Effect of sorghum grain storage systems on the performance of feedlot cattle

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Effect of sorghum grain storage systems on the performance of feedlot cattle

by

Douglas Robert Ware

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

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INTRODUCTION

Grain sorghum production has played a major role in the development of the cattle feeding industry in the southwestern United States. The adaptability of sorghum to semi-arid growing conditions is a major reason for its acceptability to this segment of the industry. Inadequate moisture in the western one-third of Iowa is a major factor in limiting corn yields in two of every five years. Sorghum may be considered as an alternative to corn as a high energy feed source for livestock fed in areas of Iowa where moisture is limiting.

The principal liability of grain sorghum as a high energy source for feeding cattle is reduced energy availability when compared to corn. Although much of the research and experience with sorghum indicates it is approximately 90 to 95 percent of the feeding value of corn, there is much greater variability in product quality with sorghum. Protein and minerals are two nutrient classes which vary widely in quality in grain sorghum. Serious questions have been raised concerning the availability and utilization of protein and energy in sorghum grain and have initiated a considerable amount of research aimed at improving its feeding quality.

Proximate analysis of sorghum indicates it is quite similar to corn in nutrient content, however total digestible nutrient (TDN) values are 76 percent and 93 percent for sorghum.
and corn respectively when compared on a dry matter basis (Hale, 1966). Since proximate analysis does not reflect this large difference in TDN, the major reasons for the decreased feeding value of sorghum seem to be lower protein and nitrogen-free extract availability. Sorghum tends to be higher in crude protein than corn, therefore it is desirable to increase the availability of nitrogen to improve the feeding value of grain sorghum.

The major area of concentration in research with sorghum grains has been to improve the availability of the starch fraction. Since sorghum is principally an energy feedstuff, it is approximately 70 to 75 percent starch. Obviously, any increase in the availability of this fraction would be very beneficial in livestock rations which contain substantial amounts of sorghum grain.

Early research focused on processing as a means to improve the utilization of feed grains. Jones et al. (1937) reported grinding dry grain increases daily gain and improves feed efficiency by about 10 percent. Other forms of physical processing such as dry rolling tend to have a similar effect (Pitzen, 1971). Riggs (1958) indicated in a review of grain processing methods that rolling or crushing has little advantage over grinding. During the 1960's newer methods of processing were used to improve utilization of feed grains. The two methods which have been most widely used particularly
in the Southwest are steam processing and flaking, and micronizing. These methods involve the addition of heat and/or moisture to alter the grain kernel to make the valuable nitrogen and carbohydrate fractions more available to the animal.

Producers in the Midwest have relied on early harvesting or reconstitution of grain to improve its utilization by livestock. Either method involves ensiling the high-moisture grain to allow fermentation to occur, thus preserving the grain and making it a more desirable livestock feed.

Ensiling of high-moisture grains is a complex process which involves several factors that can affect the quality of the ensiled product. Type of storage structure, length of storage, moisture, temperature, and supply of oxygen are all factors that influence the rate and extent of fermentation, spoilage, and feeding value of the ensiled grain.

Many factors influence the fermentation characteristics of high-moisture grain and several criteria can be used to evaluate the quality of the fermentation product. Among the methods used to evaluate grain quality are pilot silo studies, animal performance, in vivo, and in vitro studies; however, nutritional value of high-moisture ensiled grains can best be measured by animal performance studies which are the ultimate test of grain quality.

The objectives of this study were to compare three systems of storing high-moisture sorghum grain. The systems used in
the study were 1) a conventional artificial batch drying system, 2) an oxygen-limiting silo, and 3) a concrete stave silo. Evaluation of the three systems was based upon 1) cattle feedlot performance, 2) grain dry matter losses during storage and efficiency of storage systems, 3) changes in the nitrogen fractions, and 4) changes in the carbohydrate fractions.
This review of literature will involve the processing, storage, feeding and utilization of grain sorghum for ruminants. Studies relating to other cereal grains and silages will be reported only to provide additional information which is useful for the interpretation of data concerning grain sorghum. Reports relating to animal performance and the chemical and physical properties of sorghum will be of primary concern in this review of literature.

The increased use of high-moisture grains has been largely due to the advantages of reduced field and harvesting losses, earlier harvesting, lower equipment costs and easier adaptation to mechanized feeding. Burroughs et al. (1960), Beeson and Perry (1958), and Heuberger et al. (1959) have all reported an advantage in efficiency of gain for beef cattle when high-moisture ensiled grain is compared to dried grain. Research from Texas and Oklahoma reported by Riggs (1969), Riggs and McGinty (1970), and White et al. (1969b) indicates feedlot performance is improved when cattle are fed high-moisture sorghum in studies using dried sorghum as the control.

Analysis of the reasons for the improved feedlot performance of cattle fed high-moisture sorghum grain can be separated into four basic categories to assist in the interpretation of reports concerning sorghum. The categories which will be considered in this review are 1) storage
characteristics of high-moisture grain, 2) animal performance, 3) in vitro studies, and 4) in vivo studies.

Storage characteristics of high-moisture grain

Early experience in the late 1940's in Texas indicated grain sorghum could not be stored at the moisture levels at which it was harvested, therefore Texas A and M in cooperation with the United States Department of Agriculture began some of the early research with storage of early harvested grain sorghum (Sorenson et al., 1957). The maximum safe storage levels for the humid climate found in South Texas was found to be 12 percent moisture by Sorenson et al., 1957.

The first reports of research involving the safe storage of early harvested grain concentrated on artificial drying as the primary means of preserving grain. However, increased drying costs, mechanized feeding, and the desire to improve the utilization of sorghum by livestock have caused research efforts to be concentrated in the area of high-moisture storage and processing (Parret and Riggs, 1967).

The effect of storing sorghum in the high-moisture form is not fully understood, however Riggs (1969) suggested the changes which occur in reconstituted grain may be similar to those which occur during germination. In his review Riggs (1969) stated the first step in germination is the uptake of water by the whole grain. The developing embryo is then
activated by the water and probably holds most of the moisture taken up by the kernel. Hydrolysis of the starch next takes place and provides the necessary energy for the immature seed. The embryo must be present in order for the hydrolytic enzymes secreted by the aleurone layer to solubilize the starch. That grain should not be ground before reconstitution is supported by White et al. (1969a) who reported grinding before reconstitution had a detrimental effect on the fermentation process due to the disruption of the hydrolytic enzyme pathways caused by the destruction of the whole grain kernel. Grinding sorghum grain prior to reconstitution has repeatedly resulted in slower rates of gain and poorer feed efficiency in trials reported by Eudaly and Riggs, 1969; Brethour and Duitsman, 1962; Martin et al., 1969; and White et al., 1969a.

One of the principal concerns of much of the high-moisture sorghum research has been the ideal moisture level for maximum digestibility and utilization by beef cattle. Wagner (1970) reported 30 percent to be the desired moisture level for early-harvested sorghum, with a range of 25 to 35 percent. Research reported by White and Totusek (1969) indicates moisture levels of 31 and 39 percent significantly improve the utilization of reconstituted sorghum grain when compared to dry sorghum. Hale (1966) found high moisture levels difficult to attain under practical field conditions. Attempts to improve the uptake of water through the use of hot water (80 to 85 C) and
surfactants have had little effect in improving this problem (Bowers, 1970). Pantin, Riggs, and Bowers (1969) suggest that environmental temperature may have a more significant effect in improving uptake of water by reconstituted grain.

Another important factor in reconstituting sorghum grain is length of storage. Neuhaus and Totusek (1969) reported a study comparing storage times of 10, 20 and 30 days using moisture levels of 28 to 30 percent in which in vitro dry matter disappearance was improved 15 percent after 30 days. Seventy-five percent of the improvement took place during the first ten days with the remainder occurring over the remaining 20 days. Therefore, it appears dry matter utilization increases at a decreasing rate over a thirty day period. Hale et al. (1969) reported that grain moisture levels below 26 percent at the time of storage gave maximum response in dry matter utilization at 20 days but declined after 30 days. They concluded moisture levels above 26% are necessary to maintain the improved feeding value of reconstituted grain.

The widespread use of oxygen-limiting and conventional storage silos for high-moisture grain and silage has resulted in a considerable amount of research directed toward understanding more about the fermentation process which occurs during ensiling of high-moisture materials. Research designed to study the ensiling process have involved the use of both actual farm storage structures and miniature laboratory silos.
Meiske, Linn, and Goodrich (1975) stated much has been learned regarding fermentation using field silos, particularly in regard to silage fermentation, however many variables exist under field conditions that make precise evaluation of storage characteristics difficult. Therefore, numerous researchers have used laboratory silos as models for the study of the fermentation process (Dexter, 1966; Nicholson and Cunningham, 1964; Danley and Vetter, 1974a; and Owens, Meiske and Goodrich, 1969b). It should be emphasized that laboratory silos are used only as tools for studying the ensiling process and are not necessarily representative of conditions existing under actual field conditions.

Barnett (1954) divided the ensiling process into the following five stage scheme: 1) cell respiration, 2) acetic acid production, 3) onset of lactic acid production, 4) lactic acid phase, 5) butyric acid phase, if insufficient lactic acid is produced. He emphasizes the accumulation of high levels of lactic acid is the most important phase of the fermentation process. Laboratory research concerning the storage characteristics of high-moisture grains has concentrated on the chemical analysis of the constituents of the highly soluble fractions of the grain kernel. Since these fractions are the most readily available for microbial activity they serve as excellent indicators of the quality of fermentation. A modified laboratory silo unit described by Danley, Vetter, and Wedin (1973) was
used by Danley and Vetter (1974a) to evaluate dry matter and nitrogen losses and changes in the carbohydrate fractions of corn grain. They reported dry matter and total nitrogen losses during a 35-day fermentation period were higher (P < .05) for heat-treated corn when compared to ensiled corn. With adequate moisture, fermentation losses were lowest for formic acid reconstituted corn, followed by reconstituted and untreated-ensiled grain. As moisture levels decreased losses in dry matter and total nitrogen decreased in heat treated corn and were lowest in dried corn, followed by steamed and microwaved corn grain, respectively. Alteration of corn grain did not change total carbohydrates, however it did produce an effect (P < .05) on water soluble carbohydrates. Heat treated grain had lower (P < .05) soluble carbohydrates when compared with ensiled grain. Soluble carbohydrates were also lower (P < .05) for reconstituted compared to formic acid reconstituted, and microwaved compared to steamed corn. Volatile fatty acid content of ensiled grain was higher (P < .05) when compared to reconstituted and formic acid reconstituted grain.

In a related experiment Danley and Vetter (1974b) found changes in the nitrogen fractions of artificially altered corn grain. Total nitrogen was not affected by the methods of alteration used in their study which were untreated-ensiled, dried reconstituted-ensiled, formic acid-reconstituted ensiled, dried, microwaved, and steamed. Nitrogen solubility increased
(P < .05) with increasing moisture content at harvest. Reconstituted grain was lower (P < .05) for all soluble nitrogen fractions when compared to formic acid-reconstituted grain and microwaved was lower (P < .05) than steamed corn. Ensiled corn had higher (P < .05) levels of ammonia nitrogen than heat-treated corn. Ammonia nitrogen values were higher (P < .05) for reconstituted than for formic acid-reconstituted corn. The general conclusion made by the authors was ensiling increases nitrogen solubility but does not increase carbohydrate solubility.

Limited data exists concerning changes in the carbohydrate fraction of ensiled grains. Feeding trials with ensiled grains have indicated reduced feed intake, but a corresponding improvement in feed conversion (Burroughs et al., 1970). Klosterman et al. (1960) and Henderson and Bergen (1970) have attributed this improvement in feed conversion to the increased production of organic acids which occurs during the ensiling process. Goodrich, Byers, and Meiske (1975) reported a study which included an analysis of energy and dry matter losses, organic acids, lactate and ethanol. They studied the effects of moisture content, processing and reconstitution on the fermentation of corn grain. Their study included three comparisons: of 1) moisture levels of 21.5, 27.5 and 33.1 percent, 2) early harvested and reconstituted grain, and 3) whole versus rolled processing methods. Dry matter losses were greater (P < .01)
for corn ensiled at 33.1 percent moisture, corn ensiled in the whole form and early harvested-ensiled corn. Energy losses were greatest for the 33.1 percent moisture level, however time of storage or type of physical processing method had no effect.

Goodrich, Byers and Meiske (1975) also reported pH values were lower for 33.1 percent moisture grain, rolled and early harvested-grains, harvested ensiled grain compared to 21.5 and 27.5%, whole and reconstituted grains, respectively. Gas production data also showed grain with higher moisture levels underwent more extensive fermentation. Total acetic acid content appeared to increase with moisture content, however the percentage of acetic acid as a portion of the volatile end products increased as moisture levels decreased. In a similar fashion, lactic acid and ethanol production increased as moisture levels increased. Ethanol production was also higher in grain ensiled in the whole form.

Prigge et al. (1976) in a similar study reported values for acid production and soluble nitrogen of corn grain stored in sealed plastic bags to compare the effect of time on the fermentation process. Soluble nitrogen levels in ground high-moisture corn increased from 15.8 at 0 days to 38.2 percent of the total nitrogen at 56 days. Soluble nonprotein nitrogen values increased in the same manner as the soluble nitrogen. Soluble nitrogen and nonprotein nitrogen levels in whole-shelled high-moisture corn were considerably lower than
ground corn at 28 and 56 days. Lactic and acetic acid levels in ground high-moisture corn were found to increase during fermentation. Acetic acid increased up to six days while lactic acid increased up to 21 days. It was concluded that fermentation is complete at 21 days. Whole-shelled high-moisture corn showed no increase in lactic acid production, however acetic acid was higher and pH levels lower at 56 days. The authors concluded that fermentation occurs more slowly in whole grain, however, moisture levels were not reported in this study.

Lactic acid values for high roughage feedstuffs have been reported by Holzer et al., 1975; Holzer et al., 1976a; Holzer et al., 1976b; and Allen and Stevenson, 1975. Values reported for wet brewer's grain and wheat straw indicate lactate values expressed as a percent of dry matter are near zero at harvest, 3 to 4 percent at 21 days after ensiling, and .2 to .8 percent after 120 days. Increasing lactate and volatile fatty acid levels were highly correlated with a decline in pH in these studies.

Few studies with high-moisture grain have involved the study of changes in the nitrogen fraction, however Bergen, Cash, and Henderson (1974) reported a study in which changes in the nitrogen fraction of whole-plant corn silage were determined as well as the effect of ensiling on the voluntary dry matter consumption of sheep. This study indicated that
after 20 days 42 percent of the total nitrogen was water soluble nitrogen. Fifty to 60 percent of the water soluble nitrogen was amino acid nitrogen and 8 to 12 percent was ammonia nitrogen. In this study neither the extent of fermentation nor the chemical composition of the silage had any effect on voluntary intake by mature wethers.

Silage studies reported by Hillman (1959) and Gordon et al. (1960) have indicated that voluntary dry matter consumption by ruminants is depressed as a result of the ensiling process. Apparently the decrease in silage dry matter consumption is caused by the increased breakdown of plant proteins to nonprotein nitrogen compounds which decrease palatability (Hughes, 1970; Johnson et al., 1967). Watson and Nash (1960) reported this proteolysis is caused by plant enzymes in the initial stages of fermentation, however the continued breakdown is caused by bacterial enzymes (Voss, 1966). Other workers (Hawkins, Henderson and Purser, 1970; and Brady, 1965) have indicated the extent of proteolysis in grass and legume silages decreases with decreasing moisture content.

Harbers (1975) studied the changes in the starch fraction of sorghum grain as observed under a scanning electron microscope. His data seemed to verify the hypothesis of Hale (1973) that in reconstituted grain the protein matrix surrounding the
starch granule is disrupted thus improving the digestibility of the sorghum grain. This hypothesis was based on histological studies of reconstituted sorghum grain conducted by Sullins et al. (1971). McNeill et al. (1975) came to the same conclusion as Hale regarding the disruption of the protein matrix. Seib (1971) suggests the principal cause of the improvement in the digestibility and utilization of processed sorghum grain is the alteration of the starch granule via disruption of the protein matrix caused by reconstitution or gelatinization of starch resulting from heat and moisture processing.

Much research has been conducted concerning the feeding value of ensiled feeds for livestock which has resulted in recommendations to producers, however livestock performance data may be somewhat misleading when the degree of fermentation and storage dry matter losses are considered. Stoneberg et al. (1968) and Shepherd et al. (1954) have reported on the harvest and storage losses which occur in hay, haylage and silage which are a part of the total efficiency of a storage system. Their work indicated differences in the rate and extent of fermentation occur in these feedstuffs which affect their utilization by livestock. Such differences may result in extensive energy and dry matter losses which can affect animal performance, thus reducing the efficiency of the storage system. El Serafy, Goodrich and Meiske (1974) reported dry matter losses of 29.4, 22.1 and 21.3 percent for hay, haylage,
Hoffman and Self (1975) reported a study comparing oxygen-limiting, concrete stave and artificially dried storage systems for high-moisture corn fed to yearling steers. Dry matter losses of 6.0 and 12.5 percent for the oxygen-limiting and concrete stave systems, respectively were observed in their study. Units of dry matter in fresh harvested grain required per unit of live weight gain were 5.64 for the oxygen-limiting system and 5.94 for the concrete stave. The authors consider this conversion ratio to represent the efficiency of the system.

Further study on dry matter and energy losses during the storage of high-moisture grains is limited, however Baker (1969) reported dry matter losses of 4.17 percent in a concrete stave silo. Heuberger et al. (1959) conducted a study in which high-moisture corn was stored in three concrete stave silos at 24, 29 and 36 percent moisture. Dry matter, gross energy and crude protein losses in this study were 2.16, 2.10, 1.31; 3.40, 4.83, 3.96; 1.19, 1.48, 0.33, for the three storage systems, respectively.

Owens et al. (1969a) expressed concern over the use of oven-drying methods to determine the dry matter content of ensiled materials. Hoffman and Self (1975) also indicated that method of dry matter determination may be important when comparing storage systems since oven-drying methods are assumed
to drive off volatiles other than water and thus inherently overestimate moisture content. Hood et al. (1971) stated that errors in dry matter determination methods have been well documented (Mayland, 1968; Schmidt, Marten and Goodrich, 1970; and Brahmakshatriya and Donker, 1971) therefore they proposed a rapid method of chemical determination of water in high-moisture feedstuffs. When this chemical saponification process was compared to conventional oven-drying methods a significant increase in dry matter was observed in silages. Danley and Vetter (1971) reported a similar significant increase in silage dry matter when the toluene distillation method described by Dewar and McDonald (1961) was compared to conventional drying methods.

**Feedlot performance studies**

Performance trials reported in the literature concerning high-moisture sorghum grain have primarily been conducted in the southwestern United States. Merrill (1971) reviewed research at the Texas, Oklahoma, Kansas and Arizona stations concerning the use of sorghum grain. In these studies early harvested or reconstituted sorghum grains at moisture levels of 25 to 30 percent were compared to dry sorghum grain at 10 to 13 percent. Riggs (1969) and Riggs and McGinty (1970) reported studies in which early harvested grain (23 percent moisture) was fed in the whole and ground forms. Cattle fed the ground high-moisture sorghum gained 11 percent faster, had
37 percent less grain dry matter intake and 24 percent less total ration dry matter intake than cattle fed whole grain. Other studies have indicated rolling of high-moisture sorghum has been superior to fine grinding for increasing feed efficiency (White et al., 1969a; White et al., 1969b; and Brethour and Duitsman, 1962). Merrill (1971) reported cattle fed ground moist sorghum grain required about 20 percent less grain dry matter per unit of gain than cattle fed dry grain. Total dry matter saved per unit of gain has ranged from 8 to 15 percent. Neuhaus and Totusek (1969) reported that grinding sorghum grain prior to storage tends to decrease rate of gain slightly and increase feed efficiency about 2 to 4 percent. Riggs (1969) recommends reconstituting sorghum in the whole form and processing before feeding. This practice results in equal gains when compared to dry processed sorghum and improved feed efficiency of 9 to 13 percent.

The desired moisture level for high-moisture sorghum grain is approximately 30 percent with a range of 25 to 35 (Wagner, 1970). Average daily gains have not been significantly affected by increasing moisture levels, however cattle fed 38 percent moisture sorghum showed a 7.6 percent decrease in rate of gain when compared to those fed 25 percent moisture grain (White and Totusek, 1969). In their study reconstituting grain to 31 and 38 percent moisture improved feed efficiency by 12 percent over dry rolled grain while 23 percent early
harvested grain only improved feed efficiency by 4 percent.

More recent reports have compared the feeding value of chemically preserved high-moisture corn and sorghum to ensiled grain. Bolsen, Cox and Riley (1974) reported a study in which they compared cattle fed sorghum prepared as follows: 1) steam flaked; 2) reconstituted, ensiled whole in an oxygen-limiting silo; 3) reconstituted, acid-treated and stored whole in a metal grain bin 4) reconstituted, acid-treated and stored whole in a concrete stave silo; 5) reconstituted, rolled and ensiled in a concrete stave silo. Moisture levels for the five treatments were 16.5, 25.0, 26.5, 25.1, and 24.5. The results of their study indicated cattle fed sorghum reconstituted whole and ensiled or acid-treated performed similarly. Those fed grain ensiled whole gained faster and more efficiently than those fed sorghum ensiled in the rolled form. Steers fed steam-flaked milo gained 4 to 15 percent more efficiently than the other treatments. In a second steer trial cattle fed early harvested sorghum gained faster and more efficiently than cattle fed dry sorghum. The addition of organic acids in their study increased feed consumption and feed required per unit of gain.

In a similar study Tonroy, Perry and Beeson (1974) reported cattle fed ensiled high-moisture corn gained equally to cattle fed dry corn on 3 to 13 percent less dry matter. No differences were observed between ensiled high-moisture corn
and acid-treated corn. These researchers also compared the effect of feeding dry corn in the whole versus the rolled form and found no difference. In their study the percent improvement in total feed and corn grain utilization of the ensiled early harvested and acid-treated corn was approximately double that of whole reconstituted ensiled corn when compared to dry corn. Perry et al. (1975) reported another study comparing the gains of cattle fed corn raw (whole or rolled), roasted (whole or rolled) or ensiled in the high-moisture form. Rate of gain was significantly improved by roasting; high-moisture ensiled corn depressed gain. Dry matter intake was the same for raw or roasted corn but less for ensiled corn. Cattle gained more efficiently on roasted versus raw corn and roasting also lowered silage dry matter intake. Ensiled high-moisture corn lowered corn dry matter per unit gain but also increased silage dry matter per unit gain, thus no effect in total dry matter consumption was observed.

Harpster, Long and Wilson (1975) reported a study on the nutritive value of dried, high-moisture, and acid-treated corn and sorghum grains for sheep. Grain dry matter intake and total dry matter intake were slightly higher for sorghum than corn. Feed and grain dry matter conversion to live weight gain was more efficient for corn than sorghum. Average daily gain was greater for lambs receiving corn. Lambs receiving ensiled grain consumed less total feed and grain dry matter, gained
more slowly but more efficiently than those fed either dried or high-moisture acid-treated grain. Rate of gain was slowest for sheep receiving dried sorghum and most rapid for those receiving acid-treated corn. No difference was observed between ensiled high-moisture corn and sorghum.

In vitro studies

In most studies feed efficiency has been improved when high-moisture ensiled grains have been fed to cattle. This improvement has been attributed to the increased digestibility of moist grain. Neuhaus and Totusek (1971) reported in vitro dry matter digestibility of 50.5 percent for whole reconstituted ensiled sorghum grain (28.5 percent moisture) compared to 35.0 percent for dried sorghum. McNeill, Potter and Riggs (1970) reported an in vitro study in which starch utilization was compared for the following methods of sorghum processing: 1) ground-dry, 2) steam-flaked, 3) reconstituted-ground and 4) micronized-rolled. Gas production, digestibility of total carbohydrate, and percent insoluble dry matter digestion were greater for steam-flaked grain, followed by reconstituted, dry and micronized grain. Starch digestion was greater for steam-flaked and reconstituted grains. Subsequent in vivo studies indicated that most of the increased utilization of starch as a result of processing occurs in the rumen. Post-ruminal utilization of dry and micronized sorghum grain is not improved
to the degree necessary to compensate for decreased ruminal
digestion. Potter, McNeill and Riggs (1971) and Yauk, Drake
and Schalles (1971) have indicated the increased ruminal
utilization of reconstituted sorghum is caused by rupturing
the poorly soluble, low quality protein complex which surrounds
the starch molecule, indicating it is not the alteration of the
starch molecule which causes improved utilization of high-
moisture sorghum, but the breakdown of the protein complex
enclosing the starch molecule. Understanding of the alteration
of the starch molecule is further complicated by differences
in grain sorghum types i.e. waxy, yellow endosperm and bird
resistant. These differences have been observed under a
scanning electron microscope by Davis and Harbers (1974).

In vitro studies reported by Helm (1970) and Bade, Lane
and Thompson (1971) were reviewed by Merrill (1971). Helms
found in vitro utilization of dry matter was 16 percent more
efficient for reconstituted sorghum when compared to air-dry
grain. Reconstituted grain also produced a narrower acetate:
propionate ratio in vitro than did air-dry grain. Cows fed
the air-dry grain had higher yields of milk and milkfat and a
higher milkfat percentage than those fed reconstituted sorghum.
Bade, Lane and Thompson (1971) found sorghum grain reconsti-
tuted with acetic acid had similar in vitro dry matter digesti-
bility and VFA patterns when compared to sorghum reconstituted
with water.
Danley and Vetter (1974c) reported a study evaluating the in vitro utilization of corn grain comparing reconstituted, formic acid-reconstituted, untreated-ensiled, dried, microwaved and steamed. It was found after 12 hour incubation ensiled corn had higher in vitro digestible dry matter and digestible total carbohydrates than heat-treated corn. Differences in in vitro digestible dry matter and digestible total carbohydrates existed between reconstituted and formic acid-reconstituted, and between microwaved and steamed corn. No differences were observed among treatments for α- and β-amylase soluble carbohydrates. Differences in VFA production were observed between reconstituted and formic acid-reconstituted and between microwaved and steamed corn.

Total soluble nitrogen and digestible ethanol soluble nitrogen were lower and ammonia nitrogen, total insoluble nitrogen and residual nitrogen were higher for reconstituted compared with formic acid-reconstituted and for microwaved compared with steamed corn in the study reported by Danley and Vetter (1974c). The authors stated differences in total soluble nitrogen and residual nitrogen were due to altering corn grain at different moisture levels.

In vivo studies
The interpretation of data from feeding trials has been facilitated greatly by the use of in vivo digestion studies. Feeding studies have indicated improved feed efficiency where
sorghum grain has been altered in some manner. In vivo studies have been useful in determining what factors are acting to improve the utilization of sorghum grain by ruminants (Riggs, 1969; and Wagner, 1970).

Franks et al. (1972) reported a study in which they measured rumen volatile fatty acid production as an indicator of utilization of sorghum processed as follows: 1) coarse ground-dry, 2) fine ground-dry, 3) reconstituted-rolled, 4) reconstituted-steam rolled, and 5) steam-flaked. Method of processing did not affect ruminal VFA production in their study, however a significant positive correlation existed between propionate production and daily gain, and a significant negative correlation existed between daily gain and acetate: propionate ratio. When the processing methods were compared in a feeding trial feed and grain dry matter efficiency favored cattle receiving the high-moisture reconstituted grains. The authors concluded with the limited number of samplings involved in this study ruminal VFA production did not provide an accurate indicator of performance although some trends were apparent.

McNeill, Potter and Riggs (1969) reported a study comparing carbohydrate utilization of sorghum grain processed by drying, steam-flaking, reconstituting and micronizing. Reconstituted grain produced less ethanol soluble carbohydrates and less reconstituted sorghum reached the abomasum. Ruminal
digestion of starch was greater for reconstituted and steam-flaked grains. The authors concluded that quantities of starch digested in the lower tract reflected differences in quantities of starch reaching the abomasum. Further work reported by McNeill, Potter and Riggs (1971) indicated reconstituted and steam-flaked grains significantly improved total starch and ruminal starch digestion when compared to dry ground grain.

Potter, McNeill and Riggs (1971) also investigated the effect of sorghum grain processing on the in vivo digestion of the grain protein fraction. Using lysine and leucine ratios they determined reconstitution and steam-flaking of sorghum grain enhanced the conversion of sorghum protein to bacterial protein. Micronizing decreased ruminal conversion to bacterial protein when compared to dry ground grain. The authors concluded reconstitution and steam-flaking increased the biological value of grain protein while micronizing decreased its value when compared to dry ground sorghum grain.

Digestion coefficients for reconstituted sorghum grain have ranged from 17 to 29 percent higher for dry matter, organic matter and nonprotein organic matter when compared to dried grains (McGinty, Breuer and Riggs, 1967; and Riggs and McGinty, 1970). Buchanan-Smith, Totusek and Tillman (1968) showed an improvement of 7 percent in dry matter, organic matter, nonprotein organic matter and energy digestibility when reconstituted sorghum was compared to dry grain. Pantin,
Riggs and Bowers (1969) also showed improved digestion coefficients for reconstituted sorghum compared to dried.

Kiesling, McCroskey and Wagner (1972) used comparative slaughter and respiration calorimeter techniques to compare energy utilization of steers fed sorghum processed by reconstitution or drying to 38 percent moisture. Grain was rolled prior to feeding. The net energy of the reconstituted rolled sorghum was significantly higher when determined by comparative slaughter, and higher but not significantly when compared by respiration calorimetry. Net energy for both processing methods was significantly higher when determined by comparative slaughter.

Husted, Hale and Theurer (1966) used a four by four Latin Square design to determine in vivo digestibility of sorghum processed by: 1) dry rolling, 2) steam processed-flaking, 3) steam processed-cutting, and 4) water soaking. Subsequent analysis showed only steam processed-flaked sorghum was significantly more digestible than dry rolled sorghum for dry matter, gross energy, TDN, NFE and protein. Steam-processed-cut was similar to dry rolled for all parameters indicating the roller pressure of the steam-flaking process is essential for improving digestibility. Soaking of sorghum also tended to improve the digestibility of TDN and protein fractions and improve the utilization of the NFE fraction over the dry rolled, but to a lesser degree than steam processed-flaking.
Loynachan, Hale and Theurer (1970) used the nylon bag technique to study in vivo dry matter disappearance of reconstituted sorghum. They found increasing water temperature had no effect on dry matter disappearance when grain was reconstituted to 25 percent moisture. Maximum utilization was found to be at a level of 30 percent moisture stored for 23 days at 38°C. Dry matter and protein disappearance were highest for reconstituted grain compared to dry grain. Starch disappearance, ethanol soluble nitrogen and water soluble glucose were also significantly increased by reconstitution to 30 percent moisture. This study indicates increased ruminal and total digestion of the starch fraction of high-moisture sorghum.

Ayala, Riggs and Potter (1968) compared different ratios of reconstituted sorghum and alfalfa hay which were 1) 100:0, 2) 65:35, 3) 35:65, and 4) 0:100. The sorghum was reconstituted to 42 percent moisture and stored for 25 days prior to feeding. Dry matter, organic matter and nonprotein organic matter digestion coefficients were significantly increased for treatments 1 and 2. Differences in crude protein digestibility were not significant. The results of this study indicate the digestibility of reconstituted sorghum is enhanced where high levels of concentrate to roughage are concerned. A study reported by White, Hembry and Reynolds (1974) comparing the digestibility of different sorghum varieties indicates that some differences
in the response of sorghum to processing methods may be due to differences in variety. Walker and Lichtenwalner (1974) indicated reconstitution of waxy sorghum resulted in higher digestibility than did reconstitution of nonwaxy sorghum.

Reports of research comparing the effects of processing on the nutritive value of corn are more limited than sorghum, however Tonroy, Perry and Beeson (1974) reported an in vivo study comparing dry, ensiled high-moisture, ensiled reconstituted high-moisture and volatile fatty acid treated high-moisture corn for growing-finishing cattle. Results of the digestibility comparisons in their study indicated differences in chemical composition were small. Crude protein digestibility was significantly higher for high-moisture ensiled corn compared to dried or VFA treated, but not over reconstituted. All other digestibility coefficients were not significantly different. The authors suggest the improvement obtained from feeding high-moisture corn may be caused by increased protein digestibility.

In a similar study, Galyean, Johnson and Wagner (1975a) compared the effects of dry rolling, steam-flaking, ensiling and acid-treating on the site and extent of starch digestion of corn using steers in a four by four Latin Square design. Ruminal starch digestibility was lower for the acid-treated and dried grain treatments. Total starch digestibility was higher for ensiled and steam-flaked compared to acid-treated
and dried grain. Ruminal, intestinal and total dry matter digestibilities followed patterns similar to starch. Gelatinization and in vitro gas production were greatest for steam-flaked grain. Rumen pH and total VFA production were higher for the ensiled high-moisture corn treatment.

Further work reported by Galyean et al. (1975b) used the in vivo Latin Square technique to determine ruminal protein utilization of corn processed by different methods. Soluble nitrogen levels were 15, 8, 64 and 12 percent for acid-treated, steam-flaked, ensiled high-moisture and dry-rolled corn, respectively. Nitrogen intakes were 85, 67, 74 and 72 g/day for the four treatments, respectively. Peak rumen ammonia levels at one-half hour post-feeding were 22, 19, 36 and 28 mg percent. From the passage of abomasal microbial nitrogen it was estimated that high-moisture storage or steam-flaking of corn increased microbial protein synthesis as compared to dry rolling, according to the authors. The total nitrogen passage through the abomasum was 105, 87, 82 and 77 g/day, which the authors concluded indicated a higher nitrogen recycling with the acid-treated and steam-flaked rations and less ruminal protein degradation from the acid-treated grain. This report is consistent with earlier work reported by Buchanan-Smith, Totusek and Tillman (1968) which indicated nitrogen digestibility is higher for reconstituted sorghum compared to dry sorghum.
MATERIALS AND METHODS

A study to evaluate sorghum grain storage systems for beef cattle was begun in the fall of 1972 at the Allee Experimental Farm, Newell, Iowa. The study was designed to compare two high-moisture grain storage systems, the concrete stave silo, and the oxygen-limiting silo with the artificial drying system.

Six tests to evaluate the storage systems on the basis of cattle feedlot performance were conducted. Dry matter (DM) determination methods, DM losses and changes in the carbohydrate and nitrogen fractions were also used to compare the effect of storage system on sorghum grain.

Feedlot performance study

The purpose of this study was to compare the effects of grain stored in three systems on cattle performance. The cattle feeding study consisted of six trials (three winter and three summer) begun with the winter trial of 1972-1973 and concluded with the completion of the summer 1975 trial. Winter Trials I, III and V were started in November of 1972, 1973 and 1974, respectively and completed in April 1973, May 1974 and April 1975. Summer Trials II, IV and VI were begun in May of 1973, 1974 and 1975 and completed in August 1973, September
1974 and August 1975, respectively.

Six lots 10.67 by 30.48 m were used to accommodate 17 to 20 steers each. Three lots had access to 4.2 m² of overhead shelter per steer while the remaining three lots had only a 2.13 m high board fence across the north side of the lot. Fenceline bunks provided 0.54 m of bunk space per steer. Automatic waterers with electric heating elements provided ice free water.

Yearling steers of mixed British breeding were individually identified, weighed twice to obtain an average starting weight, and randomly allotted to treatment group by weight from within-breed character. See Table 1. Feedlot performance parameters were determined from weight gains of treatment groups calculated by the difference between initial and final weights of individual animals.

Cattle received a full feed of 35 percent DM silage (corn, sorghum or sorghum stover), 2.27 kg of sorghum grain and .68 kg of a protein, vitamin and mineral supplement (Table 2) at the beginning of each trial. Sorghum grain was increased at a rate of .45 kg per day and silage was decreased proportionately until the animals were receiving 2.27 kg of silage, .68 kg of supplement and grain ad libitum for the remainder of the trial.

Trials I, III and V were terminated when it was estimated that 80 percent of the cattle would yield U.S.D.A. choice grade carcasses. Trials II, IV and VI were completed when
<table>
<thead>
<tr>
<th>Season</th>
<th>System^a</th>
<th>Initial weight (kg)</th>
<th>Final weight (kg)</th>
<th>Length of trial (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter 1972-73</td>
<td>CS (34)b</td>
<td>286</td>
<td>427</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>OL (34)</td>
<td>287</td>
<td>421</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>D (34)</td>
<td>286</td>
<td>426</td>
<td>126</td>
</tr>
<tr>
<td>Summer 1973</td>
<td>CS (36)</td>
<td>291</td>
<td>408</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>OL (36)</td>
<td>291</td>
<td>414</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>D (36)</td>
<td>291</td>
<td>411</td>
<td>105</td>
</tr>
<tr>
<td>Winter 1973-74</td>
<td>CS (32)</td>
<td>312</td>
<td>464</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td>OL (32)</td>
<td>314</td>
<td>477</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td>D (32)</td>
<td>311</td>
<td>483</td>
<td>167</td>
</tr>
<tr>
<td>Summer 1974</td>
<td>CS (40)</td>
<td>304</td>
<td>475</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>OL (40)</td>
<td>304</td>
<td>473</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>D (40)</td>
<td>303</td>
<td>471</td>
<td>120</td>
</tr>
<tr>
<td>Winter 1974-75</td>
<td>CS (36)</td>
<td>337</td>
<td>491</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>OL (36)</td>
<td>338</td>
<td>485</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>D (36)</td>
<td>337</td>
<td>489</td>
<td>140</td>
</tr>
<tr>
<td>Summer 1975</td>
<td>CS (40)</td>
<td>348</td>
<td>487</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>OL (40)</td>
<td>348</td>
<td>465</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>D (40)</td>
<td>348</td>
<td>498</td>
<td>98</td>
</tr>
</tbody>
</table>

^aCS = concrete stave silo; OL = oxygen-limiting silo; D = artificially dried grain.

^bNumbers in parentheses indicate number of steers per sorghum treatment.
Table 2. Ingredient composition for protein, vitamin and mineral supplement

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>kg</th>
<th>%a</th>
<th>Protein (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybeans, seeds, meal solv-extd, grnd, mx 7% fiber</td>
<td>454.0</td>
<td>49.6</td>
<td>208.1</td>
</tr>
<tr>
<td>(5-04-604)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa, aerial part, dehy meal mn 17% protein</td>
<td>227.0</td>
<td>24.8</td>
<td>40.4</td>
</tr>
<tr>
<td>(1-00-023)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea, mn 45% nitrogen</td>
<td>114.0</td>
<td>12.4</td>
<td>320.6</td>
</tr>
<tr>
<td>(5-05-070)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>23.0</td>
<td>2.5</td>
<td>--</td>
</tr>
<tr>
<td>(6-01-080)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limestone, grnd, min 33% calcium</td>
<td>68.0</td>
<td>7.4</td>
<td>--</td>
</tr>
<tr>
<td>(6-02-632)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trace mineralized salt</td>
<td>23.0</td>
<td>2.5</td>
<td>--</td>
</tr>
<tr>
<td>Vitamin premixb</td>
<td>7.0</td>
<td>0.8</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>916.0</td>
<td>100.0</td>
<td>569.1</td>
</tr>
<tr>
<td>Percent</td>
<td>--</td>
<td>--</td>
<td>62.1c</td>
</tr>
</tbody>
</table>

^aPercent composition of total mixture.

^bSufficient vitamin premix to give 66,000 IU vitamin A per kg of supplement.

^cPercent protein in the supplement as determined by calculation.

grain supplies from each system were exhausted. Cattle were fed to market weight on other grain. Only sorghum grain removed from the storage systems which were evaluated in this study are reported.
Each steer in this study received growth-promoting implant agents (two 15 mg implants of diethylstilbestrol in Trials I, IV, V and VI; and 200 mg progesterone and 20 mg estradiol benzoate\(^1\) in Trials II and III).

The three storage systems used in all studies were 1) high-moisture whole grain stored in a 4.27 m diameter by 16.67 m high concrete-stave tower silo (CS), 2) high-moisture whole grain stored in 4.27 m by 12.19 m oxygen-limiting silo (OL), and 3) whole grain dried in a batch dryer and stored in conventional storage bins.

All grain was grown on the farm and harvested so that every third set of four rows was stored in each of the three systems in succession to assure uniformity of grain varieties.

Harvest began when the moisture level of the grain dropped below 30 percent and field conditions permitted equipment to operate. The desired moisture level for the high-moisture storage systems was 25 percent, therefore water was added to any loads which tested less than the desired level. All grain was harvested within an eight day period in all three years however, some difficulty was encountered in early harvesting because of the fast drying characteristics of the sorghum head. It was necessary to add water to most of the loads stored in the high-moisture systems. Each load was weighed and sampled

\(^1\)Synovex S, a registered trademark of Syntex Agribusiness, Inc., Des Moines Iowa.
for moisture determination and subsequent laboratory analysis. A Steinlite grain moisture tester was used to obtain an immediate determination of moisture, and a duplicate sample was placed in a 103°C forced-draft oven for 72 hr to obtain data on pre-storage DM going into each system (see Table 3).

Table 3. Sorghum weight and percent moisture as stored by system and year

<table>
<thead>
<tr>
<th></th>
<th>CS&lt;sup&gt;a&lt;/sup&gt;</th>
<th>OL&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Dried</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1972 sorghum crop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture, %&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>24.3</td>
<td>24.4</td>
<td>27.5</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>77,328</td>
<td>74,860</td>
<td>77,776</td>
</tr>
<tr>
<td><strong>1973 sorghum crop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture, %&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>24.8</td>
<td>22.9</td>
<td>17.0</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>102,808</td>
<td>98,700</td>
<td>99,680</td>
</tr>
<tr>
<td><strong>1974 sorghum crop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture, %&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>25.0</td>
<td>25.1</td>
<td>19.7</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>103,428</td>
<td>88,590</td>
<td>99,098</td>
</tr>
</tbody>
</table>

<sup>a</sup>Concrete stave silo.

<sup>b</sup>Oxygen-limiting silo.

<sup>c</sup>Mean weighted for load weight and percent moisture differences.

<sup>d</sup>Moisture determination based upon 100 g sample from each load dried for 72 hours in a 103°C forced-draft oven.
Sorghum grain was transferred into the high-moisture storage systems with a silage blower. Water was added at the blower. Sorghum to be dried was placed in a holding bin, then dried in a batch dryer approximately 1 hour at a temperature of 68 C, allowed to cool for 1 hour at ambient temperature, weighed and transferred to storage. Grain for feeding was removed daily from each system, processed through a roller mill and mixed with the silage and supplement prior to delivery to fenceline bunks with a self-unloading mixer wagon.

Average daily live weight gains (ADG) were a result of total ration DM intake, however silage and supplement were held at a constant intake level allowing only grain dry matter intake to vary according to appetite. Other parameters used to compare the three systems used in the study were daily post-storage grain DM consumption (GDMC), post-storage grain DM conversion to live weight or grain DM efficiency (GDME), pre-storage grain DM conversion to live weight gain or system efficiency (SE) and storage DM losses (DML).

Grain DM losses (DML) were determined by the difference between the total weight and percent DM pre-storage and post-storage grain. Samples were taken twice weekly prior to rolling and post-storage DM was determined in a 103 C forced-draft oven for 72 hours.
Statistical procedures  Analysis of variance with least squares procedures was used to analyze the effects of year, season, housing and treatment upon daily grain dry matter consumption, average daily gain, pre-storage and post-storage grain dry matter required per unit of live weight gain and storage dry matter losses. Orthogonal comparisons of system means were used to determine treatment differences as outlined by Snedecor and Cochran (1967).

The following model was used in this analysis:

\[ y_{ijklm} = \mu + y_i + s_j + y_{si} + h_k + t_\ell + h_{tk\ell} + y{hi}k + \\
sh_{jk} + ysh_{ijk} + yt_{i\ell} + st_{j\ell} + yst_{ij\ell} + \\
e_{ijklm} \]

where  \( y_{ijklm} \) = parameter

\( \mu \) = overall mean

\( y_i \) = effect of year, where \( i = 1, 2, 3 \)

\( s_j \) = effect of season, where \( j = 1, 2 \)

\( y_{si} \) = effect of year by season interaction

\( h_k \) = effect of housing, where \( k = 1, 2 \)

\( t_\ell \) = effect of treatment where \( \ell = 1, 2, 3 \)

\( h_{tk\ell} \) = effect of kth housing by lth treatment interaction

\( y{hi}k \) = effect of ith year by kth housing interaction

\( sh_{jk} \) = effect of jth season by kth housing interaction

\( ysh_{ijk} \) = effect of ith year by jth season by kth housing interaction
\[ \gamma_{i,l} = \text{effect of } i\text{th year by } l\text{th treatment interaction} \]
\[ s_{j,l} = \text{effect of } j\text{th season by } l\text{th treatment interaction} \]
\[ y_{st,ij,l} = \text{effect of } i\text{th year by } j\text{th season by } l\text{th treatment interaction} \]
\[ e_{ijklm} = \text{random error associated with a particular observation on a single pen, where } m = 1, 2, \ldots 6. \]

with the following restrictions: \( \sum y_i = 0, \sum s_j = 0, \sum s_{ij} = 0, \sum y_{st,ij} = 0, \sum h_k = 0, \sum t_l = 0, \sum h_{lk} = 0, \sum h_{ij} = 0, \sum y_{ijk} = 0, \sum s_{ijkl} = 0, \sum y_{ijkl} = 0, \sum s_{ijkl} = 0, \sum y_{st,ijkl} = 0, \sum st_{ijkl} = 0, \) and \( \sum y_{st,ijkl} = 0. \)

**Methods of dry matter determination**

It has been suggested that feed efficiency data may favor high-moisture ensiled feeds over dried feeds where oven-drying methods are used to determine DM (Owens et al., 1969a; Hoffman and Self, 1975; Danley and Vetter, 1971; and Hood et al., 1971). Studies designed to measure the effect of oven-drying methods have considered only forage feeds consisting of 50 to 75 percent moisture. Limited information exists which indicates the effect of oven-drying on high-moisture ensiled grain. This study was designed to determine the effect of oven-drying methods on the DM determination of sorghum grain.
Two hundred-fifty gram samples were taken from every sixth load of freshly harvested sorghum grain, frozen immediately at -12 C and subsequently analyzed for moisture content and nitrogen and carbohydrate components. Dry matter was determined on pre-storage samples in a 103 C forced-draft oven for 72 hr (Method 1). One of eight monthly post-storage samples were selected from the concrete stave (CS), oxygen-limiting (OL) and artificially dried (D) systems for DM determination using Method 1. Duplicate samples were stored at -12 C in a sealed glass pint jar for later DM determination and laboratory analysis. All samples were taken during a three-year high-moisture sorghum grain feeding study which was begun in October 1972 and completed in August 1975.

The effect of DM determination method on the percent DM in freshly harvested sorghum grain was evaluated using Method 1. Dry matter was also determined on the duplicate sample frozen at -12 C using 105 C, 72 hr (Method 2) and 85 C, 48 hr (Method 3) conventional ovens without forced air, and a lyophilizer, 24 hr (Method 4) described by Martin (1973).

The effect of DM determination method on the percent DM in pre-storage and post-storage samples was measured using Methods 1, 2, 3 and 4. Frozen samples were sub-sampled, freeze-ground (Danley and Vetter, 1971) and triplicate determinations were made using each DM determination method.
Statistical procedures

Analysis of variance with least squares means was used to analyze the effects of system and method on the determination of grain dry matter. The criterion used to detect differences between means was the Least Significant Difference procedure described by Snedecor and Cochran (1967).

The following model was used in this analysis:

\[ Y_{ijk} = \mu + s_i + m_j + sm_{ij} + e_{ijk} \]

where \( Y_{ijk} \) = grain dry matter
\( \mu \) = overall mean
\( s_i \) = effect of system, where \( i = 1, 2, 3, 4 \)
\( m_j \) = effect of method, where \( j = 1, 2, 3, 4 \)
\( sm_{ij} \) = effect of sth system by mth method interaction
\( e_{ijk} \) = random error associated with a particular observation where \( k = 1, 2, \ldots, 9 \)

with the following restrictions: \( \sum s_i = 0, \sum m_j = 0, \sum sm_{ij} = 0 \).

Chemical determination of carbohydrate and nitrogen fractions

The storage and fermentation characteristics of high-moisture grains have been studied by Goodrich, Byers and Meiske, 1975; Danley and Vetter, 1974a; and Prigge et al., 1976. However the data reported in these studies have been obtained using pilot silos under controlled laboratory conditions. Reviewing the use of laboratory silos to study
fermentation of ensiled feeds Meiske, Linn and Goodrich (1975) indicated that laboratory silos, although quite useful for the determination of factors that affect the ensiling process, do not duplicate actual conditions which exist in large silos. The major objective of this study was to characterize several parameters considered to be indicative of the fermentation process which occurs under actual field conditions CS, OL and artificially dried systems.

The fermentation characteristics of pre-storage and post-storage grain in the three systems were compared by measurement of the nitrogen, carbohydrate and volatile fatty acid (VFA) fractions of sorghum grain. Pre-storage samples were obtained from every sixth load as the grain entered each storage system and frozen immediately at -12 C to inhibit microbial activity until analysis could be completed. Post-storage samples were obtained monthly throughout an approximately 300 day storage and feeding period including the months of November through August of 1972 to 1973, 1973 to 1974 and 1974 to 1975, respectively. Post-storage samples were frozen at -12 C for later analysis.

The samples analyzed in this study were prepared by a freeze-grinding technique described by Danley and Vetter (1971) which involves grinding the grain in an Osterizer blender in the presence of liquid nitrogen to prevent the loss of moisture
and volatile dry matter. The method results in a uniform particle size suitable for further analysis (Martin, 1973).

Triplicate determinations were chemically analyzed by the following procedures. To minimize the loss of volatile components DM was determined after freeze-grinding using the lyophilization procedure outlined by Martin (1973). Percent ash was determined using the procedure described in A.O.A.C. (1965). The Technicon Auto Analyzer was used to determine total nitrogen (TN) by modifying the procedure described by O'Neill and Webb (1970). One-half gram sorghum samples were subjected to digestion on a hot plate using 10 ml of digestion mixture consisting of 82% sulfuric acid, 10% perchloric acid and 0.3% selenium dioxide. The digested sample was allowed to cool 1 hr, diluted to 50 ml and stored at 4°C for subsequent analysis.

Total nonstructural carbohydrates (TNSC) were determined by modifying the enzyme procedures of MacRae and Armstrong (1968) and Auricchio et al., (1968). Freeze-ground sorghum samples (0.5 g) were diluted with 15 ml distilled water and heated at 100°C for 10 minutes on a hot plate to complete gelatinization of the starch and prevent microbial growth. Samples were allowed to cool before the addition of 10 ml acetate buffer (0.2 M acetic acid-sodium acetate, pH 4.5) and 10 ml enzyme
solution (0.5% Takadiatase). The mixture was then incubated for 40 hr at 55 C.

Water extracts were prepared in triplicate by diluting a 7.0 g freeze-ground sorghum sample to 100 ml with distilled water, agitating it in a horizontal shaker for 2 hr and filtering through Whatman No. 40 filter paper. The water extract was then subjected to pH determination using the procedure outlined by Barnett (1954).

Water soluble nitrogen (WSN) was determined on a 10 ml aliquot of the water extract which was digested on a hot plate by adding 10 ml of the digestion mixture used for the determination of total nitrogen. The mixture was cooled, diluted to 100 ml with distilled water and stored at 4 C for subsequent colorimetric analysis for ammonia by the phenol-hypochlorite procedure described by O'Neill and Webb (1970).

Water insoluble nitrogen (WISN) was determined by the difference between TN and WSN. Soluble ammonia nitrogen (NH₃-N) was determined on the water extract by the procedure described by Technicon Corporation (1960).

Analysis of water soluble carbohydrates (WSCHO) was conducted on the water extract using the TNSC procedure described by MacRae and Armstrong (1968) and Auricchio et al. (1968) involving enzyme extraction of the water soluble nonstructural

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1Available from Parke, Davis and Company, Detroit, Michigan under the trade name "Taka-Diatase."
carbohydrates. A 10 ml aliquot of the water extract was incubated for 44 hr at 39°C with 10 ml acetate buffer and 10 ml enzyme solution (0.5% Takadiatase\textsuperscript{1}). Samples were stored at 4°C prior to analysis.

Lactate determination was conducted on the water extract using the automated enzymatic procedure described by Apstein, Punchner and Brachfield (1970). The determination is based on the enzymatic conversion of lactate to pyruvate in the presence of nicotinamide-adenine-dinucleotide (NAD+) and lactic dehydrogenase (LDH). L-lactate and D-lactate were determined by reacting the water extract with L-(+) and D-(−) isomers of LDH. The Auto Analyzer system and fluorometer II (Technicon Corp., Tarrytown, N.Y.) were used to measure the enzymatic reaction. Total lactate represents the sum of the L-(+) and D-(−) isomers of lactate.

Acetate, propionate and butyrate concentrations in the water extract were determined by a modification of the procedure described by Barnett (1954). Three ml of aqueous extract were reacted with 1 ml of a 3:1 mixture of 25% metaphosphoric and formic acids. The solution was allowed to react for 30 minutes to precipitate soluble proteins and centrifuged at 4°C for 10 minutes at 12,000 G. The supernatant

\textsuperscript{1}Available from Parke, Davis and Company, Detroit, Michigan under the trade name "Taka-Diatase."
was stored at -12°C for subsequent analysis for acetate, propionate and butyrate using the gas chromatographic procedure by Baumgardt (1964).

**Statistical procedures** Analysis of variance with least squares means was used to analyze the effects of year, season, and time on the parameters which were chemically analyzed. The criterion used to detect differences between means was the Least Significant Difference procedure described by Snedecor and Cochran (1967).

The following model was used in this analysis:

\[ Y_{ijk} = \mu + y_i + s_j + y_{si} + t_k + st_{jk} + yt_{ik} + yst_{ijk} \]

where \( y_{ijk} \) = parameter

\( \mu \) = overall mean

\( y_i \) = effect of year, where \( i = 1, 2, 3 \)

\( s_j \) = effect of system, where \( j = 1, 2, 3, 4 \)

\( y_{si} \) = effect of \( y \)th year by \( s \)th system interaction

\( t_k \) = effect of time, where \( k = 1, 2, \ldots 9 \)

\( st_{jk} \) = effect of \( j \)th system by \( k \)th effect of time interaction

\( yt_{ik} \) = effect of \( i \)th year by \( k \)th effect of time interaction

\( yst_{ijk} \) = effect of \( i \)th year by \( j \)th system by \( k \)th effect of time interaction
with the following restrictions: \( \sum_{i} y_i = 0, \sum_{j} s_j = 0, \)

\( \sum_{i} y_{s_{i j}} = 0, \sum_{k} t_k = 0, \sum_{j} s_{t_{j k}} = 0, \sum_{i} y_{t_{i k}} = 0. \)
RESULTS AND DISCUSSION

Feedlot performance study

The parameters to be discussed in this section are daily post-storage grain DM consumption (GDMC), average daily gain (ADG), post-storage grain DM required per unit of live weight gain or grain DM efficiency (GDME), pre-storage grain DM required per unit of live weight gain or system efficiency (SE) and grain DM losses during storage (DML). The effects of year, season and housing related to this study will also be reported and discussed briefly.

Daily grain dry matter consumption

The results for GDMC are shown in Table 4. GDMC was greater (P < .01) for cattle fed grain from the dried system compared to either high-moisture system. The data are consistent with those of others who have compared dried and ensiled high-moisture sorghum grain. Riggs (1969) and Riggs and McGinty (1970) reported studies in which cattle fed ensiled high-moisture sorghum consumed 37 percent less grain DM than cattle fed dried grain. Neuhaus and Totusek (1969) reported a study in which cattle fed reconstituted-ensiled high-moisture sorghum consumed less grain DM than those fed dried grain. Tonroy, Perry and Beeson (1974) reported five feeding trials comparing ensiled high-moisture corn to dried corn which indicated cattle consumed 4 to 25 percent less grain DM when offered the high-moisture grain.
In an Iowa study Hoffman and Self (1975) reported cattle fed dried corn consumed 5.2% and 4.1% more grain DM than cattle fed grain stored in OL and CS silos, respectively. Our study indicates cattle fed sorghum grain stored in CS, OL and dried systems consumed 7.38, 7.16 and 7.72 kg daily. These results represent an increase of 4.6 and 7.8% in grain DM consumption for cattle fed dried grain compared to those fed grain stored in either the CS or OL systems. Increases in GDMC of dried grain compared with ensiled grain may be caused by lower digestibility of dried grain which would require greater GDMC to compensate for lowered starch and protein availability.

The significance level of the effects of year, season and housing are shown in Table 7. Year \( (P < .01) \) and season \( (P < .05) \) had a significant effect on the GDMC, however housing did not have an effect. Year and season effects were found to be significant in the earlier study comparing CS, OL and dried corn storage systems (Hoffman and Self, 1975). The results of these two studies indicate the importance of the effects of environment on the consumption of grain in feeding studies where such environmental factors as year, season and housing are uncontrolled variables.

**Average daily gain** The results for ADG are shown in Table 4. Cattle fed dried grain gained 1.25 kg per head daily compared to 1.22 and 1.20 kg for the cattle receiving grain from the CS and OL systems, respectively. The 3.3 percent
Table 4. Least squares means for daily grain dry matter consumption (GDMC), average daily gain (ADG) and post-storage grain dry matter units per unit gain (GDME) by storage system, season and year of harvest

<table>
<thead>
<tr>
<th>Year harvest</th>
<th>Storage system</th>
<th>GDMC&lt;sup&gt;1,a,b&lt;/sup&gt; (kg)</th>
<th>ADG&lt;sup&gt;a,c&lt;/sup&gt; (kg)</th>
<th>GDME&lt;sup&gt;a,c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972 Winter</td>
<td>CS&lt;sup&gt;2&lt;/sup&gt;</td>
<td>7.29</td>
<td>1.11</td>
<td>6.58</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>6.73</td>
<td>1.04</td>
<td>6.44</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.08</td>
<td>1.11</td>
<td>6.37</td>
</tr>
<tr>
<td>Summer</td>
<td>CS</td>
<td>6.97</td>
<td>1.29</td>
<td>5.39</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>7.28</td>
<td>1.27</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.04</td>
<td>1.42</td>
<td>4.96</td>
</tr>
<tr>
<td>1973 Winter</td>
<td>CS</td>
<td>7.25</td>
<td>0.91</td>
<td>7.98</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>7.44</td>
<td>0.98</td>
<td>7.66</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.97</td>
<td>1.03</td>
<td>7.76</td>
</tr>
<tr>
<td>Summer</td>
<td>CS</td>
<td>6.79</td>
<td>1.42</td>
<td>4.76</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>6.43</td>
<td>1.41</td>
<td>4.55</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.67</td>
<td>1.40</td>
<td>5.50</td>
</tr>
<tr>
<td>1974 Winter</td>
<td>CS</td>
<td>7.75</td>
<td>1.09</td>
<td>7.23</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>7.78</td>
<td>1.05</td>
<td>7.46</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>8.43</td>
<td>1.04</td>
<td>8.09</td>
</tr>
<tr>
<td>Summer</td>
<td>CS</td>
<td>8.26</td>
<td>1.48</td>
<td>5.60</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>7.29</td>
<td>1.46</td>
<td>4.98</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>8.15</td>
<td>1.53</td>
<td>5.36</td>
</tr>
</tbody>
</table>

<sup>1</sup>Dry matter intake based on post-storage samples dried 72 hours in a forced-draft oven at 103 C.

<sup>2</sup>CS = high-moisture sorghum stored in concrete stave silo; OL = high-moisture sorghum stored in oxygen-limiting silo; D = artificially dried sorghum.

<sup>a</sup>Effect of year significant (P < .01).

<sup>b</sup>Effect of season significant (P < .05).

<sup>c</sup>Effect of season significant (P < .01).
Table 4 (Continued)

<table>
<thead>
<tr>
<th>Year harvest</th>
<th>Storage system</th>
<th>GDMC&lt;sup&gt;1,a,b&lt;/sup&gt; (kg)</th>
<th>ADG&lt;sup&gt;a,c&lt;/sup&gt; (kg)</th>
<th>GDME&lt;sup&gt;a,c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average, all tests&lt;sup&gt;3&lt;/sup&gt; Winter</td>
<td>CS</td>
<td>7.43</td>
<td>1.03</td>
<td>7.26</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>7.31</td>
<td>1.02</td>
<td>7.19</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.83</td>
<td>1.06</td>
<td>7.40</td>
</tr>
<tr>
<td>Summer</td>
<td>CS</td>
<td>7.34</td>
<td>1.40</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>7.00</td>
<td>1.38</td>
<td>5.10</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.62</td>
<td>1.45</td>
<td>5.27</td>
</tr>
<tr>
<td>Summary of 6 tests CS</td>
<td>7.38&lt;sup&gt;4,d&lt;/sup&gt;</td>
<td>1.22&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.26&lt;sup&gt;4,g&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>7.16&lt;sup&gt;4,d&lt;/sup&gt;</td>
<td>1.20&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.14&lt;sup&gt;4,e&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.72&lt;sup&gt;4,f&lt;/sup&gt;</td>
<td>1.25&lt;sup&gt;4,g&lt;/sup&gt;</td>
<td>6.34&lt;sup&gt;4,g&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>3</sup>Average of 3 winter and 3 summer tests.

<sup>4</sup>SEM = .072, .014 and .053 for GDMC, ADG and GDME, respectively.

<sup>d,f</sup>Means within the same column with different superscript differ (P < .01).

<sup>e,g</sup>Means within the same column with different superscript differ (P < .10).
advantage of the dried system over the high-moisture storage systems and the 4.2% advantage of the dried system compared to the OL system were significant (P < .10). Most cattle feeding studies have found little difference in rate of gain when high-moisture sorghum is compared to dried. Merrill (1971) reviewed several studies by Riggs (1969) which found results from feeding ensiled sorghum ranged from an 8.0 percent increase to a 7.6 percent decrease in average daily gain. All of these studies involved grain which was reconstituted prior to storage and rolled before feeding. Merrill (1971) concluded the trend in the studies which he reviewed was decreasing gain with increasing moisture levels. Riggs and McGinty (1970) reported an 11% increase in ADG when ensiled high-moisture sorghum was ground before feeding compared to whole grain. Riggs (1969) recommends processing sorghum after storage for maximum rate of gain response. Results of a study conducted by Neuhaus and Totusek (1969) indicated that grinding sorghum before storage was undesirable and resulted in decreased ADG and increased feed efficiency.

Hoffman and Self (1975) reported no difference in ADG when cattle were fed high-moisture corn stored in CS or OL systems or dried corn in a four-year study. However, their study indicated cattle fed dried corn gained 3.5% faster (1.21 vs. 1.17 kg daily) than cattle fed corn stored in the OL system. Their
results are consistent with the 4.2% advantage for dried sorghum found in our study.

Average daily gain was affected by year ($P < .01$), season ($P < .01$) and housing ($P < .05$). Year differences are represented by the means for 1972, 1973 and 1974 which were 1.21 kg, 1.20 kg and 1.27 kg daily, respectively. Season differences are illustrated by the results in Table 4 which indicate ADG for the CS, OL and dried systems were 1.03, 1.02 and 1.06 kg daily in winter compared to 1.40, 1.38 and 1.45 kg, respectively in the summer. Similar results were reported by Hoffman and Self (1975). Our study indicated that cattle with access to shelter gained .04 kg per day faster than those without shelter (1.24 vs. 1.20 kg daily). The effects of housing have been discussed in greater detail by Hoffman and Self (1970).

Post-storage grain dry matter efficiency

Earlier studies refer to the conversion of grain DM to live weight gain as a measure of animal performance which in this study will be reported as post-storage grain DM efficiency (GDME).

The results for GDME can be found in Tables 4 and 5. GDME for the CS, OL and dried systems respectively were 6.26, 6.14 and 6.34. These results represent a significant advantage ($P < .10$) for the OL system compared to the CS and dried systems. Merrill (1971) reported that cattle fed ground moist sorghum grain required 20 percent less grain DM than cattle fed dry grain. Riggs (1969) found GDME was improved 9 to 13% in several
studies reported from the Texas station. White and Totusek (1969) found sorghum grain reconstituted to 31 or 38% resulted in 12% improvement in GDME compared to dried sorghum rolled prior to feeding. Their study indicated that early harvested grain stored at 23% moisture resulted in only a 4% improvement in grain dry matter efficiency.

Studies comparing high-moisture ensiled corn to dried corn have found results similar to the sorghum studies. Tonroy, Perry and Beeson (1974) reported cattle fed high-moisture corn gained as rapidly as those fed dried corn on 3 to 13% less grain DM in five feeding trials. Hoffman and Self (1975) reported a 3.8% improvement in GDME favoring an OL system compared to dried corn. They observed only a slight improvement in GDME when grain was stored in a CS system.

Our study indicates that ensiling sorghum grain in an OL system improves GDME 3.2% compared to the drying system. A CS system improved GDME 1.3%. The minimal improvement in GDME in this study with early harvested sorghum ensiled at 23-25 percent moisture is consistent with results reported earlier by White and Totusek (1969) indicating a 4% improvement in GDME when early harvested sorghum was ensiled at 23% and rolled prior to feeding. Ensiling sorghum grain at moisture levels below 25% does not appreciably improve GDME. Riggs (1969) indicated a maximum improvement of 10% in GDME occurs at moisture levels between 26 and 30 percent with little additional
improvement above 30 percent.

The effects of year, season and housing on GDME are reported in Table 7. All three environmental factors were significant ($P < .01$). Hoffman and Self (1970) observed that cattle with access to shelter more efficiently converted grain DM to liveweight gain. Our results indicate cattle with access to shelter are 3.3% more efficient than those without shelter (6.14 vs. 6.35). The highly significant effect of season in this study is illustrated by the overall means for all treatments which were 7.28 in winter and 5.21 in summer. This difference represents a 28.4% improvement in GDME in summer. The data indicate the major effect of environment was on GDME indicating energy utilization is significantly affected by climatic conditions.

**Pre-storage grain dry matter efficiency**

The concept of system efficiency (SE) applied to grain storage systems was described by Hoffman and Self (1975) as the amount of pre-storage grain DM required per unit of live weight gain. The authors suggested SE expresses the efficiency of a beef production system more accurately than GDME since it accounts for storage and handling DM losses and animal performance. System efficiency provides a basis for comparison of storage systems used in beef cattle production.

Results for SE are shown in Table 5. SE values for the CS, OL and dried systems were 6.83, 6.53 and 6.79, respectively.
Table 5. Least squares means for pre-storage and post-storage grain dry matter required per unit of liveweight gain by storage system and year of harvest

<table>
<thead>
<tr>
<th>Year harvest</th>
<th>Storage system</th>
<th>SE$^{1,a,b}$</th>
<th>GDME$^{2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>CS$^{3}$</td>
<td>6.51</td>
<td>5.99</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>6.43</td>
<td>6.10</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>6.17</td>
<td>5.67</td>
</tr>
<tr>
<td>1973</td>
<td>CS</td>
<td>6.90</td>
<td>6.37</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>6.56</td>
<td>6.11</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.02</td>
<td>6.63</td>
</tr>
<tr>
<td>1974</td>
<td>CS</td>
<td>7.09</td>
<td>6.42</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>6.60</td>
<td>6.22</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>7.19</td>
<td>6.73</td>
</tr>
<tr>
<td>Average 6 tests</td>
<td>CS</td>
<td>6.83$^{4,c}$</td>
<td>6.26$^{4,d}$</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>6.53$^{4,e}$</td>
<td>6.14$^{4,f}$</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>6.79$^{4,c}$</td>
<td>6.34$^{4,d}$</td>
</tr>
</tbody>
</table>

$^{1}$SE = pre-storage grain dry matter required per unit of liveweight gain or system efficiency.

$^{2}$GDME = post-storage grain dry matter required per unit of liveweight gain.

$^{3}$CS = high-moisture sorghum stored in concrete stave silo; OL = high-moisture sorghum stored in oxygen-limiting silo; D = artificially dried sorghum.

$^{4}$SEM = .059 and .053 for SE and GDME, respectively.

$^{a}$SE differs from GDME ($P < .01$) in all systems.

$^{b}$Effect of year significant ($P < .01$).

$^{c,e}$Means within the same column with different superscripts differ ($P < .01$).

$^{d,f}$Means within the same column with different superscripts differ ($P < .10$).
The 4.4% advantage in SE favoring the OL system was significant \( (P < .01) \). Hoffman and Self (1975) reported the OL system had a 4.0% advantage over conventionally dried grain and a 5.0% advantage over the CS system. SE ratios reported in their study were 5.94, 5.64 and 5.86 for the CS, OL and dried systems.

Conventional feed efficiency data is useful for interpreting the utilization of feedstuffs by livestock, however it does not provide for adequate comparisons of feed storage systems for beef.

Expression of the efficiency of beef production systems on a GDME or SE basis is shown in Table 5. SE and GDME values for the CS, OL and dried systems, respectively are 6.83, 6.26; 6.53, 6.14; and 6.79, 6.34. When the efficiency of grain DM conversion to live weight gain is reported on a pre-storage rather than post-storage basis the value is considerably higher. This greater value \( (P < .01, \text{for all three systems}) \) reflects animal performance and losses which occur during storage, handling and feeding grain.

**Grain dry matter losses** Results for DML are reported in Table 6. Pre-storage and post-storage grain moisture content and weight and percent dry matter losses are reported by year. An increase \( (P < .01) \) in DML occurred when sorghum grain was stored in the CS system compared to the OL or dried systems. This represents a 39.3% increase in DML for the CS compared to the OL system and a 30.8% increase over the dried
<table>
<thead>
<tr>
<th>Harvest year</th>
<th>System</th>
<th>Pre-storage</th>
<th>Post-storage</th>
<th>Pre-storage</th>
<th>Post-storage</th>
<th>Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>CS(^1)</td>
<td>24.3</td>
<td>23.0</td>
<td>58,537</td>
<td>53,813</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>24.4</td>
<td>25.1</td>
<td>56,594</td>
<td>53,758</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>27.5</td>
<td>13.9</td>
<td>56,387</td>
<td>51,858</td>
<td>8.0</td>
</tr>
<tr>
<td>1973</td>
<td>CS</td>
<td>24.8</td>
<td>23.2</td>
<td>77,312</td>
<td>71,338</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>22.9</td>
<td>24.6</td>
<td>76,098</td>
<td>70,567</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>17.0</td>
<td>13.7</td>
<td>82,734</td>
<td>78,124</td>
<td>5.6</td>
</tr>
<tr>
<td>1974</td>
<td>CS</td>
<td>25.0</td>
<td>22.4</td>
<td>77,571</td>
<td>70,118</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>25.1</td>
<td>24.0</td>
<td>66,354</td>
<td>62,545</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>19.7</td>
<td>12.6</td>
<td>79,576</td>
<td>74,464</td>
<td>6.4</td>
</tr>
<tr>
<td>Summary, all tests</td>
<td>CS</td>
<td>24.7</td>
<td>22.9</td>
<td>213,420</td>
<td>195,269</td>
<td>8.52,(^b)</td>
</tr>
<tr>
<td></td>
<td>OL</td>
<td>24.1</td>
<td>24.6</td>
<td>199,046</td>
<td>186,870</td>
<td>6.12,(^c)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>20.9</td>
<td>13.4</td>
<td>218,697</td>
<td>204,446</td>
<td>6.52,(^c)</td>
</tr>
</tbody>
</table>

\(^1\) CS = high-moisture sorghum stored in concrete stave silo; OL = high-moisture sorghum stored in oxygen-limiting silo; D = artificially dried sorghum.

\(^2\) SEM = .031.

\(^a\) Effect of year significant (P < .01).

\(^b,\(^c\) Means within the same column with different superscript differ (P < .01).
Table 7. Probability level of significance for factors in analysis of variance for GDMC, ADG, GDME, SE and DML

<table>
<thead>
<tr>
<th>Factor</th>
<th>GDMC</th>
<th>ADG</th>
<th>GDME</th>
<th>SE</th>
<th>DML</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
</tr>
<tr>
<td>Season</td>
<td>.05</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
</tr>
<tr>
<td>Year X Season</td>
<td>.05</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
</tr>
<tr>
<td>Housing</td>
<td>NS</td>
<td>.05</td>
<td>.01</td>
<td>.01</td>
<td>NS</td>
</tr>
<tr>
<td>System</td>
<td>.01</td>
<td>.10</td>
<td>.10</td>
<td>.01</td>
<td>.01</td>
</tr>
<tr>
<td>Housing X System</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Year X Housing</td>
<td>NS</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
<td>NS</td>
</tr>
<tr>
<td>Season X Housing</td>
<td>NS</td>
<td>NS</td>
<td>.05</td>
<td>.05</td>
<td>NS</td>
</tr>
<tr>
<td>Year X Season X Housing</td>
<td>NS</td>
<td>NS</td>
<td>.01</td>
<td>.05</td>
<td>NS</td>
</tr>
<tr>
<td>Year X System</td>
<td>.05</td>
<td>NS</td>
<td>.01</td>
<td>.05</td>
<td>.01</td>
</tr>
<tr>
<td>Season X System</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>.01</td>
</tr>
<tr>
<td>Year X Season X System</td>
<td>.05</td>
<td>SN</td>
<td>.01</td>
<td>.01</td>
<td>.01</td>
</tr>
</tbody>
</table>

1 See Tables 4, 5 and 6 for codes.

2 Not significant.

system. Hoffman and Self (1975) reported DML of 12.5 and 6.0 percent for whole-shelled high-moisture corn stored in CS and OL systems. Sorghum grain DML in this study were 8.5, 6.1 and 6.5 percent for the CS, OL and dried systems respectively.

Baker (1969) reported DML 4.17% for grain stored in an OL silo. Heuberger et al. (1959) found that corn stored in three CS structures had DML of 2.2, 3.4 and 1.2%. Danley and Vetter
(1974a) reported DML of 3.9% for corn dried to 12% moisture in a 100 C forced-draft oven. A study reported by Goodrich, Byers and Meiske (1975) indicated corn grain stored at moisture levels of 21.5, 27.5, and 33.1% resulted in DML of 2.7, 3.7 and 5.6%. Energy losses were 1.9, 2.6 and 3.7% or approximately 70% of the dry matter losses.

The DML reported in our study are higher than others have found. Higher DML might be expected to occur under farm storage conditions where full size silos and dried grain storage bins are used. All losses which occur in storage, handling and feeding grain from the time it comes from the field until it is consumed by livestock should be included in studies comparing DML in storage systems. Lower dry matter losses increased the advantage of the OL system which produced the most efficient live weight gains in this study. GDME indicated the OL system was the most efficient, but not by the magnitude indicated by the SE ratios. Dry matter losses are seldom measured in feeding studies, however freshly harvested grain quantities are usually known, which allows the SE ratio to be implemented for comparison of different methods of grain storage.

The results of our study indicate physical and chemical factors act to affect the percentage of the nutrients in freshly harvested grain which is ultimately utilized by the animal.
Summary

The results indicate cattle fed sorghum grain stored in a conventional drying system consume more (P < .01) grain DM and gain slightly faster (P < .10) than cattle fed grain stored in either CS or OL systems. Cattle fed grain from an OL system were more efficient than cattle fed grain from either the CS or dried systems on both a pre-storage (P < .01) and a post-storage (P < .10) basis. Dry matter losses were highest (P < .01) in the CS system compared to the OL and dried systems. Year, season and type of housing affected DGMC, ADG and system efficiency. Environmental effects on livestock performance parameters should be considered in feeding studies where environment is not controlled.

Methods of dry matter determination

Results for the comparison of dry matter determination methods are shown in Table 8. The amount of sorghum grain DM was different (P < .05) among the four methods compared within pre-storage and post-storage grain stored in CS, OL or artificially dried systems. Drying pre-storage grain in conventional ovens at 105 C (Method 2) or 85 C (Method 3) resulted in increased (P < .05) DM compared with a 103 C forced-draft oven (Method 1). Determination of grain DM by Method 3 or lyophilization (Method 4) resulted in the highest DM value (P < .05).

Post-storage grain from the CS system had higher DM values when DM was determined by Methods 3 and 4 (P < .05) compared to Methods 1 and 2. Method 3 resulted in higher DM
Table 8. Percent sorghum grain dry matter determined by four different methods

<table>
<thead>
<tr>
<th>System</th>
<th>Method (1) Forced-draft</th>
<th>Method (2) 105 C</th>
<th>Method (3) 85 C</th>
<th>Method (4) Lyophilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-storage</td>
<td>79.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.6&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>82.5&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>CS&lt;sup&gt;2&lt;/sup&gt;</td>
<td>76.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.8&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>78.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>OL&lt;sup&gt;2&lt;/sup&gt;</td>
<td>75.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>76.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>77.5&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>78.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>D&lt;sup&gt;2&lt;/sup&gt;</td>
<td>86.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>86.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>87.7&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>88.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1Methods are 1) 103 C forced-draft oven for 72 hours; 2) 105 C conventional oven for 72 hours; 3) 85 C conventional oven for 48 hours; 4) lyophilizer for 24 hours.

2CS = high-moisture sorghum stored in concrete silo; OL = high-moisture sorghum stored in oxygen-limiting silo; D = artificially dried sorghum.

3SEM = 0.44 for dry matter determination methods.

<sup>a,b,c</sup>Means within the same row with different superscripts are different (P < .05).

Values than Method 1 (P < .05), but no difference existed between Methods 2 and 3 (P > .05). Method 4 resulted in higher DM values than 1 and 2 (P < .05), but Methods 3 and 4 were not different (P > .05).

Methods 3 and 4 indicated higher (P < .05) DM values for post-storage samples from the OL system when compared to Methods 1 and 2. No differences existed between Methods 2 and 3 or 3 and 4 (P > .05), however Method 2 resulted in higher
(P < .05) DM values than Method 1 and Method 4 increased the amount of DM compared to Method 2.

Post-storage grain from the artificially dried system had higher DM values when DM was determined by Method 3 or 4 (P < .05). However, no differences existed between Methods 1 and 2, 2 and 3 or 3 and 4 (P > .05). Although differences existed between methods within prestorage, CS, OL and dried grain, no interaction existed between method of DM determination and type of storage system.

A review of high-moisture grain studies (Merrill, 1971) indicated DM values reported for high-moisture grain commonly use conventional oven-drying techniques to determine dry matter. He concluded oven-drying procedures inherently underestimate DM which favors high-moisture fermented grain when compared to dried grain on a feed efficiency basis. This conclusion has been well documented by Mayland, 1968; Schmidt, Marten and Goodrich, 1970; Brahmakshatriya and Donker, 1971; and Danley and Vetter, 1971. However, the reported error in conventional oven-drying methods compared to toluene distillation, saponification and freeze-drying techniques has only been reported for studies using silages containing much higher moisture levels and undergo more extensive fermentation than high-moisture grain.

Determination of grain DM by lyophilization (freeze-drying) or drying in an 85 C conventional oven results in higher DM values than either 105 C conventional or 103 C
forced-draft oven regardless of whether the grain is freshly harvested, dried or fermented. Hood et al. (1971) indicated the principle concern in the use of oven-drying methods is driving off volatile nonaqueous DM components such as acetic and lactic acid and ethanol. Since high-moisture fermented feeds have higher levels of these components, many have concluded feed efficiency data will favor fermented feeds where oven-drying methods are used. However, Danley and Vetter (1974a) reported acetate, propionate and butyrate values of 1.38, 0.64 and 0.86 mg/g; and 1.44, 0.70 and 0.97 mg/g, for 22 and 16% moisture ensiled corn, respectively. Lactate and ethanol were not measured in their study however, their results indicate that nonaqueous volatile organic matter is also present in feeds with very low moisture.

The results of our study indicate volatile organic matter is probably removed in 103 C forced-draft and 105 C conventional drying ovens used to determine grain DM. No difference existed in between an 85 C conventional oven and lyophilization. Dry matter values tended to be higher in the lyophilizer for pre-storage, CS, OL and dried samples.

Our study clearly indicates differences in grain DM can result from the use of different methods of DM determination. There was no interaction between method of determination and storage system. Moisture levels varied from a low of 13.4% for dried grain to a high of 24.3% for grain stored in the OL
system. These levels may be too low to detect major differences or interactions among methods, since recommended moisture levels for the fermentation of sorghum grain are 26 to 30% (Riggs, 1969). Future studies should include grain stored at higher moisture levels than were used in our studies.

Summary

Four DM determination methods were used to compare the effect of oven-drying and lyophilization on the amount of DM in freshly harvested sorghum grain or grain stored in CS, OL or artificially dried systems. Methods 3 and 4 resulted in higher (P < .05) DM values for freshly harvested or stored grain. Method 2 resulted in higher (P < .05) DM values than Method 1 in pre-storage and OL samples, but not in CS or dried samples. Methods 2 and 3 were not different in any system (P > .05). Dry matter determined by Method 4 was greater (P < .05) than Methods 1 and 2 in all systems. Although methods differed, no interaction between DM determination method and storage system was found in this study.

Chemical determination of carbohydrate and nitrogen fractions

A cattle feeding study indicated DM was lost during storage, handling and feeding of sorghum grain stored in CS, OL or dried systems. Dry matter losses include chemical and physical factors which affect the efficiency of storage systems. Chemical changes occurring during storage contribute DML by increasing solubilization of carbohydrate and nitrogen fractions. Microorganisms utilize soluble carbohydrates during
fermentation liberating volatile organic acids, ethanol and CO₂ (Whittenbury, McDonald and Bryan-Jones, 1967). Volatile organic materials constitute a major portion of the DML during storage (Danley and Vetter, 1974a). Cell respiration and fermentation which cause DML during storage increase solubilization of carbohydrate and nitrogen fractions which improves in vivo and in vitro digestibility (Husted, Hale and Theurer, 1966; and Danley and Vetter, 1974c). Changes occurring in carbohydrate and nitrogen fractions of high-moisture sorghum grain have not been reported for studies of longer than 56 days duration. Our study provides data indicating changes occurring in sorghum grain from the time of harvest and storage for approximately 300 days. Data reported here were derived from studies over a three-year period (1972, 1973 and 1974) involving laboratory analysis of pre-storage and post-storage grain from CS, OL and dried systems.

pH The results for pH determination are given in Table 9. No difference existed between pre-storage and artificially dried grain or, between the two high-moisture systems (P < .05), however a decrease (P < .05) occurred in the CS (4.85) and OL (4.94) systems. Goodrich, Byers and Meiske (1975) reported pH values of 5.94 and 5.55 for 21.5 and 27.5% moisture whole corn grain. Values for corn rolled prior to storage were 5.64 and 4.88. The pH values found in our studies indicate sufficient fermentation occurred to
Table 9. pH and percent ash of sorghum grain stored in three systems

<table>
<thead>
<tr>
<th>System</th>
<th>pH</th>
<th>Percent ash</th>
<th>SEM pH</th>
<th>SEM percent ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-storage</td>
<td>5.65²,a</td>
<td>1.10²,b</td>
<td>0.14</td>
<td>0.03</td>
</tr>
<tr>
<td>CS³</td>
<td>4.85²,b</td>
<td>1.22²,c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OL³</td>
<td>4.94²,b</td>
<td>1.08²,b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D³</td>
<td>5.86²,a</td>
<td>1.35²,d</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Percent of dry matter.
²SEM = 0.14 for pH; 0.03 for percent ash.
³CS = high-moisture sorghum stored in concrete stave silo; OL = high-moisture sorghum stored in oxygen-limiting silo; D = artificially dried sorghum.

Means within the same column with different superscripts are different (P < .05).

Preserve high-moisture sorghum. Since high-moisture feeds have extensive buffering capacity pH may not be sufficiently sensitive to be used as an indicator of fermentation activity (Whittenbury, McDonald and Bryan-Jones, 1967).

Percent ash

Percent ash values are shown in Table 9. No difference was observed between pre-storage and OL systems (P > .05) but the values were higher in the CS and dried systems than in the pre-storage grain (P < .05). Dried grain was higher in ash than grain in the CS system (P < .05). Ash percentage may indicate the extent of organic matter losses.
occurring as a result of fermentation since inorganic con-
stituents should remain constant. It is difficult to explain
why no change in percent ash occurred between the pre-storage
and OL grain. The increase in percent ash observed in the
comparison of CS and dried grain was also unexpected. It may
be that the loss of certain volatile minerals such as sulfur
and phosphorus during the ashing process makes percent ash a
crude measure of apparent dry matter loss. It may be worth
noting, however, that the two systems with the highest observed
DML (CS and dried) also had the highest percent ash.

Total nonstructural carbohydrates

Results for TNSC appear in Table 10. No difference existed between pre-storage
and dried grain (P > .05). Post-storage grain from high-
moisture storage systems was lower (P < .05) than pre-storage
grain. The difference (P < .05) between the CS and OL systems
indicates greater change occurred in the CS system. Total
nonstructural carbohydrates are not commonly reported in
literature concerning high-moisture grain, however Danley and
Vetter (1974a) reported values of 717.5, 720.5 and 748.5 mg/g
for ensiled or dried corn harvested at 22% moisture. Values
of 774.2, 752.4 and 786.4 mg/g were observed for 16% moisture
ensiled or dried corn.

The results of our study indicate a 6.0% decrease in TNSC
for CS compared to pre-storage grain. A 3.4% decrease occurred
in the OL system. The changes observed in our study are
different than those which Danley and Vetter (1974a) observed at a moisture level of 22%, however changes they observed at the 16% level are quite similar to the results of our study. Since much of the grain used in our study was harvested at 16 to 20% and reconstituted prior to storage the results are consistent with observations of Danley and Vetter (1974a). Significant DML apparently occurs in the form of TNSC in CS and OL systems as a result of the fermentation process.

Table 10. Changes in the carbohydrate fraction of sorghum grain stored in three systems

<table>
<thead>
<tr>
<th>System</th>
<th>TNSC&lt;sup&gt;1&lt;/sup&gt; mg/g DM</th>
<th>WSCHO&lt;sup&gt;1&lt;/sup&gt; % TNSC</th>
<th>WSCHO&lt;sup&gt;1&lt;/sup&gt; % DM</th>
<th>WISCHO&lt;sup&gt;1&lt;/sup&gt; % DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-storage</td>
<td>741.9&lt;sup&gt;2&lt;/sup&gt;,a</td>
<td>4.94&lt;sup&gt;2&lt;/sup&gt;,b</td>
<td>4.46&lt;sup&gt;2&lt;/sup&gt;,b</td>
<td>95.54&lt;sup&gt;2&lt;/sup&gt;,b</td>
</tr>
<tr>
<td>CS&lt;sup&gt;3&lt;/sup&gt;</td>
<td>697.6&lt;sup&gt;2&lt;/sup&gt;,c</td>
<td>5.05&lt;sup&gt;2&lt;/sup&gt;,b</td>
<td>4.49&lt;sup&gt;2&lt;/sup&gt;,b</td>
<td>95.51&lt;sup&gt;2&lt;/sup&gt;,b</td>
</tr>
<tr>
<td>OL&lt;sup&gt;3&lt;/sup&gt;</td>
<td>716.6&lt;sup&gt;2&lt;/sup&gt;,b</td>
<td>4.98&lt;sup&gt;2&lt;/sup&gt;,b</td>
<td>4.57&lt;sup&gt;2&lt;/sup&gt;,b</td>
<td>95.43&lt;sup&gt;2&lt;/sup&gt;,b</td>
</tr>
<tr>
<td>D&lt;sup&gt;3&lt;/sup&gt;</td>
<td>751.6&lt;sup&gt;2&lt;/sup&gt;,a</td>
<td>4.50&lt;sup&gt;2&lt;/sup&gt;,c</td>
<td>3.83&lt;sup&gt;2&lt;/sup&gt;,d</td>
<td>96.17&lt;sup&gt;2&lt;/sup&gt;,d</td>
</tr>
</tbody>
</table>

<sup>1</sup>Total nonstructural carbohydrate (TNSC); water soluble carbohydrate (WSCHO); water insoluble carbohydrate (WISCHO); dry matter (DM).

<sup>2</sup>SEM = 3.57 for TNSC; 0.08 for WSCHO(TNSC); 0.07 for WSCHO(DM); 0.07 for WISCHO.

<sup>3</sup>CS = high-moisture sorghum stored in concrete stave silo; OL = high-moisture sorghum stored in oxygen-limiting silo; D = artificially dried sorghum.

Means within same column with different superscript are different (P < .05).
Water soluble carbohydrate  The results for WSC are shown in Table 10. No differences existed between pre-storage, CS and OL grain (P > .05) when WSC was expressed either as a percent of TNSC or DM. Artificial drying resulted in decreased (P < .05) water soluble carbohydrates. Lower WSC in dried grain are probably a result of the heat involved in the artificial drying process. Lower WSC in dried feeds have been observed in earlier studies with silage (Danley and Vetter, 1971) and corn grain (Danley and Vetter, 1974a).

No change in WSC expressed as a % of TNSC or DM is apparent when SC or OL are compared to pre-storage grain, however when percent WSC grain values are converted to mg/g of DM WSC in high-moisture systems are decreased as observed by Danley and Vetter (1974a). Water soluble carbohydrates expressed in mg/g of DM are 36.6, 35.2 and 35.6 for pre-storage, CS and OL systems, respectively. The lower WSC values reflect the DML observed in ensiled grain.

Lactate  D-(+), D-(-) and total lactate values appear in Table 11. The results indicated no difference (P > .05) existed between pre-storage and dried grain for L-(+), D-(-) or total lactate. High-moisture ensiled grain was higher (P < .05) in L-(+), D-(-) and total lactate compared with pre-storage grain and the CS system was higher (P < .05) than the OL system.
Barnett (1954) and Whittenbury, McDonald and Bryan-Jones (1967) indicated lactate is the most desirable end product of fermentation because it lowers pH rapidly preserving the forage or grain crop. Lactate concentration may indicate the quality of the fermentation process. The importance of lactate is often emphasized, however it is seldom reported in high-moisture grain studies. Goodrich, Byers and Meiske (1975) reported total lactate values for corn grain stored (time not reported) whole or rolled at 21.5 and 27.5% moisture. Lactate levels in their study were 41.2 and 27.5 uM/g of DM ensiled in 21.5% moisture corn and 185.2 and 254.1 uM/g for 27.5% grain. Their data indicate a dramatic increase in lactate occurs with increased moisture levels.

Previous studies have not reported L-(+) and D-(−) lactate values. The results our study indicate little L-(+) lactate remains after initial fermentation is completed. Low levels which occurred in pre-storage grain indicate little L-(+) lactate was present initially. It has been reported the L-(+) form is rapidly utilized by micro-organisms (Whittenbury, McDonald and Bryan-Jones, 1967). A 5% solution of mercuric chloride was added to each sample to prevent microbial activity, however activity may have occurred during harvest which caused the unexpected low levels of L-(+) lactate in pre-storage grain. Another possible conclusion is that most of the lactate in sorghum grain is D-(−) lactate.
Higher total lactate values in the CS system indicate it may have undergone more extensive fermentation than the OL system. Since the moisture levels were similar in both systems it is difficult to explain the higher lactate concentration and lower pH which occurred in the CS system.

Table 11. Changes in the lactate fraction of sorghum grain stored in three systems

<table>
<thead>
<tr>
<th>System</th>
<th>L-lactate mg/g DM</th>
<th>D-lactate mg/g DM</th>
<th>Total lactate mg/g DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-storage</td>
<td>0.18¹,a</td>
<td>1.23¹,a</td>
<td>1.41¹,a</td>
</tr>
<tr>
<td>CS²</td>
<td>0.44¹,b</td>
<td>3.04¹,b</td>
<td>3.48¹,b</td>
</tr>
<tr>
<td>OL²</td>
<td>0.36¹,c</td>
<td>2.52¹,c</td>
<td>2.88¹,c</td>
</tr>
<tr>
<td>D²</td>
<td>0.12¹,a</td>
<td>1.10¹,a</td>
<td>1.22¹,a</td>
</tr>
</tbody>
</table>

¹SEM = 0.04 for L-lactate; 0.08 for D-lactate; 0.09 for total lactate.
²CS = high-moisture sorghum grain stored in concrete stave silo; OL = high-moisture sorghum grain stored in oxygen-limiting silo; D = artificially dried sorghum.

a,b,c Means within the same column with different superscripts are different (P < .05).

Acetate, propionate and butyrate The values for acetate, propionate and butyrate are shown in Table 12. Results indicated all three volatile fatty acids (VFA) increased (P < .05) in high moisture ensiled grain. Acetate and total VFA levels decreased (P < .05) in the dried system.
Table 12. Changes in the acetate, propionate and butyrate fractions of sorghum grain stored in three systems

<table>
<thead>
<tr>
<th>System</th>
<th>Acetate</th>
<th>Propionate</th>
<th>Butyrate</th>
<th>Total VFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/g DM</td>
<td>mg/g DM</td>
<td>mg/g DM</td>
<td>mg/g DM</td>
</tr>
<tr>
<td>Pre-storage</td>
<td>0.74(^1,a)</td>
<td>0.29(^1,b)</td>
<td>0.32(^1,c)</td>
<td>1.35(^1,d)</td>
</tr>
<tr>
<td>CS(^2)</td>
<td>1.40(^1,b)</td>
<td>0.69(^1,c)</td>
<td>0.88(^1,d)</td>
<td>2.97(^1,e)</td>
</tr>
<tr>
<td>OL(^2)</td>
<td>1.26(^1,c)</td>
<td>0.58(^1,d)</td>
<td>0.79(^1,e)</td>
<td>2.63(^1,f)</td>
</tr>
<tr>
<td>D(^2)</td>
<td>0.61(^1,g)</td>
<td>0.23(^1,b)</td>
<td>0.28(^1,c)</td>
<td>1.12(^1,h)</td>
</tr>
</tbody>
</table>

\(^1\)SEM = .03 for acetate; .03 for propionate; .03 for butyrate; for .07 total VFA.

\(^2\)CS = high-moisture sorghum grain stored in concrete stave silo; OL = high-moisture sorghum grain stored in oxygen-limiting silo; D = artificially dried sorghum.

\(a,b,c,d,e,f,g,h\) Means within the same column with different superscripts are different (P < .05).

compared to pre-storage grain; but propionate and butyrate did not change (P > .05).

Goodrich, Byers and Meiske (1975) observed increased acetic acid concentrations with increasing moisture levels. The results of our study indicate higher acetate concentration in the CS system compared to the OL system. The higher level may have resulted from slightly higher moisture content in the CS system. Danley and Vetter (1974a) did not observe a consistent effect of moisture level on acetate concentration, but moisture levels in their study were lower (16, 18 and 22%) than the 21.5, 27.5 and 33.1% levels used by Goodrich, Byers
and Meiske (1975).

Butyric acid concentrations have been observed to increase with increasing moisture levels (Goodrich, Byers and Meiske, 1975). The results of our study indicate higher concentrations of butyrate in ensiled sorghum grain and in the CS system compared with the OL system.

Higher propionate levels found in ensiled grain in our study are consistent with increased concentrations of lactate, acetate and butyrate. Somewhat greater fermentation activity occurred in the CS system resulting in higher propionate concentrations than in the OL system. Others have observed increased propionate levels in ensiled high-moisture corn (Goodrich, Byers and Meiske, 1975; and Danley and Vetter (1974a).

**Molar percent acetate, propionate, butyrate and lactate**

Molar percent volatile organic matter measured in this study are shown in Table 13. The results indicate no changes occurred in propionate and lactate fractions (P > .05). Molar percent acetate and butyrate were the same for pre-storage and dried grain, but CS and OL grain were higher (P < .05) than either pre-storage or dried grain.

Acetate concentration increased as moisture level of sorghum grain increased, however molar percent acetate decreased. Similar results have been observed by others (Goodrich, Byers and Meiske, 1975; and Danley and Vetter,
Table 13. Molar percent acetate, propionate, butyrate and lactate in sorghum grain stored in three systems

<table>
<thead>
<tr>
<th>System</th>
<th>Molar percent (DM basis)</th>
<th>Acetate</th>
<th>Propionate</th>
<th>Butyrate</th>
<th>Lactate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-storage</td>
<td></td>
<td>26.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.55&lt;sup&gt;c&lt;/sup&gt;</td>
<td>51.26&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>CS&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td>21.75&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.63&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.67&lt;sup&gt;d&lt;/sup&gt;</td>
<td>53.95&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>OL&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td>22.97&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.38&lt;sup&gt;d&lt;/sup&gt;</td>
<td>52.10&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>D&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td>26.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.08&lt;sup&gt;c&lt;/sup&gt;</td>
<td>51.69&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> SEM = 0.67 for acetate; 0.45 for propionate; 0.57 for butyrate; 1.50 for lactate.

<sup>2</sup> CS = high-moisture sorghum grain stored in concrete stave silo; OL = high-moisture sorghum grain stored in oxygen-limiting silo; D = artificially dried sorghum.

Means within the same column with different superscripts are different (P < .05).

1974a). Acetate production is apparently favored at low moisture levels, but lactate, and butyrate are favored in high-moisture grains. Goodrich, Byers and Meiske (1975) also observed ethanol production increases in concentration and molar percent in high-moisture corn.

Changes in the nitrogen fraction Changes in the nitrogen fraction of sorghum grain are shown in Table 14. Total nitrogen and crude protein (N X 6.25) were not different (P > .05) among pre-storage and post-storage grain samples. The results of our study and others (Prigge et al., 1976; and
Table 14. Changes in the nitrogen fraction of sorghum grain stored in three systems

<table>
<thead>
<tr>
<th>System</th>
<th>% DM&lt;sup&gt;1&lt;/sup&gt;</th>
<th>% TN</th>
<th>% WSN</th>
<th>% NH&lt;sub&gt;3&lt;/sub&gt;-N&lt;sup&gt;1&lt;/sup&gt;</th>
<th>% TN</th>
<th>% TN</th>
<th>% TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-storage</td>
<td>1.40&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>8.24&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>37.90&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>3.12&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>91.76&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.44&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>22.82&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td>68.83&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td>15.71&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td>77.18&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OL&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.48&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>19.41&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td>58.89&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td>11.43&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td>80.59&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.41&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>7.18&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>70.43&lt;sup&gt;2,b&lt;/sup&gt;</td>
<td>5.06&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td>92.82&lt;sup&gt;2,a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>Total nitrogen (TN); crude protein (CP); water soluble nitrogen (WSN); ammonia nitrogen (NH<sub>3</sub>-N); water insoluble nitrogen (WISN); dry matter (DM).

<sup>2</sup>SEM = 0.04 for TN; .24 for CP; 3.46 for WSN(TN); 5.95 for NH<sub>3</sub>-N(WSN); 2.24 for NH<sub>3</sub>-N(TN); 3.46 for WISN.

<sup>3</sup>CS = high-moisture sorghum grain stored in concrete stave silo; OL = high-moisture sorghum grain stored in oxygen-limiting silo; D = artificially dried sorghum.

<sup>a,b</sup>Means within same column with different superscripts are different (P < .05).
Danley and Vetter, 1974b) indicate total nitrogen does not change during storage in high-moisture or dried systems.

Water soluble nitrogen (WSN) was higher (P < .05) in high-moisture grain compared to pre-storage and dried grain. No difference existed between pre-storage and dried, or CS and OL grain (P > .05). Prigge et al. (1976) reported WSN values of 38.2 and 14.8% for ground and whole-shelled high-moisture corn stored 56 days. Our study indicated WSN levels are higher (22.82 and 19.41% for CS and OL systems) than whole corn and less than ground corn indicating the smaller particle size of whole-ensiled sorghum may result in increased nitrogen solubility compared to whole-shelled corn.

Water soluble nitrogen was the only parameter measured affected by time. Figure 1 illustrates the increase in WSN which occurred in both high-moisture storage systems. The affect of time was not linear (P > .05), however WSN levels during the last trimester in each year of the study were higher (P < .05) than the previous two. Increased water soluble nitrogen during the summer months may be an effect of environmental temperature and increased proteolytic activity of molds and yeasts. However, further investigation is necessary to elucidate the nature of increased water soluble nitrogen.

Ammonia nitrogen expressed as a percent of WSN was increased (P < .05) in CS, OL and dried systems compared to pre-storage grain. When ammonia nitrogen was expressed as a
Figure 1. The relationship of month of year to the percentage of water soluble nitrogen of total nitrogen in two high-moisture sorghum grain storage systems.
percent of total nitrogen high-moisture grain was higher 
(P < .05) than either pre-storage or dried grain. Ammonia 
nitrogen concentrations indicate fermentation was sufficient 
for significant increases in the solubility of the nitrogen 
fraction to occur as reported by Prigge et al. (1976) and 

Riggs (1969) suggested ensiling early-harvested or re- 
constituted grain results in activity similar to seed germina-
tion. Water disrupts the insoluble protein matrix allowing 
endogenous enzymes to hydrolyze the starch molecule and causing 
increased solubilization of nitrogen. Apparently little 
nitrogen is lost during this process, however soluble protein 
is increased (Merrill, 1971). Prigge et al. (1976) have sug-
gested solubilization of the nitrogen fraction increases 
energy availability and may be an important factor in improv-
ing energy utilization.

Summary Ensiling high-moisture sorghum resulted in 
lower (P < .05) pH values than freshly-harvested or dried 
samples. Percent ash was higher (P < .05) in CS and dried 
systems and unchanged in the OL system compared with freshly-
arvested grain. Changes in the carbohydrate fraction indi-
cated TNSC was lower (P < .05) in high-moisture systems 
compared to pre-storage or dried grain. Water soluble carbo-
hydrates were lower (P < .05) in artificially dried grain 
compared to pre-storage, CS or OL grain. Lactate, acetate,
propionate and butyrate were increased \((P < .05)\) in CS and OL systems compared to pre-storage and dried systems, and values for the CS system were higher \((P < .05)\) than the OL system. Higher \((P < .05)\) WSN and ammonia nitrogen values indicated nitrogen solubility was increased in the CS and OL systems. Water soluble nitrogen increased \((P < .05)\) during the last trimester of each year of the study in both high-moisture systems.
GENERAL DISCUSSION AND SUMMARY

A three-year study was conducted to determine the effects of storing early harvested sorghum grain in concrete stave and oxygen-limiting silos or an artificial drying system. The research was reported in three sections: 1) a cattle feedlot performance study, 2) a comparison of dry matter determination methods, and 3) determination of the carbohydrate and nitrogen fractions of sorghum grain.

Six feeding trials indicated cattle fed artificially dried sorghum consumed significantly more grain dry matter, gained slightly faster, and were less efficient than those fed grain stored in concrete stave or oxygen-limiting silos. Compared on the basis of pre-storage grain dry matter converted to liveweight gain, the oxygen-limiting storage system was more efficient than either the concrete stave or dried systems. Grain dry matter losses were greater in the concrete stave system than in the oxygen-limiting or artificial drying systems. The greater efficiency of the oxygen-limiting system was a result of slightly improved grain dry matter utilization and fewer dry matter losses during storage. Feedlot performance and efficiency of storage systems were limited in ensiled grain since the moisture level of 24% used in this study was less than optimal for maximum improvement in feed utilization.
Method of dry matter determination can influence the results of high-moisture feeding studies. Other research has indicated oven-drying methods drive off volatile non-aqueous dry matter components from ensiled feedstuffs which may bias feed efficiency data when comparisons are made on a post-storage dry matter determination basis. Comparisons based on pre-storage dry matter determination where volatile components are lower may be more valid.

The data comparing dry matter determination methods for sorghum grain indicated 103 C forced-draft and 105 C conventional ovens drive off more volatile dry matter components than an 85 C conventional oven or a lyophilizer. The effect was the same for pre-storage grain or post-storage grain from concrete stave, oxygen-limiting or artificial drying systems, therefore no interaction between method of dry matter determination and storage system was observed. Moisture levels varied from a low of 13.4% for dried grain to a high of 24.3% for grain stored in the oxygen-limiting system. These levels may be too low to detect major differences or interactions among methods, since recommended moisture levels for the fermentation of sorghum grain are 26 to 30 percent. The feed efficiency data reported in this study were based on dry matter determination in a 103 C forced-draft oven. It is apparent from the results of this study that method of dry matter determination did not favor ensiled grain, however, in
studies involving higher moisture levels method may have a greater influence.

The results of this study indicate changes occur during the ensiling process which alter the carbohydrate and nitrogen fractions of sorghum grain. Artificial drying decreased carbohydrate and nitrogen solubility. Ensiling did not increase water soluble carbohydrates, however this was probably caused by the utilization of most of the more soluble carbohydrates during the ensiling process.

Total carbohydrates were decreased in ensiled grain indicating dry matter losses during storage may be primarily a function of carbohydrate loss during the fermentation process. The higher losses of total carbohydrates in the concrete stave silo indicate fermentation was more extensive in this system. Lower pH and higher percent ash values confirm the greater dry matter and total carbohydrate losses observed in the concrete stave system.

Levels of lactate, acetate, propionate and butyrate were higher in ensiled grain than freshly harvested or dried grain which indicates fermentation did occur, however the total of these acids was less than 1% of the dry matter. Earlier studies with corn indicate organic acid levels should be greater than 1% of the dry matter when adequate fermentation has occurred. The low acid levels observed in this study indicate limited fermentation occurred in both silos, but was
somewhat greater in the concrete stave silo.

The low moisture levels used probably limited the extent of fermentation. Acetate was a major portion of the organic acids measured which is consistent with earlier work indicating acetate composes a larger portion of the volatile organic components at low moisture levels. Lactate concentration was also quite low indicating fermentation was not extensive enough to lower pH adequately.

Water soluble nitrogen was increased which is consistent with other reports indicating the process which occurs during reconstitution is similar to seed germination. The insoluble grain protein matrix is disrupted causing increased solubility without changing total nitrogen. The destruction of the protein matrix allows hydrolysis of starch by endogenous enzymes.

The marked increase of water soluble nitrogen during the summer months indicates proteolytic activity may have occurred as a result of yeast and mold activity in both high-moisture storage systems, but was more pronounced in the concrete stave.

The limited fermentation and proteolysis observed in this study were a result of low moisture levels and prevented maximum utilization of high-moisture sorghum by cattle. Although carbohydrate and nitrogen solubility increased, the changes were not of the magnitude required for maximum improvement in
the utilization of energy and protein fractions of sorghum grain.
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