Church, D. C. 1977. Livestock Feeds and Feeding. Oxford Press, Oregon.

Church, D. C. and W. G. Pond. 1974. Basic Animal Nutrition and Feeding. Schultz, Wack and Weir, Oregon.

Crawshaw, R., D. M. Thorne and R. H. Llewelyn. 1980. The effects of formic and propionic acids on the aerobic deterioration of grass silage in laboratory units. J. Sci. Food Agr. 31:685.

Danley, M. M. and R. L. Vetter. 1973. Changes in carbohydrates and nitrogen fractions and digestibility of forages: maturity and ensiling. J. Anim. Sci. 37:994.

Darrah, C. H., P. J. Van Soest and G. W. Fick. 1977. Microwave treatment and heat damage artifacts in forages. Agron. J. 69:120.

Edwards, R. A. and P. McDonald. 1978. The chemistry of silage. In: M. E. McCullough (Ed.) Fermentation of Silage--A Review. pp.27-59. National Feed Ingredients Assoc., Iowa.

El Hag, M. C., R. L. Vetter, and M. D. Kenealy. 1982a. Effects of silage additives on fermentation characteristics of corn silage and performance of feedlot heifers. J. Dairy Sci. 65:259.

El Hag, M. C., R. L. Vetter, M. D. Kenealy and R. J. Smith. 1982b. Evaluation of a model laboratory silo. J. Dairy Sci. 65:250.

Ely, L. O. 1978. The use of added feedstuffs in silage production In: M. E. McCullough (Ed.) Fermentation of Silage--A Review. pp.233-279. National Feed Ingredients Assoc., Iowa.

Ely, L. O., E. M. Sudweeks and N. J. Moon. 1981. Inoculation with lactobacillus plantarum of alfalfa, corn, sorghum, and wheat silages. J. Dairy Sci. 64:2378.

Gibson, T. 1965. Clostridia in silage. J. Appl. Bact. 28:56.

Gibson, T., A. C. Stirling, R. M. Keddie and R. F. Rosenberger. 1958. Bacteriological changes in silage made at controlled temperatures. J. Gen. Microbiol 19:112.

Gordon, C. H., J. C. Derbyshire, W. C. Jacobson, E. A. Kane and C. G. Melin. 1961. Comparisons of unsealed and plastic sealed silages for preservation efficiency and feeding value. J. Dairy Sci. 44:1113.

Gordon, C. H. 1967. Storage losses in silage as affected by moisturecontent and structure. J. Dairy Sci. 50:397.

Gross, F. and T. Beck. 1970. Investigations into the prevention of aerobic degradation processes after unloading of silage with propionic acid. Wirtschaftseigene Futter 16:1. Cited in: M. E. McCullough (Ed.) Fermentation of Silage--A Review. National Feed Ingredients Assoc., Iowa.

Gunsalus, I. C. and J. J. R. Campbell. 1944. Diversion of the lactic acid fermentation with oxidised substrate. J. Bacteriol. 48:455.

Honig, H. and M. K. Woolford. 1980. Changes in silage on exposure to air. Br. Grassld. Soc. Occ. symp. No. 11, Brighton 1979:76.

Huber, J. T., R. E. Lichtenwalner, F. Sleiman and D. D. Makdani. 1972. Organic acid treatment of corn silage. J. Dairy Sci. 55:702.

Huber, J. T. and M. Soejono. 1976. Organic acid treatment of high dry matter corn silage fed lactating dairy cows. J. Dairy Sci. 59:2063.

Langston, C. W., H. Irvin, C. H. Gordon, C. Bouma, H. G. Wiseman, C. G. Melin and L. A. Moore. 1958. Microbiology and chemistry of grass silage. USDA Tech. Bull. No. 1187.

Leask, W. C. and T. B. Daynard. 1973. Effects of percent moisture and compaction pressure on the ensiling of corn stover in laboratory silos. Can. J. Plant Sci. 53:523.

Leaver, J. D. 1975. The use of propionic acid as an additive for maize silage. J. Brit. Grassl. Soc. 30:17.

Macpherson, H. T. and P. Violante. 1961. The influence of pH on the metabolism of arginine and lysine in silage. J. Sci. Food Agr. 17:128.

McCullough, M. E. 1977. Silage and silage fermentation. Feedstuffs 49:12.

McDonald, P. 1973. Chemistry and Biochemistry of Herbage. Academic Press, London. Cited in: The Biochemistry of Silage. John Wiley and Sons, Ltd., New York.

McDonald, P. 1981. The Biochemistry of Silage. John Wiley and Sons, Ltd., New York.

McDonald, P., A. R.Henderson and R. Whittenbury. 1966. The effect of temperature on ensilage. J. Sci. Food Agr. 17:476.

McDonald, P. and A. R. Henderson. 1974. The use of fatty acids as grass silage additives. J. Sci. Food Agr. 25:791.

McDonald, P. and P. R. Attwood. 1958. An experimental silo unit for the continuous measurement of losses occurring during ensilage. J. Br. Grassl. Soc. 13:115.

McDonald, P. and R. A. Edwards. 1976. The influence of conservation methods on digestion and utilization of forages by ruminants. Proc. Nutr. Soc. 35:201.

Moon, N. J., L. O. Ely and E. M. Sudweeks. 1980. Aerobic deterioration of wheat, lucerne, and maize silages prepared with Lactobacillus acidophilus and a Candida spp. J. App. Bact. 49:75.

Moon, N. J., L. O. Ely and E. M. Sudweeks. 1981. Fermentation of wheat, corn, and alfalfa silages inoculated with Lactobacillus acidophilus and Candida spp. at ensiling. J. Dairy Sci. 64:807.

Mutdock, J. C., D. A. Balch, A. S. Foot and S. J. Rowland. 1955. The ensiling of lucerne with addition of formic and glycollic acids, molasses and barley meal, and with wilting. J. Brit. Grassl. Soc. 10:139.

N.R.C. 1976. Nutrient Requirements of Domestic Animals. Number 5. Nutrient Requirements of Beef Cattle, National Academy of Sciences, Washington, D. C.

Ohshima, M. and P. McDonald. 1978. A review of the changes in nitrogenous compounds of herbage during ensilage. J. Sci. Food Agr. 29:479.

Ohyama, Y. and S. Hara. 1975. Factors influencing aerobic deterioration of silages and changes in chemical composition after opening silos. J. Sci. Food Agr. 26:1137.

Ohyama, Y., S. Hara and S. Masaki. 1977. The use of caproic acid to prevent aerobic deterioration of silages after opening, with special reference to the amounts and time of application. J. Sci. Food Agr. 28:369.

Ohyama, Y., S. Masaki and T. Morichi. 1973. Effects of inoculation of lactobacillus plantarum and addition of glucose at ensiling on the silage quality. Japanese J. Zootechnical Sci. 44:404. Cited in M.E. McCullough (Ed.) Fermentation of Silage--A Review. National Feed Ingredients Assoc., Iowa.

Ohyama, Y., T. Morichi and S. Masaki. 1975. The effect of inoculation with Lactobecillus plantarum and addition of glucose at ensiling on the quality of derated silages. J. Sci. Food Agr. 26:1001.

Oginsky, E. L. and R. F. Gehrig. 1953. Thearginine dihydrolase system of streptococcus faecalis. J. Biol. Chem. 204:721.

O'Leary, J and L. S. Bull. 1977. Effect of additives on fermentation of direct cut and wilted alfalfa. J. Dairy Sci. 60:159 (Abstr.).

Otis, C. K., J. H. Pomeoy and D. Gawreluk. 1959. The laboratory silo: a tool for silage research. Agricultural Engineering 40:736.

Owens, F. G. and S. H. Senel. 1963. Effect of moisture level and grain addition on organic acids in alfalfa silage. J. Dairy Sci. 46:993.

Parker, R. B. 1978. Methodology for Determining Quality of Silage. National Feed Ingredients Assoc., Iowa.

Pennington, R. J. and T. M. Sutherland. 1956. Ketone-body production from various substrats by sheep-rumen epthelium. Biochem. J. 63:353.

Perkins. A. E. and A. D.Pratt. 1951. A laboratory silo and its uses. J. Dairy Sci. 34:606.

Olayne, M. J., A. C. Stirling and P. McDonald. 1967. Changes in organic acid composition during incubation of aseptically-grown grass. J. Sci. Food Agr. 18:19.

Stirling, A. C. 1953. Lactobacilli and silage-making. Proc. Soc. Appl. Bact. 16:27.

U.S.D.A. 1980. Agricultural Statistics. U.S. Government, Washington, D.C.

Virtanen, A. E. 1938. The A.I.V. method for the preservation of fresh fodder and its importance in agriculture. In: A. I. Vistanen (Ed.) Cattle Fodder and Human Nutrition. Cambridge University Press, England.

Viranen, A. I. 1947. Econ. Proc. R. Dublin Soc., 3:311. Cited in: Silage Fermentation. Butterworths Scientific Publications, London.

Van Soest, P. J. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications). ARS, USDA Agr. Handbook No. 379.

Van Soest, P. J. 1982. Nutritional Ecology of the Ruminants. O and B Books, Inc., Oregon.

Waldo, D. R., J. E. Keys, L. W. Smith and C. H. Gordon. 1971. Effect of formic acid on recovery intake, digestibility and growth from unwilted silage. J. Dairy Sci. 54:77

Watson, S. J. and M. J. Nash. 1960. The Conservation of Grass and Forage Crops. Oliver and Boyd Ltd., Edinburgh. Cited in: P. McDonald (Ed.) The Biochemistry of Silage. John Wiley and Sons, Ltd., New York.

Webster, N. 1957. Webster's New Collegiate Dictionary. G. and C. Merrian Co., Massachusetts.

Weise, F. 1967. Die wirkung von Futterzucker als Sicher ungszusatz zu Gras-Garfutter. Landw. Forschung 20:171. Cited in: M. E. McCullough (Ed.) Fermentation of Silage--A Review. National Feed Ingredients Assoc., Iowa.

Whittenbury, R. 1968. Microbiology of grass silage. Proc. Biochem. 3:27.

Whittenbury, R., P. McDonald and D. G. Ryan-Jones. 1967. A short review of some biochemical and microbiological aspects of ensilage. J. Sci. Food Agr. 18:441.

Wieringa, G. W. 1960. Some factors affecting silage fermentation. Proc. Eighth International Grassl. Congress 1960:537.

Wilson, G. S. and A. A. Miles. 1975. Topley and Wilson's Principles of Bacteriology, Virology and Immunity. Vol. I. Edwards Arnold, London.

Wilson, R. F. and R. J. Wilkins. 1972. The ensilage of autumn-sown rye. J. Brit. Grassl. Soc. 27:35.

Wood, W. A. 1961. Fermentation of carbohydrates and related compounds. The Bacteria. Academic Press, New York and London. Cited in: the Biochemistry of Silage. John Wiley and Sons, Ltd., New York.

VITA

Bertil Gunnar Johnson, III was born in Nashville, Tennessee, on March 2, 1954. He attended elementary school in Madison, Tennessee, middle school and secondary school in Hendersonville, Tennessee, and was graduated from Hendersonville Senior High School in June 1972.

After a four-year tour of duty with the United States Air Force, he entered Western Kentucky University, Bowling Green, Kentucky, in January 1977. He received the Bachelor of Science degree with a major in Agriculture in May 1981.

In the fall of 1981, he began graduate studies at The University of Tennessee, Knoxville, in the Department of Animal Science. In December 1983, he received the Master of Science degree in Animal Science.

He is married to the former Tina O'Neil Colburn of Calvert City, Kentucky.