YIELD, COMPOSITION, AND NUTRITIVE VALUE OF GRAIN SORGHUM HARVESTED AS SILAGE: STAGE OF MATURITY AND PROCESSING EFFECTS

by

RUSSELL LEON SMITH

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Approved by:

Keith K. Bolsen

Major Professor

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Introduction

Although corn (Zea mays L.) has been the primary silage crop for the beef cattle industry in the High Plains region of the United States, limited water resources and high production costs have forced a search for alternative crops of similar yield and nutritive value.

Grain sorghum (Sorghum bicolor L. Moench) has greater drought resistance than corn (Beadle et al., 1973) and has greater ability to recover from drought (Sanchez-Diaz and Kramer, 1971). Ruff and Schake (1978) proposed that the feeding potential of grain sorghum could be significantly improved by harvesting the whole-crop, because it provided a nearly complete diet for ruminants. Buice et al. (1981) showed that feeding whole-crop grain sorghum silage could increase beef production per hectare by almost 28% compared with feeding only the grain.

One problem in feeding whole-crop grain sorghum silage; however, is the lower apparent digestibility of the grain. Processing (rolling) the silage has been investigated in several trials with inconsistent results (Brethour and Duitsman, 1970, 1971a; Fox et al., 1970; Pund, 1970; Gutierrez et al., 1982; Acosta et al., 1983; Bolsen et al., 1983). Stage of maturity at harvest could also affect digestibility as well as yield and composition of whole-crop grain sorghum silage (Browning and Lusk, 1967; Johnson et al., 1971) and the benefits from processing these silages.

Another concern is the potential of grain sorghums to yield sufficient quantities of silage dry matter to support acceptable beef production per hectare.

These experiments were conducted to determine the effect of processing and harvest maturity on the nutritive value of grain sorghum silages for growing cattle, and to study the effect of harvest maturity on yield and composition of grain and forage sorghum hybrids.

Chapter I

REVIEW OF LITERATURE

Grain Sorghum Growth and Development

The sorghum plant has been the subject of many studies, some under controlled environmental conditions, others under field conditions. However, a complete understanding of the plant's growth and development has eluded scientists for many years.

Pauli et al. (1964) broke the life cycle of the sorghum plant into three major stages of development. They indicated that, in general, the plant spends one-third of its life cycle in each stage. Eastin (1971) defined these growth stages as follows: Growth Stage 1 (GS1), the time period between emergence and floral initiation; Growth Stage 2 (GS2), the time period between floral initiation and anthesis; and Growth Stage 3 (GS3), the time period between anthesis and physiological maturity. Vanderlip and Reeves (1972) gave a much more detailed description of the sorghum plant's growth and development. Shown in table 1 are the identifying characteristics for these stages. Their growth stages 3, 6, and 9 correspond with the end of each of Eastin's growth stages.

The time required to reach each stage depends both on the hybrid and the environment in which it is growing. This could change for the same hybrid at the same location if planting date were changed, or if results from two seasons were compared. Other factors such as soil fertility, insect or disease damage, moisture stress, plant population, and weed competition can also affect both the timing of the various stages of development and the condition of the plant at each stage (Vanderlip, 1979).

In terms of dry weight, nearly all growth is leaves in the first 30 to 35 days after the plant emerges. Then the culm or stalk starts rapid growth and leaves and stalk continue until maximum leaf weight is reached at about 60 days and maximum stalk weight at about 65 days. After about 50 days, the head increases in weight rapidly. Following pollination, the grain increases in weight rapidly, sometimes faster than the rate total dry matter accumulates. That results in a net decrease in the stalk weight as materials are moved from the stalk to the head (Vanderlip, 1979).

The following discussion will be centered around the three growth stages outlined by Eastin (1971).

Growth Stage 1

Of the three major growth stages, GS1, beginning with emergence and ending at floral initiation, may be the most significant. There are many factors which can influence the duration of GS1. Early planting dates often result in poor seed germination and emergence due to cool soil conditions. Pinthus and Rosenblum (1961) stated that the minimum temperature for sorghum seed germination apparently was between 8 and 10 C, but slightly higher temperatures were required for emergence from the soil. Stickler et al. (1962) showed maximum growth of sorghum seedlings at 21.1 C under controlled conditions. Stoffer and Van Riper (1963) reported that sorghum emergence was more rapid with increased temperatures from 10 to 21.1 C, but emergence rate did not increase between 21.1 and 26.7 C.

The duration of GS1 is important in the development of grain sorghum. Sorghum is a species with a terminal inflorescence, therefore, leaves continue to be initiated in the meristem until the floral bud is initiated. If floral initiation is delayed, more leaves are formed (Liang et al., 1969). Downes (1972) used controlled temperature conditions to study the growth and development of grain sorghum. Flower primordia were first observed at the eighth, tenth, and twelfth leaf stage for 21/16, 27/22, and 33/28 C day/night temperatures, respectively. Maunder (as cited by Schaffer, 1980) concluded that total grain number, whose potential was determined shortly after floral initiation, was the most important contributor to yield. But a growing point capable of producing a large inflorescence was essential and dependent on optimum conditions in GS1.

The genetic control of flowering in sorghum appears to be genetically simple because only four gene loci have been recognized. The continuous variation in flowering is thought to result from allelic series at the four loci and because of complementary action between gene loci (Quinby, 1973).

The identity of the floral stimulus has received much discussion in the literature. Chailakhian (1961) suggested that the floral stimulus appears to consist of auxin and gibberellin, and an interaction between the two hormones produces the stimulus that changes a vegetative bud into a fruiting bud (Evans, 1969). Auxin is produced largely during darkness, and gibberllin during daylight. Quinby (1973), therefore postulated that the floral stimulus accumulates at the growing point at different rates in different genotypes. This lead to the belief that auxin and gibberellin are being synthesized in the leaves at different rates in different genotypes and that there must be some genetic mechanism to control the rate of synthesis of the two hormones. Dominant and recessive alleles at the maturity gene loci and gene interaction appear to exercise this control (Quinby, 1973).

Many researchers have studied the effects of photoperiodism on the development of grain sorghum, especially in GS1. Caddel and Weibel (1972) found that sorghum grew vegetatively and was not affected by photoperiod for the first 15 days. They also noticed that the length of time to floral initiation increased as the length of time plants were subjected to long days increased. However, the longer the plants were subjected to long days, the fewer short days were required to cause floral initiation. Those researcers implied that the change in the plant from photoperiod insensitivity to sensitivity was due to an increased leaf area which allowed the plant to discern the stimulus.

Lane (1963) determined that the length of day necessary to delay floral initiation was 13 hours for early maturing sorghum, 12.5 hours for medium and late sorghum, and 12 hours for ultra-late sorghum.

Miller et al. (1968) divided varieties of sorghum into five classes depending on the day length required to delay floral initiation. The data showed that tropical varieties of different maturities had different critical dark periods and that tropical varieties needed longer nights to allow floral initiation than temperate varieties. Temperate varieties, many of which would flower in continous light, had no critical dark periods but differed in the length of night that would delay floral initiation (Quinby, 1973). This information lead to the conclusion that the photoperiodic effect was apparent only if the nights were too short to allow the synthesis of sufficient auxin to allow early floral initiation (Quinby, 1973).

Total leaf number is indicative of relative maturity, since all the leaves must be initiated prior to the initiation of the panicle. Sieglinger (1936) found that the number of leaves and the length of the vegetative period were highly correlated. The period between emergence and heading averaged 2.8 to 3.5 days per leaf for 21 different sorghum cultivars.

Growth Stage 2

The importance of GS2 to development and yield has been debated in the literature. Maunder (as cited by Schaffer, 1980) stated that sorghum hybrids spent the least percent of their time (as measured in days) in GS2, suggesting that GS2 had low importance to yield. Eastin (1971) also found no association between yield and events in GS2. Luebe (1977) reported that although all leaf initiation is complete at floral initiation, stage 4, as described by Vanderlip and Reeves (1972), was reached slower in late cultivars. The number of days between floral initiation and stage 4 for an early and a late cultivar was 10.9 and 18.7 days, respectively. This shorter period for the early cultivar was closely related to the number of leaves pending development at floral initiation.

Another important function taking place in GS2 is panicle development. Lee et al. (1974) claimed that the size of the apex increased as the vegetative period was prolonged, giving the vegetative period a significant influence on floral development. If spikelets begin to differentiate from the apex downward too soon, this could have an adverse effect on the number of branches and the total number of grains per head, because the primary branch primordia differentiate from the base upwards while the spikelets differentiate from the tip downwards (Lee et al., 1974).

Growth Stage 3

The grain filling period, GS3, has been studied by many researchers. The end of GS3 (physiological maturity) is signified by the appearance of a dark closing layer in the placental area near the point of sorghum kernel attachment (Eastin et al., 1973). This "black layer" coincides closely with the cutoff of carbon assimilate to the kernel, which permits identification of physiological maturity or date of maximum dry weight (Eastin et al., 1973). Giles et al. (1975) reported that formation of the "black layer" coincided with the formation of pectic compounds and callose, indicating that the phloem tissues had senesced and the active translocation had ceased. These researchers agreed that the formation of the "black layer" was a good indication of physiological maturity.

Many factors affect how long and how much DM will accumulate in the grain. Fischer et al. (1976) reported that after anthesis, almost all photosynthesis occurred in the inflorescence and upper four to five leaves. The relative photosynthesis for the head and the upper four leaves was 17.5, 17.0, 25.0, 20.0, and 17.0 percent, respectively. Total photosynthesis declined from immediately after anthesis until 25 days after anthesis, at which time no further measurements were taken.

Temperature can play a large role in grain filling. Millington et al. (1977) reported significant regressions of yield on maximum temperature for the periods of emergence to anthesis and anthesis to maturity. Williams et al. (1977) claimed that the effect of maximum temperature was diminished by anthesis and disappeared by maturity, while that of the minimum temperature was retained until maturity.

Many reports of duration of grain filling can be found in the literature. Collier (1963) found the duration of the grain filling period was 24 to 27 days for all cultivars, except RS 610 which was 35 days in the first year of a 2-year study. In the second year, the grain filling period was 31 to 35 days for all cultivars. In another 2-year study, Kersting et al. (1961) showed that maximum dry weight occurred 45 days after pollination in the first year, while in the second year, it occurred 33 days after pollination.

Kebede and Hume (1977) reported that the length of the grain filling period declined as night temperature increased, with a constant day temperature (30 C). But as day temperature increased from 25 to 35 C with a constant night temperature (20 C), the length of the grain filling period reached a minimum at 30 C day temperature and increased under 35 C day temperatures. They also suggested that longer photoperiods showed a tendency toward shorter grain filling periods.

Neild and Seeling (as cited by Schaffer, 1980) reported that an early sorghum hybrid went from stage 8 to stage 9 (Vanderlip and Reeves, 1972) in 11 days compared with 18 days for a late hybrid. These researchers claimed that about half of this difference in days came from differences in the rate of development, while the other half resulted from the cooler temperature that prevailed between these stages for the later hybrid.

Johnson (1967) measured the growth rate of irrigated grain sorghum. A growth sensor was used which converted the extension of a leaf from the whorl, or head from the boot, into an electrical signal which was continuously recorded on a strip chart recorder. Daily growth rate curves showed that the minimum growth rate on a typical day occurred between 7:00 and 9:00 am. The growth rate increased rapidly after that and reached a maximum value for the day near noon. The growth rate decreased sharply during a 3 to 4 hr period which began on different days between 4:00 and 7:30 pm and lasted until 8:00 to 10:00 pm. After this evening period of sharp growth rate decline, the growth rate decreased more gradually and paralleled the air temperature decline until the morning growth minimum was reached. It was also noted that the growth rate of the head decreased with age of the plant.

TABLE 1. IDENTIFYING CHARACTERISTICS AND APPROXIMATE TIME INTERVALS AMONG STAGES OF GROWTH OF SORGHUM[1]

Growth stage	Approximate days after emergence[2]	Identifying Characteristics
0	0	Emergence. Coleoptile visible at soil surface.
1	10	Collar of 3rd leaf visible.
2	20	Collar of 5th leaf visible.
3	30	Growing point differentiation. Approximately 8 leaf stage by previous criteria.
4	40	Final leaf visible in whorl.
5	50	Boot. Head extended into flag leaf sheath.
6	60	Half-bloom. Half of the plants at some stage of bloom.
7	70	Soft dough.
8	85	Hard dough.
9	95	Physiological maturity. Maximum dry matter accumulation.

[1]From Vanderlip and Reeves (1972).

[2]Approximate days required for hybrids of RS 610 maturity grown at Manhattan, Kansas.

Methods of Forage Conservation

The two most common methods of forage conservation are hay and silage and both are used extensively and with varying degrees of success. To achieve satifactory preservation, it is necessary to minimize respiration and proteolysis by plant enzymes and also to minimize microbial degradation during the harvest and storage periods (Bolsen, 1985).

The three major groups of crops grown in Kansas that have been effectively conserved as either hay or silage include: 1) forage legumes (ie. alfalfa or clover); 2) winter cereals (ie. wheat, triticale, oats or barley); and 3) summer annuals (ie. sudangrass, sorghum-sudan, or pearl millet). Numerous studies have been conducted comparing the alterative methods of conserving the same crop. However, the choice of one method over the other varies from producer to producer and crop to crop. There are distinct advantages and disadvantages of each method that should be recognized.

Losses in Hay and Silage Conservation

Much of the potential production from the original crop is lost during harvest and storage. Both forage quantity and quality are affected (Waldo, 1977). The major sources of losses of dry matter (DM) are field losses in hay-making and storage losses in silage-making.

Gordon et al. (1969) identified three causes of field losses in hay-making: 1) biochemical, 2) mechanical, and 3) leaching. Biochemical losses are due mainly to respiration and other enzymatic processes occurring in the plant after harvesting. Respiratory loss is influenced by ambient temperature and forage dry matter. Mechanical losses due to fragmentation during mowing or conditioning, tedding, final windrowing, and loading are most severe during the final stages of drying (Honig, 1980), and are generally higher for legumes than grasses (Klinner, 1976). Factors affecting leaching loss are forage moisture content at the start of rainfall, amount of rainfall, number of rains, and mowing or conditioning treatments (Gordon et al., 1969).

Gordon (1967) also catagorized storage losses in silage-making into three groups: 1) seepage or effluent, 2) spoilage, and 3) losses due to gas production (CO_2, NH_4, or CH_4). The major factor affecting effluent loss is the DM content of the crop. Thus, seepage loss tends to increase with higher crop moisture levels (Gordon, 1967). Other factors such as type and height of the silo, crop species, and pre-ensiling of the crop may also contribute significantly to the seepage problem. Spoilage to the extent that the crop is no longer suitable to be fed is usually the result of excess air entrapped in the ensiled crop. Gaseous losses are also increased by increasing the permeability of the silo structure to air. In addition, forages of high moisture content tend to undergo more extensive fermentation, resulting in greater gaseous losses (Gordon, 1967). Zimmer (1980) also categorized the losses in silage-making. These losses and their causative factors are shown in table 2.

Of the losses that occur during the conservation processes, DM has been followed most commonly. In studies reviewed by Waldo (1977), it was noted that direct-cut (DC) silage, wilted or low-moisture (LM) silage, and field-dried hay had recoveries of DM near 80, 85, and 75%, respectively. Zimmer (1980) summarized data with Italian ryegrass, comparing DC silage, LM silage and barn- dried hay and reported DM recoveries of 80.6, 86.7, and 84.0%, respectively. The grassland performance in these data, expressed as starch equivalents (SE) per hectare, was 4430, 4860, and 4630, respectively. Bolsen et al. (1974) compared three similar systems of conservation using alfalfa and reported DM recoveries of 75, 77.5 and 71%, respectively. These researchers concluded that potential beef gain per unit of land area was lowest from baled hay.

Dry matter losses generally parallel energy losses. Honig et al. (1983) conducted several experiments in which a grass mixture was conserved as DC silage, LM silage (40 to 50%), barn-dried hay, or dehydrated grass. Net energy losses (mj/kg of DM) for the different conservation systems were categorized into field and storage losses. Under optimum weather conditions, field losses for DC silage and dehydrated grass were the lowest at 3%, and barn-dried hay had the highest energy loss (9.5%). When unfavorable weather conditions existed, barn-dried hay had much higher field losses (24%). As a result of effluent formation and extensive fermentation, storage losses were greatest for DC silage, being 22.8% for optimum conditions and 35.7% during unfavorable conditions. Barn-dried hay had the lowest storage loss at 7%, with LM silage being intermediate in all instances. Total losses were nearly the same for LM silage, barn-dried hay, and dehydrated grass. DC silage had significantly higher total net energy losses which were due to its greater storage loss.

Zimmmer (1980) summarized data from several experiments on the net energy content (SE/kg of DM) of conserved forages. Direct-cut silage was 110%, LM silage 106%, and dehydrated 109% the 100% relative value assigned to barn-dried hay.

Optimum preservation of DM and energy does not necessarily imply optimum preservation of protein. Data reviewed by Waldo (1977) indicated that recoveries of digestible protein for the three major methods of conservation were 60% for DC silage, 73% for wilted silages, and 67% for field-cured hay. Silage protein losses occur predominantly during storage, as contrasted to hay which incures most of its loss of protein in the field.

Nutritive Value of Hay and Silage

Animal production is the ultimate test of the nutritive value of a feedstuff, whether it be live weight gain, milk production, or wool yield. These products are a function of intake and digestibility, as well as nutrient adequacy of the diet.

Demarquilly and Jarrige (1970) reported data on intakes and digestibilities of preserved forages relative to fresh forages when fed alone to sheep. The DM intakes from the major conservation systems were 61% for DC silage, 70% for wilted silage, and 70% for field-dried hay. The organic matter digestibilities were 89% for DC silage, 94% for wilted silage, and 91% for field-cured hay.

Dry matter intake of silage has been shown to be positively related to the DM content of the ensiled forage (Gorden et al., 1961; Ward et al., 1966), therefore better animal production would be expected from high DM silages. However, there are indications that as the DM increases, nitrogen utilization decreases (Gorden et al., 1961; Owen and Howard, 1965). Merrill and Slack (as cited by Waldo, 1977) summarized data on the feeding value of perennial forages conserved as either silage or barn-dried hay (table 3). Relative to barn-dried hay, silages above 60% moisture had lower DM intakes and barn-dried hay, intakes of 55% moisture silages were higher. Silages at all moisture levels appeared to be more efficiently utilized than hay, with milk production per day being the greatest for 55% moisture silage.

Campling (1966) conducted three experiments to compare the intake of hay and silage by non-lactating cows. Silages and hays for the three experiments were made from a mixed stand of primarily timothy and meadow fescue. On the average, 28% more hay DM was consumed than silage. Silage and hay had similar digestibilities, but silage residues tended to remain in the gut for a longer time than those of hay.

In a series of experiments using summer annual forages, Bolsen et al. (1980, 1982) reported that beef calves fed silages consumed less DM, but they were more efficient than calves fed the same forages conserved as hay. Brethour and Duitsman (1971) compared silage and hay using a hybrid forage sorghum and found that silage produced significantly faster gains than hay. Although DM intakes were similar, the authors pointed out that feed wastage was a greater problem with the forage sorghum hay.

Oltjen et al. (1977) compared wheat and oat hays and silages with growing lambs and concluded that silage diets supported faster gains than hay diets and were used somewhat more efficiently, suggesting a higher feeding value for silage than hay.

Mechanization of Hay and Silage

Earlier reports in the literature (Murdock, 1962; Hemken and Vandersall, 1967) indicated that silage had an advantage over hay because mechanization allowed larger quantities of forage to be handled in a shorter period of time. However, the ability to mechanize the entire harvesting, storing, and feeding operation is no longer a unique advantage for silage. Engineering advancements in the past decade have increased the use of high capacity hay-harvesting machines which produce larger hay packages. This equipment has allowed hay-making and feeding to be a one-man operation, thus reducing the high labor required for handling hay bales. However, storage and feeding losses from these packages have often far exceeded those of traditional hay systems (Kjelgaard et al., 1983).

A potential disadvantage of silage is its high water content. This water must be handled several times during harvest, storage, and feeding and, in turn, increases the cost of the system.

The decision to harvest forage as silage or hay will likely involve several "non-nutritional" factors, such as existing equipment, availability of custom harvesting, storage facilities, and feed handling and processing capabilities.

TABLE 2. ENERGY LOSSES AND CAUSAL FACTORS[1]

Process	Classified as	Approximate losses (%)	Causal factors
Residual respiration	Unavoidable	1 - 2	Plant enzymes;
Fermentation	Unavoidable	2 - 4	Micro-organisms;
Effluent or	Mutual	5 - >7 or	DM content;
Field losses by wilting	Unavoidable	2 - >5	Weather, technique, management, crop;
Secondary fermentation	Avoidable	0 - >5	Crop suitability, environment in silo, DM content;
Aerobic deterioration during storage	Avoidable	0 - >10	Filling time, density, silo, sealing, crop suitability;
Aerobic deterioration after unloading (feeding)	Avoidable	0 - >15	As above, DM content silage, unloading technique, season.
		Total 7 - >40	

[1]Adapted from Zimmer, 1980.

TABLE 3. INTAKE, UTILIZATION, AND MILK PRODUCTION FROM SILAGES RELATIVE TO BARN-DRIED HAY WHEN FED WITH CONCENTRATES TO MILKING COWS[a]

Forage	Dry matter recovery	Dry matter intake	Efficiency	Milk production per day	Milk production per hectare
	(%)				
Hay, barn-dried	80	100	100	100	100
Silage, >70% moisture	75	83	110	100	104
Silage, 60 to 70% moisture	84	86	108	100	114
Silage, 55% moisture	81	102[b]	101	104[b]	103

[a]Data of Merrill and Slack, as reviewed by Waldo, 1977.

[b]Data for silage with 35 to 60% moisture.

Harvesting and Processing Methods

Michigan workers (Newland et al., 1964) utilized a machine which harvested only the center portion of the corn plant, including the ear. The DM yield was 73% of the amount harvested by conventional methods and TDN was 25% higher. However, weight gain by steers fed the center portion silage was not as good as gain by steers fed the conventional silage plus corn grain.

Playne and Skerman (1964) harvested sweet sorghum (Saccaline) at different above ground heights. Cutting at 61 cm increased crude protein content by 13% while cutting at 152 cm increased it by 45 percent. Corresponding DM yields were 75 and 37% of the standard cutting height. They concluded that this was an impractical method for improving silage protein content.

In an effort to increase silage digestibility, Hart (1982) harvested WAC 710 DR grain sorghum at three cutting heights (10.2, 40.6, and 63.5 cm) in the soft-dough and mature stages of maturity. Even though the grain content was increased and the proportion of the stem decreased, silage digestibilities were improved only slightly by increasing the height of cut. The reduction in yield at higher cutting was not compensated for by the small increase in digestibility.

Pund (1970) harvested two varieties of grain sorghum, Georgia 615 (bird resistant) and DeKalb 57E (non-bird resistant) at 38 cm above ground level or about 76 cm below the top of the grain head. By cutting only the upper two-thirds of the plant, a relatively high grain, high energy silage was produced, however no comparison was made to a conventional cutting height silage.

Leighton et al. (1969) compared a head-chop sorghum ration silage to a similar dry ration for lactating dairy cows and reported greater milk production, feed costs, and weekly weight changes for cows fed the dry ration than for those fed the head-chop ration.

Daura (1980) used lactating dairy cows and compared three diets: one containing silage made from grain sorghum harvested as head-chop; another containing whole-plant sorghum silage with added sorghum grain; and a third containing sorghum grain and alfalfa hay. Neither milk production nor average daily gain was influenced by diet treatment, although whole-plant silage did produce milk with significantly higher DM and milkfat content than head-chop silage. The author concluded that the reduced DM yields per unit of land area produced by harvesting head-chop only served to favor the ensiling the whole-plant.

Rolling or Grinding

One problem in feeding whole-crop sorghum silage is the apparent low digestibility of the grain when fed in the whole-kernel form. This is thought to be due to a dense proteinaceous matrix in the peripheral endosperm layer of the sorghum kernel, which renders starch granules inaccessible for digestion in the rumen (Gutierrez et al., 1981). Several attempts have been made to improve the digestibility of the grain within the silage by processing the kernels before or after ensiling.

Boren et al. (1962, 1963) reported that grinding the heads of hybrid forage sorghum prior to ensiling did not improve subsequent cattle performance. In two of the three comparisons, beef calves fed processed silage actually had slower gains, lower DM intakes, and poorer feed conversions than calves fed unprocessed silages.

Narasimhalu (1964) used the same silages as Boren et al. (1963) but fed them in lactation and digestion trials. Silages made with ground seed heads were consumed in significantly lower amounts but they had higher apparent digestibilities for DM, nitrogen-free extract, and energy. Silages made with ground seed heads were also utilized more efficiently for milk production than unprocessed silage.

Brethour and Duitsman (1970, 1971a) rolled whole-crop grain and forage sorghum silages prior to feeding. In the first trial, average daily gains were significantly higher when silages were rolled and, although both silages responded to rolling, the utilization of grain sorghum silage was improved more than forage sorghum. When grain sorghum silage was rolled the second trial, the response was less than in the first trial and the authors concluded that processing increased feed value much less than it would cost.

In an extensive 3-year study, Pund (1970) evaluated the rolling of high energy grain sorghum silages prior to feeding. Rolling silage from both bird resistant and non-bird resistant varieties proved to be a significant and economical means of increasing beef production per unit of silage fed. Steers fed rolled silage gained 8% faster than those fed unrolled silage and feed efficiency was improved significantly by rolling. The improved performance from the rolled silage was attributed to an increase in digestible energy, which was in agreement with the study of Withers et al. (1969). It was noted that rolling the bird resistant silage prior to feeding was 8.4 and 11.8% more effective in improving rate and efficiency of gain, respectively, than rolling the non-bird resistant silage. Fox et al. (1970) also reported a 29% increase in gain and a 19% improvement in feed efficiency from rolling bird resistant grain sorghum silages over unrolled silage.

Bolsen et al. (1974, 1975) fed rolled and unrolled head-chop grain sorghums in two trials. Processing the silages to break all the kernels did not influence rate of gain, but in both trials steers fed rolled silage consumed less DM than those fed whole silage. As a result, steers fed rolled silage were 11.5 and 14.0% more efficient than those fed whole silage.

Davis et al. (1981) harvested grain sorghum by cutting the upper 56 cm of the plant. One-half of the head-chop was placed into storage through a Wetmore recutter-blower to reduce the particle size below the original field-cut material. The remaining head-chop entered storage through a Gehl tractor powered forage blower. The field-cut and re-cut head-chop silages were either ensiled in oxygen-limited structures or free-standing high density modules. With module storage, field-cut and re-cut silages gave similar steer performance. However, when the head-chop was stored in the oxygen-limited structure, re-cut silage improved rate of gain and feed efficiency.

The question of pre- or post-ensiled processing was studied by Texas A&M researchers. Gutierrez et al. (1982) reported that calves receiving unprocessed whole-crop grain sorghum silage had slightly better performance than calves receiving processed silage, with the grain rolled prior to ensiling. When the silage was rolled post-ensiling but prior to feeding, organic matter and starch digestibilities were increased over those of silages fed unprocessed or processed prior to ensiling. Schake et al. (1981) also indicated that whole-crop grain sorghum silage containing whole kernels was equal or superior to pre-ensiled, rolled grain sorghum silage. In another study, Acosta et al. (1983) found no improvement in steer performance when the grain component of whole-crop grain sorghum silage was rolled and recombined with the stover. The authors postulated that the kernel within the whole-crop sorghum silage absorbs moisture from the stover, resulting in a softer kernel that does not respond to physical processing.

In recent studies by Bolsen et al. (1983) there was very little response in improved feeding value by processing either forage or grain sorghum silages. Good performance by calves lead the authors to suggest that the whole kernel in the silages was well utilized.

Dehydrating and Pelleting

In attempts to improve DM intake, several investigators have dehydrated and pelleted silage. Richardson et al. (1961) harvested whole-crop RS 610 grain sorghum and stored it as either silage or dehydrated pellets. No significant differences occurred in steer gains or feed efficiencies when the two forages were compared.

Anthony et al. (1959) dehydrated and pelleted whole-crop corn, sorghum, and oat silages. When fed to yearling steers as silage, daily DM intakes were 3.09, 2.98, and 2.57 kg for corn, sorghum, and oats, respectively. Comparable daily DM intakes for these silages after dehydrating and pelleting were 8.32, 8.03, and 7.99 kg. In the pelleted form, the silages possessed similar nutritive value, when fed as silages, corn silage had superior feeding value. In another study, Anthony et al. (1961) indicated that cattle did not relish pelleted sorghum silages harvested at three stages of maturity.

Bolsen et al. (1974a) pelleted grain sorghum stover and compared it to the same forage preserved as silage. Pelleting the stover increased DM consumption over stover silage but resulted in a poorer feed conversion.

Factors Affecting the Yield, Composition, and Nutritive Value of Sorghums

Stage of Maturity at Harvest

The process of maturity is highly complex, involving numerous alterations in plant morphology and composition. The effects of maturity differ not only among sorghum varieties, but within varieties and between years.

Black et al. (1980) harvested forage sorghum (DeKalb FS24) at six stages of maturity: early-bloom, bloom, milk, late-milk to early-dough, dough, and hard-dough. When evaluated in digestion trials with sheep, the highest yields of gross (Mcal/ha) and digestible energy (Mcal/ha) were obtained at late-milk to early-dough stages and declined rapidly at the two later harvests. The highest digestibility of the other silage nutrients were obtained at the early-bloom stage. Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) content of the silages all decreased with advancing maturity. The amount of neutral detergent solubles tended to increase with advancing maturity. The greatest amount of the plant was in the stalk at all stages of growth. The percentage of plant dry weight in the head increased from 5% at the early-bloom stage to 36% at the hard-dough stage, but the percentage leaves decreased from 31 to 18% with advancing maturity.

When Atlas sorghum was harvested at milk, soft-dough, hard-dough, and mature stages, Owen (1962) found that as maturity advanced, DM intake increased and 4% fat-corrected milk (FCM) per kg of DM intake decreased. Milk fat percentage and body weight change were not significantly affected by maturity at harvest. Dry matter yields increased 33% from the milk stage to the mature stage. The author concluded that since daily performance of the lactating cow was not appreciably influenced by stage of maturity, Atlas sorghum should be harvested when the DM yield was near maximum, usually at the hard-seed stage.

In a later study by Owen and Kuhlman (1967), Atlas and Rox forage sorghum varieties were each harvested at the milk, soft-dough, and hard-dough stages. The apparent DM digestibility of Atlas silage was depressed from 55 to 46% by advancing maturity from the milk to the hard-dough stages. Energy and protein digestibilities were also decreased. Digestibility of Rox silage was not appreciably affected by maturity.

Johnson et al. (1971) investigated the effect of maturity on the chemical composition and digestibility of silages made from bird resistant grain sorghums. As the sorghum plant matured, the DM in the leaves and heads increased rapidly while the DM content of the stalks changed very little. Heads constituted over 50% of the plant dry weight at the hard-dough stage. Percent protein and cellulose declined with maturity, while the content of cell wall constituents and lignin increased. Soluble carbohydrates declined rapidly after the milk stage. Maturity had little effect on intake or digestibilities of DM or organic matter, while the digestibility of cellulose and protein declined with maturity until after frost, at which time an increase in protein digestibility was noted.

Schake et al. (1982) harvested two varieties of grain sorghum at 10 stages of maturity from 35 to 189 days post-planting. Whole-plant DM yields increased for both varieties as plant maturity advanced, but crude protein content of the leaf, stem, and whole plant declined with advancing maturity.

In a 2-year study, Browning and Lusk (1967) determined the relative feeding value of RS 610 grain sorghum cut at three stages of maturity. There was a decrease in crude fiber (CF) and an increase in nitrogen-free extract with advancing maturity. From the first to the third stages, DM yields increased by .70

and 1.33 metric tons/ha in the first and second year, respectively. The percent of the plant dry matter represented by seed doubled from the first to the third stages. Lactating cows and bred heifers were used in milk production and digestion trials in both years. Daily silage DM intake by lactating cows increased with advancing maturity, however, there was no significant difference in average daily FCM or milk fat percent. The digestion coefficients for CP decreased significantly with increasing maturity in both years. In the second year there was a significant reduction in digestibility of CF, and a nonsignificant trend toward lower digestibility of DM, ether extract, and gross energy with increased maturity.

Dotzenko et al. (1965) harvested seven varieties of sorghum (including one grain sorghum), at six stages of maturity. From panicle emergence to hard-dough stage, percent DM and DM yields showed significant increases. Hand refractometer readings of the stalk juice showed marked increases in sugar percentages in all varieties from the panicle-emergence stage to the pollination-completed stage, after which sugar percentages generally declined.

Hart (1982) found only a slight reduction in DM yield when WAC 710 DR grain sorghum harvest was delayed from the soft-dough to the mature stage. The percent of the plant dry weight in the head, leaves, and stems changed from 62, 17, and 21% at the soft-dough stage to 54, 16, and 30% at the mature stage. When fed to steers in a digestion trial, silage DM digestibility dropped from 65.8 to 62.4% as maturity progressed.

Danley and Vetter (1973) used two varieties of forage sorghum and two corn varieties to study the effects of advancing maturity and the ensiling process on the carbohydrate and nitrogen fractions and in vitro digestibility. Increased maturity resulted in a significant increase in DM and hemicellulose content and a significant decrease in CP and estimated total digestible nutrients (TDN). However, advancing maturity did not affect the water-soluble nitrogen or soluble non-protein nitrogen content. Of the relationships studied, the lignin-cellulose ratio resulted in the best correlation of maturity and digestibility. With advancing maturity, the lignin content of the ADF increased and digestibility decreased.

Variety

Large variation exists in yield, composition, and nutritive value of sorghum varieties and one area studied in much of the literature was grain content. Male sterile hybrids, which produce little or no grain, have often been compared with higher grain containing varieties. Owen et al. (1962) evaluated two sterile forage sorghum hybrids (RS 303F and RS 301F) as silages for lactating cows. In the first trial, FS 303F was compared with corn and Axtell sorgo. Corn silage was superior in FCM produced, however, DM intake was highest for Axtell. RS 303F and Axtell were found not to differ in any other respects. In the second trial, FS 301F was compared with Tracy forage sorghum silage harvested at the early-dough and mature seed stages. The silage from FS 301F was significantly superior to that of Tracy harvested at early-dough in FCM produced and milk fat percentage, however these values were not different for silages from FS 303F and mature Tracy.

The sterile and fertile parent of FS210 hybrid forage sorghum were evaluated by Boren et al. (1962). When fed to beef calves, the fertile parent silage was superior to the sterile parent silage in average daily gain, DM intake and feed efficiency. Dry matter yields/ha were also greater for the fertile parent.

More recently, Ritchie et al. (1972) compared Pioneer 931, a tall late-maturing male sterile hybrid, to NK 300, a shorter, early-maturing, high grain producing variety. When fed to bred heifers, the NK 300 silage produced significantly faster gains and higher intakes, but DM yields/ha favored the Pioneer 931.

Danley and Vetter (1973) compared Pioneer 931 with Rudy Patrick (RP-30F) forage sorghum. RP-30F had higher soluble carbohydrates and lower ADF than Pioneer 931, but the two varieties had similar CP values. Significant differences in estimated digestible energy and TDN and in vitro digestible DM favored the RP-30F.

Research by Brethour (1977, 1978) comparing Pioneer 931 with DeKalb FS4 also showed an advantage for the grain containing forage sorghum. In the first year, DM intake was lower for the wetter (23 vs 30% DM) Pioneer 931 silage. However, there was little difference in average daily gain in steers. Harvest of the Pioneer 931 was delayed in the second year so that the forage would be dry enough to prevent seepage from the silo. Steer performance, however, was substantially lower for Pioneer 931 silage the second year.

Three sorghum types were compared by Bolsen et al. (1983). The hybrids were: non-heading forage sorghum, Funk's G-1990; Pioneer 947 forage sorghum; and DeKalb E 67 grain sorghum. Based on rates and efficiencies of gain (by beef calves) relative feeding values for the three silages were 62, 94, and 100, respectively. Nearly identical silage DM yields/ha were obtained for the Pioneer 947 and DeKalb E 67, with the non-heading hybrid having the lowest yield.

Non-heading Funk's G-1990 silage was compared with Cargill 200 (another grain-producing forage sorghum) in sheep digestion studies (Smith et al., 1984). Both hybrids were harvested pre- and post-freeze. Dry matter digestibilities were lower for non-heading silages, both pre- and post-freeze, than for the grain-producing silages. Post-freeze silages had lower CF digestibilities, regardless of sorghum type. Later results by Smith et al. (1985) comparing sorghum types indicated a similar trend. Funk's G-1990 non-heading sorghum, DeKalb FS-25A+ forage sorghum, and DeKalb DK-42Y grain sorghum silages were evaluated using growing steers. Again, based on rates and efficiencies of gain, relative feeding values for the three sorghum silages were 67, 75, and 100, respectively.

Schake et al. (1982) compared a tall grain sorghum, ORO-T and an intermediate height forage sorghum, FS-1b, both harvested at 10 stages of maturity. The forage sorghum accumulated 60% more total plant DM than ORO-T with advancing maturity. Leaves, stems, and head contributions to total DM yield differed with variety and stage of maturity. ORO-T heads weighed more than stem and leaf at four consecutive harvests, while FS-1b head weight tended to be intermediate to stem and leaf. The stems contributed 35 and 50% of the mean DM yield/ha for ORO-T and FS-1b, respectively.

In another study, Rupp et al. (1975) compared to digestibilities of ORA-T grain sorghum and FS-1a forage sorghum silages using Holstein heifers. Apparent digestion coefficients of ORA-T and FS-1b silages were: whole-crop DM, 74 and 65; energy, 74 and 66; and stover DM, 66 and 55 percent. The digestible energy values were 2.75 and 3.08 kcal/g of DM , respectively.

Johnson et al. (1971) reported that there were no significant differences in chemical composition or apparent digestibility among silages made from four varieties of bird resistant grain sorghum. However, Pund (1970) found bird resistant grain sorghum silage to be inferior to non-bird resistant variety silage. Steers fed the bird resistant silage gained significantly less and required 17.2% more DM per kg of gain. Silage DM yield/ha was not similar for the two varieties.

The chemical composition of five forage sorghum varieties (Beefbuilder, Tracy, L 115F, Milkmaker, and NK 320) was determined by Owen and Furr (1967). There were significant differences among varieties for nitrogen, calcium, phosphorus, potassium, sulfur, zinc, and manganese. Beefbuilder had the highest silage DM yield/ha; L 115F was was intermediate and the remaining three varieties were similarly lower.

Data showing both the yield and quality of silages made from several sorghum hybrids in one experiment are limited. Cummins et al. (1970) evaluated 25 sorghum varieties at two stations over a 3-year period, with 12 varieties being common to all experiments. Hybrids compared included short (up to 6 feet tall), medium (6 to 9 feet tall), and tall (over 9 feet tall) sorghum types. Results indicated that DM yields were directly related to plant height. Over the 3-year period at one station, the percentage of plant dry weight in the head ranged from 11 to 35%, in the leaves from 14 to 22%, and in the stalks from 43 to 71 percent. Two-year averages from the other station gave 26 to 56% heads, 10 to 15% leaves, and 30 to 59% stalks. In vitro DM digestibilities ranged from 40 to 52% for a 2-year average at the one station. There digestibility values were not related to the percent heads or any other component.

Correlations between agronomic and quality characteristics of 14 sorghum varieties grown over a 3-year period were reported by Schmid et al. (1976). The varieties represented a wide range of types, including a sudangrass, a grain sorghum, several sweet sorghums, and a sorghum-sudangrass hybrid (table 4). Several of the varieties were grown each year, but some were grown only one year. Sheep were used to measure gains and intakes for the silages. Plant height and DM ranges were 117 to 308 cm and 23.3 to 38.1%, respectively. The highest average daily gain was obtained from a grain type (NK 133). Linear regression analysis of gains and digestible DM intakes (DDMI) showed that the low gains of sheep fed the sorghum silages (when compared with corn silages) were primarily due to DDMI differences. Of the agronomic characteristics, percent stems and heads were most highly and consistently correlated with quality measurements. Height was highly negatively correlated with quality measurements.

Many Land Grant University Experiment Stations conduct sorghum performance tests on several hybrids at various locations within a state, however, very rarely are quality measurements reported.

Row Spacing and Plant Population

Grain Yield. A review of the literature concerning the effects of different systems of row and plant spacings on the grain yield of grain sorghums indicates that the sorghum plant has a remarkable ability to compensate for variations in plant populations and planting arrangements. Intercompensation has been observed for the number of heads per unit area (tillering), the number of seeds per head (panicle size), and seed weight, (Stickler and Wearden, 1965; Karchi and Rudich, 1966; and Stickler and Younis, 1966). Tillering, and consequently the number of heads per unit area, is probably the most important individual yield component (Karchi and Rudich, 1966).

Most investigations pertaining to the problem of row spacing and plant population in grain sorghum have been conducted either in regions of adequate moisture or with the use of irrigation. Results have shown that under conditions of abundant moisture supply, highest yields were obtained from narrow row spacings (25 to 51 cm), whereas under limited moisture supply, wider row spacing (102 cm) has been beneficial (Brown and Shrader, 1959; Bond et al., 1964; and Robinson et al., 1964).

Grimes and Musick (1960) obtained, under irrigated conditions similar grain yields for populations ranging from 138,000 to 553,000 plants/hectare.

Robinson et al. (1964), observed a linear trend for increased yield with NK 120 hybrid grain sorghum as row widths narrowed from 102 to 25 cm. Panicles/ha and seeds/panicle tended to increase with narrow row spacings, whereas 100 seed weight tended to decrease. Planting rates of approximately 190, 380, and 760 thousand plants/ha were evaluated at each of four row widths and were observed to have little effect on grain yield.

Stickler et al. (1961) stated that grain yield was due primarily to higher plant populations rather than to narrow row spacing. These authors found grain yields to be generally highest when a plant area of 152 or 203 cm^2 was provided.

Plant height, as a factor affecting response of sorghum to row width and stand density, was studied by Stickler and Younis (1966). In their experiments, short genotypes performed better at the high standard density (774 cm^2/plant), but the tall genotypes were superior at the lower stand densities of 1,548 and 2,323 cm^2/plant.

Blum (1970) planted three hybrids, differing in maturity, at 12 plant densities and found that grain yield of the late maturing hybrid was the highest under the low density and that yield of the early maturing hybrid was highest under the high density.

Forage yield. Although considerable information has accumulated in the literature on the effects of row spacing and plant population on grain yield in grain sorghums, very few studies have determined the effects of these two factors on whole-plant or forage yield.

Strickler and Laude (1960) found that neither row spacings nor plant populations affected the silage yield of Atlas forage sorghum. Yields tended to be less in narrow rows, particularly those not cultivated, and less tillering and finer stems were noted at the higher plant populations.

Corn (Pioneer 3658), grain sorghum (SD 451) and forage sorghum (Pioneer 931) were grown in three populations and two row spacings by Olson (1971). All three crops gave increasing total DM yields with increasing population throughout the range of populations used.

Bond et al. (1964) found that, in dryland grain sorghum production, greater forage yields resulted from increased moisture, higher seeding rate, and narrower rows. Moisture supply at seeding had a greater effect on forage production than did either seeding rate or row spacing. Rows 51 cm wide generally produced more forage and less grain than 102 cm rows. Consequently, the grain:forage ratio decreased with the higher seeding rate and narrower rows.

Porter et al. (1960) studied the relationships of row spacing (four), planting rate (three), and nitrogen (N) level (two) in irrigated grain sorghum. Higher average forage yields were produced at the higher N level and higher planting rates. Differences among planting rate means were associated with differences in plant populations but not proportional to them. More forage was produced at the narrow row spacings on the high N level but less on the low N level. A similar N x population interaction for forage yield in grain sorghum was also found by Welch et al. (1966). Working under dryland conditions, these researchers evaluated five plant populations and three N levels. Effect of treatments on forage yields were similar to those on grain yields. Forage yields increased with increasing plant populations and N rates. Grain:forage ratios were affected more by N rates than by plant populations with ratios decreasing with increasing plant populations in the absence of N fertilizer. With sufficient N, grain:forage ratios remained constant over the range of populations studied.

Fischer and Wilson (1975) studied the effect of plant density on growth and yield of grain sorghum. Differences in crop growth rate between populations in the early stages were attributed to leaf area development and not to differences in leaf growth rates. At grain maturity total plant dry weight and grain yield increased significantly with plant density. There were no significant differences in grain:forage ratio, although for the high population, it tended to be lower.

Planting Date

The average number of frost free days in Kansas varies from 150 to 200 days (Vanderberry and Ruckman, 1979). The range of potential planting dates span 60 to 80 days, from late April to early July. Studies by Stickler and Pauli (1961), Praeger (1977), Jaiyesimi (1979), and Bunck (1979) have observed dates of planting for optimum grain yield of grain sorghum to be May 1 to May 20; May 10 to May 14; May 3 and June 5, April 26 to May 29, respectively, indicating an advantage for an early to middle date of planting.

Schaffer (1980) used serial plantings at several locations within Kansas to study the phenological development of grain sorghum. For the temperate locations studied, early planting retarded early plant development, had little effect on the duration of panicle development, increased the number of leaves a plant produced, and placed the plant in a position where it went through high temperatures during the grain filling period. Conversely, later plantings were subjected to high temperatures during early growth and hastened vegetative development with a reduction in the number of leaves produced. Also, the grain filling period was extended by cooler autumn temperatures which were usually encountered. This study showed that the grain filling period is temperature dependent and that development continues at a faster rate with a rise in temperature up to a point within which most of the temperatures fall.

Fertilization

Fertilization is usually essential to obtain the most economical yields of sorghum, whether it be for forage or grain production. However, the effect of fertilization practices on yield, composition, and nutritive value of sorghums for silage has received little attention. Research on the effects of corn fertilization generally indicate that with increasing levels of N, silage DM yields increase only moderately and silage quality is affected very little (Vandersall et al., 1962; Alexander et al., 1963).

Genter (as cited by Owen, 1967) reported a pronounced improvement in the protein content of corn silage with levels of N ranging from 26 to 246 kg/hectare. The main increase was in the stalks and leaves, with stalks increasing from 3.1 to 5.5% protein and leaves from 9.7 to 15.3 percent. The overall change in protein in the whole-crop silage was from 7.7 to 11.1 percent.

Robinson and Murphy (1972) conducted experiments at five locations in Kansas during a three year period to determine the effects of N and phosphorus (P) fertilization and plant populations on yield and quality of forage corn. Forage and grain yields were significantly affected by N but not by P or plant population. Nitrogen fertilization increased in vitro digestibility by increasing N and decreasing cellulose concentrations in the forage.

Owen and Furr (1967) studied the effects of added trace minerals on forage yield and composition of forage sorghums. These researchers found that the addition of chelated minerals and sulfur to the soil prior to planting was not affective in changing the mineral composition or DM yield of the forage sorghums tested.

Considerably more data are available in the literature concerning the effect of N fertilization on grain yield of grain sorghum, some of which has been reviewed previously (see Row Spacing and Plant Population).

Other reports (Morrill and Ashlock, 1976; Reeves and Tucker, 1977) generally agree that responses due to increased N levels are directly related to available moisture. When moisture is abundant, increasing levels of N increase grain yields, however in dry years, higher N levels may be detrimental to grain yields.

TABLE 4. AGRONOMIC AND QUALITY CHARACTERISTICS OF 14 SORGHUM CULTIVARS INVOLVED IN 26 SILAGES[1]

Cultivar	Trial years	Type	Plant height	Dry matter	Dry matter yield	Composition			Quality measurements			
						Leaves	Stems	Ears	ADF	DDM	DMI	ADG
			cm	%	metric ton/ha	%			%		g	
NK 133	3	Grain	117	38.1	11.6	31	20	49	27.2	61.4	836	59.9
Robusto	2	Silage	160	35.5	10.5	30	30	40	29.0	61.2	748	2.1
Duet	1	Silage	184	34.8	12.8	22	27	51	25.7	59.3	729	41.1
Grace 22F	1	Silage	195	27.6	13.4	21	51	28	31.3	60.6	660	-0.5
Sumax	2	Silage	217	26.2	14.4	25	60	15	33.4	58.9	612	20.0
Pay, 401R	1	Silage	188	26.1	14.9	30	46	23	33.3	56.4	617	32.2
NK 318	2	Silage	212	24.7	13.0	37	50	13	34.3	55.3	610	26.3
DeKalb FS1a	2	Silage	230	23.3	12.1	32	51	17	37.2	55.2	588	12.8
NK 325	1	Silage	226	24.3	11.5	25	61	14	36.2	52.5	598	16.2
NK 367	1	Silage	226	23.7	15.7	36	60	5	42.4	53.9	554	-22.9
MRA FS500	1	Silage	294	25.7	16.6	28	57	15	36.0	53.5	583	14.6
Pioneer 931	3	Silage	303	27.6	14.4	36	58	6	41.1	51.8	516	-8.7
Sweet Sioux	3	Sorghum-sudan	308	32.5	12.5	25	51	24	39.8	49.2	595	8.3
Trudan II	3	Sudan	234	35.6	10.7	22	42	36	37.1	53.4	723	26.9
Mean			224	30.1	12.8	29	46	25	34.9	55.6	649	18.1
SE of mean			63	6.0	2.0	6	14	16	5.3	4.6	101	24.2

[1] Adapted from Schmid et al. (1976).

Comparison of Corn and Grain Sorghum

Silage Nutritive Value

Although whole-crop corn silages are generally regarded as superior to sorghum silages, comparisons in the literature have been with forage sorghums which have a lower grain and DM content than grain sorghums. Only a limited number of trials have made direct comparisons between corn and grain sorghum silages.

Browning et al. (1961) compared corn (Dixie 55) harvested in the early dent and grain sorghum (RS 610) in the milk to early-dough stages using lactating cows. Silage DM consumption per 45.5 kg body weight was .55 and 1.02 kg for the corn and grain sorghum silages, respectively. Average daily FCM was also significantly higher for cows fed the grain sorghum silage (11.75 vs 14.56 kg).

Later research by Browning and Lusk (1966) gave similar results. Dixie 55 hybrid corn and RS 610 grain sorghum were again compared in lactation and digestion trials. Although average daily DM intake was significantly greater for the grain sorghum, average daily FCM production was not significantly different. Cows fed the grain sorghum silage did have a significantly higher milk fat percent. In the digestion trial, heifers also consumed significantly more DM when fed grain sorghum silage than when fed corn silage. Digestion coefficients for DM, cellulose, and gross energy were greater for the corn silage. Crude protein digestibilities were similar. Three other unpublished lactation studies (as cited by Browning and Lusk, 1966) comparing grain sorghum with corn silages have shown significant differences in silage DM intake by lactating cows in favor of grain sorghum. Milk production and milk fat percentage did not differ.

In contrast to these trials, other researchers have found corn silage to be superior to grain sorghum silage. Brethour and Duitsman (1966) compared grain sorghum and corn silages and reported that steer calves fed corn silage gained significantly faster and were more efficient than those fed grain sorghum silage.

Bird resistant grain sorghum (BRGS) silage was compared with corn silage by Fox et al. (1970). Both crops were ensiled at the mature stage and fed to Hereford steer calves (231 kg initial weight) in a 172 day finishing trial and to yearling steers (409 kg initial weight) in a digestion trial. An immature stage (milk to soft-dough) BRGS silage was also included in the digestion trial. Steers fed the corn silage gained faster (1.00 vs. .73 kg/day), had lower DM intakes (5.9 vs. 6.9 kg/day) and required considerably less DM per kg of gain (5.9 vs. 9.4 kg) than those fed the BRGS silage. The low performance of the steers fed the BRGS silage was partially explained by the results of the digestion trial. The apparent digestibilities of DM, cellulose, and protein were significantly higher for corn silage than for BRGS made at the mature stage. The values for the BRGS silage made at the immature stage were not significantly different from the other two silages. The authors indicated that the low digestibility of the BRGS silage harvested at the mature stage was due to a lower digestibility of both the grain and stover portions.

Bolsen (unpublished data) and Bolsen et al. (1983) also found grain sorghum silage to be of lower nutritional value than corn silage. In the first trial, yearling steers (293 kg initial weight) were used to compare a 44% DM grain sorghum silage to a corn silage which contained 36% dry matter. In agreement with other reports, DM intake was higher for the grain sorghum silage. However, rate of gain and feed efficiency favored the corn silage. In a second trial, Ferry-Morse 81 grain sorghum (37% DM) and Ferry-Morse 3020 corn (54.4% DM) were compared trial using steer and heifer calves (188 kg initial weight). Corn silage produced signficnatly faster gains and higher intakes than the grain sorghum. Feed per unit of gain was also slightly in favor of the corn silage.

Water Use Efficiency

Levitt (1972) suggested that drought resistance of plants may depend upon drought avoidance or drought tolerance or both. Drought avoidance depends upon maintaining an adequate cell water content and/or water potential, despite a low external environmental water potential. Extreme drought avoidance, typified by a cactus, is synonymous with restricted plant growth, since the prevention of water loss also prevents CO_2 exchange into the plant (Levitt, 1972). Drought tolerance means that a plant can survive a low tissue water content and/or water potential. In drought tolerant plants, rapid growth may be prevented during water stress because the driving force for growth, tugor pressure, is low or absent or because the required metabolic reactions are inhibited (Hsiao, as cited by Stout and Simpson, 1978). Agronomically important crops are generally drought avoiders, so that photosynthesis and growth can continue, despite environmental water stress. Overdependence on an avoidance mechanism would limit CO_2 exchange and photosynthetic activity. Thus some degree of drought tolerance is desirable, particularly for short-term stress (Stout and Simpson, 1978).

Sanchez-Diaz and Kramer (1971) studied the behavior of corn and sorghum and found that sorghum closed its stomata during water stress later than corn. Beadle et al. (1973) also found that sorghum wilts at a lower water potential than corn and because inhibition of transpiration, leaf resistance and photosynthesis begins at the wilting point, there is the implication that sorghum continues to grow under a higher water stress than corn (Beadle et al., 1973).

Stout and Simpson (1978) studied the drought avoidance mechanism of two sorghum varieties in terms of osmoregulation, stomatal closure, and leaf senescence. Their results indicated that sorghum plants respond to drought by using several avoidance mechanisms with osmoregulation and leaf senescence being the most important. Those authors speculated that stomatal closure would become an important drought avoidance mechanism under more severe water stress conditions.

Water-use efficiency measurements for corn, grain sorghum, and forage sorghum grown in different populations were taken by Olson (1971). Forage sorghum consistently yielded more total DM per unit area and per unit of water used than did either corn or grain sorghum. Grain sorghum, at the highest population was more efficient in the production of total DM than was corn for any of the populations grown.

Cummins and McCullough (1969) made yield comparisons between corn and sorghum over a 3 year period at four locations in Georgia. Weather patterns varied by years and locations, which enabled comparisons to be made in relation to rainfall. Sorghum yields were, in general, fairly constant over the 3 years. The authors concluded that sorghum was more able to withstand periods of unfavorable weather and then add growth later than was corn.

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CHAPTER II

EFFECTS OF PROCESSING AND STAGE OF MATURITY AT HARVEST ON THE NUTRITIVE VALUE OF HYBRID GRAIN SORGHUM SILAGE FOR GROWING CATTLE

Abstract

Two experiments were conducted to determine the effects of processing (rolling) and stage of maturity at harvest on the nutritive value of grain sorghum silage for growing cattle. Harvests were made at the late-dough and hard-grain stages of maturity in each of 2 years, with an early-dough harvest added in the second year. Each whole-crop silage was fed without further processing (nonproc) and after processing (proc) in growth and digestion trials. Silage dry matter (DM) recovery increased and crude protein (CP) content decreased with advancing maturity. Stage of maturity at harvest did not affect avg daily gains in either experiment. In Exp. 1, steers fed proc silages gained 13% faster and were 11% more efficient than those fed nonproc silages. Digestibilities of DM, starch, and CP were significantly improved by 10, 25, and 16%, respectively, when the silages were processed. Silage DM intake was higher ($P<.10$) and feed efficiency was lower ($P<.05$) for the hard-grain stage silages. Starch and CP digestibilities were significantly higher for the late-dough stage silage. In Exp. 2, when the silages were processed, avg daily gains and feed efficiencies for heifers were significantly increased. Steers fed proc silages also had higher avg daily gains but processing did not significantly affect feed efficiency. Only starch digestibility was significantly affected (increased) by processing in Exp. 2. Dry matter intake

of the hard-grain stage silages was significantly higher than that of the early-dough silage for both heifers and steers. For the heifers, feed efficiency decreased with advancing maturity; for the steers, it was highest at the late-dough stage and lowest at the hard-grain stage. Digestibilities of starch and CP were highest ($P<.05$) for the early-dough stage silage.

Key Words: Grain sorghum silage, maturity, processing, performance, digestibility, cattle.

Introduction

Although corn (Zea mays L.) has been the primary silage crop for the beef cattle industry in the High Plains region of the United States, limited water resources and high production costs have forced a search for alternative crops of similar nutritive value.

Grain sorghum (Sorghum bicolor L. Moench) has more drought resistance and/or avoidance (Beadle et al., 1973) and has greater ability to recover from drought than corn (Sanchez-Diaz and Kramer, 1971). Ruff and Schake (1978) proposed that the feeding potential of grain sorghum could be significantly improved by harvesting the whole-crop, because it provided a nearly complete diet for ruminants. Buice et al. (1981) showed that feeding whole-crop grain sorghum silage could increase beef production per hectare by almost 28% compared with feeding only the grain portion.

One problem in feeding whole-crop grain sorghum silage, however, is the lower apparent digestibility of the grain. Processing (rolling) the silage to break the kernel has been investigated in several trials with inconsistent results

(Brethour and Duitsman, 1970, 1971; Fox et al., 1970; Pund, 1970; Gutierrez et al., 1982; Acosta et al., 1983; Bolsen et al., 1983).

Stage of maturity at harvest may also affect the digestibility of whole-crop grain sorghum silage (Browing and Lusk, 1967; Fox et al., 1970) and the benefits to processing these silages. However, a review of the literature revealed no reports which dealt with both factors (maturity and processing) in the same study. Therefore, experiments were conducted to determine the effects of processing and stage of maturity at harvest on the composition and nutritive value of grain sorghum silages for growing cattle.

Experimental Procedures

Silages. A commercial, yellow endosperm grain sorghum hybrid, DeKalb DK-42Y, was harvested as whole-crop silage in 1983 and 1984 with a precision-cut, self-propelled forage chopper. Harvests were made at the late-dough and hard-grain stages of kernel development in both years, with an early-dough harvest added in the second year. Material from the early- and late-dough harvests was ensiled in 4.2 x 18 m concrete stave silos and the hard-grain stage material was ensiled in a 4.2 x 12 m oxygen-limiting, Harvestore® structure. Dry matter (DM) losses during fermentation, storage, and feedout were measured by accurately weighing and sampling all loads of fresh crop ensiled and subsequent weighing and sampling of all silage removed from the silos.

Samples of each silage were taken twice weekly during the feedout period. A portion of each sample was dried and the remainder of the sample was frozen for future analyses.

Experiment 1. Four silage diets were compared: each of the two whole-crop silages made in 1983 was either processed through a roller mill immediately prior to being fed (proc) or fed without processing (nonproc). The roller mill was a Roskamp® model K, with two, 23 x 46 rolls, each having 3.9 corregations per cm.

Eighty, spring born crossbred steers (avg initial wt 259 kg) were allotted by weight to the four silage diets (four pens of five head/pen). Cattle were weighed individually on 2 consecutive d at the beginning and end of the trial after 16 h without feed or water. To minimize fill effects, a forage sorghum silage based diet was limit fed for 1 wk before the trial began.

Silages were fed twice daily at ad libitum levels with .82 kg of supplement per steer daily (DM basis). Composition of the supplements fed in all trials are shown in table 1. Diets were formulated to provide 12.0% crude protein (CP) on a DM basis, 200 mg of Rumensin® per steer daily and NRC (1984) requirements for calcium, phosphorus and Vitamin A. All cattle received hormonal implants at the start of the growing trial which lasted 84 days, December 16, 1983 to March 9, 1984.

Simultaneous to the growth trial, 20 individually penned steers of a similar weight and breed were used to determine the apparent digestibility of the four diets. Chromic oxide, included in the diet at approximately 10 g/steer daily, was used as an inert marker. Silages were top-dressed with the pelleted marker.

The digestion trial consisted of a 10 d adaptation period followed by a 7 d fecal collection period. Diets were fed ad libitum twice daily during the first 7 d of the adapation period. The next 3 d and during the collection period, steers were fed at 90% of their ad libitum intake.

Grab fecal samples were collected twice daily according to an advancing 2 h schedule designed to minimize diurnal variations in digestion. Fecal samples were composited and kept frozen until the end of the trial. They were then dried in a forced draft oven at 55 C and ground. Composite samples of each silage were also made during the collection period.

Experiment 2. Six silage diets were compared: each of the three whole-crop silages made in 1984 was fed either proc (as described in Exp. 1) or nonproc. Forty-eight heifers and 48 steers (avg initial wt 251 and 283 kg, respectively) were allotted by weight and previous rate of gain to the six silage diets (two pens of each sex, four head/pen). Heifer diets were formulated to provide 12.0% and steer diets 11.0% CP on a DM basis. All other procedures were the same as those outlined in Exp. 1. The growing trial lasted 84 days, February 15 to May 10, 1985.

After the completion of the growing trial, 30 of the steers (avg initial wt 400 kg) were individually penned to determine the apparent digestibility of the six diets. All other digestion trial procedures were followed as described in Exp. 1.

Chemical Analyses. Forage and silage DM was determined by drying in a forced draft oven at 55 C for 72 h. No corrections were made for volatile losses. All oven dried silage and fecal samples were ground in a Wiley mill to pass through a 1 mm screen. The two weekly silage samples (both wet and dry) were composited to form one weekly sample for analyses.

Weekly dry samples were analyzed for Kjeldahl N (AOAC, 1984), neutral detergent fiber (NDF), acid detergent fiber (ADF), permanganate lignin, cellulose, and hot water insoluble-nitrogen (HWIN) by procedures outlined by Goering and Van Soest (1975).

The composited wet weekly samples were analyzed for pH, lactic acid by colimetry (Barker and Summerson, 1941), ammonia-N by the Conway microdiffusion method (Conway, 1957), and volatile fatty acids (VFA) by gas chromatography.

The dry silage and fecal samples from the digestion trials were analyzed for proximate components (AOAC, 1984), starch (MacRae and Armstrong, 1968) chromium (feces only) by atomic absorption spectroscopy, and for the components described above for the weekly samples.

Statistical Analysis. Animal performance data were analyzed using a General Linear Models (GLM) procedure (SAS, 1982). Means were separated by the predicted difference (PDIFF) option of GLM. Statistical analyses were not performed on the chemical analyses of the silages because the samples were repeated measures from individual silos.

Results

Chemical analyses and DM recoveries of the five silages fed in Exp. 1 and 2 are shown in table 2. Good preservation was obtained for silages made at all stages of maturity. In Exp. 1, DM recovery was higher for the hard-grain stage silage compared with the late-dough silage. Likewise, DM recovery in Exp. 2 increased from the early-dough to the hard-grain stage silage. As maturity advanced, DM content increased and the extent of fermentation decreased, as was indicated by the higher pH values and lower total acid content of the hard-grain stage silages. There was a decrease in CP, ammonia-N, and cellulose and an increase in HWIN in the silages as maturity increased. No consistent trends were observed in NDF and ADF content of the silages, indicating that variation among years may be greater than the effect of stage of maturity at harvest.

Experiment 1. No significant interactions were observed between processing and stages of maturity, therefore, the results of both trials are presented and discussed as separate main effects.

Results from the growth trial are given in tables 3 and 4. Processing did not significantly affect DM intake of the silages (table 3). However, steers fed proc silages did gain 13% faster ($P<.05$) than those fed the nonproc silages and feed efficiencies were improved ($P<.05$) by 11% for the proc silages.

The effect of harvest stage on steer performance is given in table 4. Silage DM intake was higher ($P<.10$) for the hard-grain stage silage than the late-dough silage. There was no significant difference in avg daily gain for steers fed silages made at the two stages of maturity. Feed efficiency for steers fed the late-dough stage silage was superior ($P<.05$) to that of steers fed the hard-grain silage.

Data from the digestion trial are shown in table 5 and 6. Although the differences were not significant, steers fed the proc silages had higher DM intakes than those fed the nonproc silages (table 5). Digestibilities of DM, starch, and CP were significantly improved by 10, 25, and 16%, respectively, when the silages were processed. Fiber digestibilities were not affected by processing.

The effect of harvest stage on DM intake and apparent digestibilities is given in table 6. Steers fed the late-dough stage silages tended to have higher DM intakes than those fed the hard-grain silage. Starch and CP digestibilities were significantly higher for the late-dough stage silage; however, digestibilities of

ADF, NDF, hemicellulose, and crude fiber were significantly higher for the hard-grain silage.

Experiment 2. Since a significant sex x processing x stage of maturity interaction was noted, the main effects of the growth trial are presented separately for heifers and steers.

The effect of processing on heifer performance (table 7) was similar to that observed for steers in Exp. 1. Although heifers tended to consume more of the proc silages, these increases were not significant. When the silages were processed, avg daily gains and feed efficiencies for heifers were significantly increased by 14 and 9%, respectively. Steers fed proc silages also had numerically higher DM intakes than those fed nonproc silages (table 8). Significant differences were again observed in rates of gain, in favor of proc silages, but the effect of processing on feed efficiency was not significant for steers.

Shown in tables 9 and 10 are the effects of harvest stage on heifer and steer performance, respectively. Dry matter intake of the hard-grain stage silages was significantly higher than that of the early-dough stage for both heifers and steers, with the late-dough stage silages being intermediate in intake. Stage of maturity at harvest had no effect ($P<.05$) on avg daily gains of the heifers or steers. For the heifers, feed efficiency decreased as silage maturity increased, however only the difference between the early-dough and hard-grain stage silages was significant. For the steers, the late-dough stage silage was utilized more efficiently ($P<.05$) than the hard-grain stage, with the early-dough silage being intermediate.

Data from the digestion trial are shown in tables 11 and 12. The effect of processing on apparent digestibilities (table 11) was not as pronounced as in Exp.

1, with only starch digestibility significantly affected by processing. Steers fed proc silages consumed slightly less DM than those fed nonproc silages. The effect of harvest stage on DM intake and apparent digestibilities is presented in table 12. Dry matter digestibility was not significantly affected by stage of maturity at harvest, although it tended to decrease with advancing maturity. Digestibilities of starch and CP were highest ($P<.05$) for the early-dough stage silages but similar for the late-dough and hard-grain stage silages. Fiber digestibilities generally increased from the early- to late-dough stage silages, then declined at the hard-grain stage.

Discussion

In Exp. 1, 17 d elapsed between harvests of the late-dough and hard-grain stage silages. In Exp. 2, there was a 12 d difference between the early- and late-dough stage silage harvests, but only 8 d separated harvests of the late-dough and hard-grain silages. Leaf senesence had occurred by the hard-grain stage in both years. Although actual measurements were not taken in these experiments, grain content of the silages appeared to increase with maturity. Results from Chapter III as well as those from other researchers (Browning and Lusk, 1967; Johnson et al., 1971) substantiate this observation. Johnson et al. (1971) reported that as bird resistant grain sorghum matured, the percent head increased to over one-half of the dry weight at the hard-dough stage.

Silage DM recovery increased with maturity at harvest in both experiments. Although confounded by silo type, this was likely the result of more limited fermentations which occurred in the higher DM silages (Zimmer, 1980).

The decrease in CP content of the silages as maturity advanced is in agreement with other reports for grain sorghum and forage sorghum silages (Johnson et al., 1971; Danley and Vetter, 1973; Schake et al., 1982).

Processing the silages did not significantly affect DM intake in either experiment, which is in agreement with previous results (Fox et al., 1970; Pund, 1970; and Bolsen et al., 1983). The effect of processing on avg daily gain and feed efficiency was significant in most instances, which agrees with results of Fox et al. (1970). These authors reported a 29% increase in daily gain and a 19% improvement in feed efficiency when bird resistant grain sorghum silage was processed. Other researchers (Brethour and Duitsman, 1970, 1971; Bolsen et al., 1983) have reported that processing grain sorghum silages increased its nutritive value much less than the processing would cost.

The differences observed in digestibilities of the proc and nonproc silages generally support the results of the growth trials in both experiments. The consistent increase in starch digestibility of the proc silages likely accounts for much of the increased utilization of those silages. Gutierrez et al. (1982) also found starch digestibility to be significantly increased when grain sorghum silage was processed.

Silage DM intake increased with advancing stage of maturity in both experiments, probably because silage DM content increased (Ward et al., 1966) and the more mature silages had higher estimated grain to forage ratios. Browning and Lusk (1967) reported that as grain sorghum matured from the milk- to early-dough stage to the hard-seed stage, the percent of the silage DM represented by seed doubled and silage DM intake was significantly greater for the drier, hard-seed silage. Although DM intake was higher for the more mature silages, neither avg daily gains nor DM digestibilities were affected by stage of maturity at harvest.

These results agree with those of Browning and Lusk (1967) who reported no differences in daily fat corrected milk production and DM digestibility among grain sorghum silages made at three stages of maturity. The negligible effects of maturity on DM digestibility noted here are also in agreement with results of Fox et al. (1970) and Johnson et al. (1971). In Exp. 1, starch and CP digestibilities were higher for the late-dough stage silages than the hard-grain silages, which explains the better feed efficiency observed for the earlier harvested silages in the growth trial. In Exp. 2, there were no differences in starch and CP digestibilities for silages at these two stages of maturity, however digestibilities of these components were higher at the early-dough stage compared with the later harvested silages. Black et al. (1980) reported that CP digestibility of DeKalb FS24 forage sorghum decreased with maturity, from 52.8% at the early-bloom stage to only 14.8% at the hard-dough stage. The effect of harvest stage on digestibilities of the fiber components was inconsistent between experiments. The increase in fiber digestibilities from the late-dough stage silage to hard-grain silage in Exp. 1 cannot be explained. These data are in disagreement with results from Exp. 2 and other reports in the literature concerning digestibilities of grain sorghum silages harvested at different stages of maturity (Browning and Lusk, 1967; Fox et al., 1970; and Johnson et al., 1971).

The results from these experiments indicate that the nutritive value of grain sorghum silage can be improved by processing. One theory that has been given for the lack of response when grain sorghum silages have been processed is that the grain within the silage undergoes partial reconstitution during the ensiling process, resulting in softer grain that does not respond to physical processing (Gutierrez et al., 1982). Data reported here indicate that, if in fact this does happen, the softening effect diminishes as the crop is harvested at more mature stages, when the DM contents of the resulting silage and grain contained in it are high.

Stage of maturity at harvest had no effect on avg daily gains or DM digestibilities, however feed efficiency tended to decrease with advancing maturity. These results suggest that factors other than nutritive value and animal performance might need to be considered before the decision of an optimum stage of maturity at which to harvest grain sorghum for silage can be made. Whole-crop DM yields (reported in Chapter III of this thesis), recovery of silage DM from the silo, and CP content of the silages appear to be important factors that should also be considered.

TABLE 1. COMPOSITION OF SUPPLEMENTS FED IN EXP. 1 AND 2

Ingredient	Exp. 1	Exp. 2: Early- and late-dough silages heifers	Exp. 2: Early- and late-dough silages steers	Exp. 2: Hard-grain silage heifers	Exp. 2: Hard-grain silage steers
	% on a DM basis				
Sorghum grain, rolled (IFN 4-20-893)	75.91	35.01	64.16	2.90	31.80
Soybean meal (IFN 5-20-637)	2.55	55.01	28.30	87.56	60.51
Tallow (IFN 4-00-409)	1.00	1.00	1.00	1.00	1.00
Urea (IFN 5-05-070)	8.50				
Dicalcium phosphate (IFN 6-01-080)	6.55	4.25	2.35	4.65	2.25
Limestone (IFN 6-02-632)	2.95	1.25	1.65	1.35	1.90
Salt (IFN 6-04-152)	2.00	2.00	2.00	2.00	2.00
Vitamin A premix[a]	.10	.10	.10	.10	.10
Monensin premix[b]	.19	.19	.19	.19	.19
Trace mineral premix[c]	.25	.25	.25	.25	.25

[a]Supplied 25,000 IU of vitamin A/head/d.

[b]Supplied 200 mg/head/d.

[c]Contained 11% Ca, 10% Mn, 10% Fe, 10% Zn, 1% Cu, .3% I, and .1% Co.

TABLE 2. CHEMICAL ANALYSES AND DRY MATTER RECOVERIES OF SILAGES FED IN EXP. 1 AND 2

	Exp. 1		Exp. 2		
Item	Late-dough	Hard-grain	Early-dough	Late-dough	Hard-grain
Silage DM, %	42.3	50.9	31.9	42.3	56.2
DM recovery, % of the DM ensiled	96.7	97.9	87.0	92.2	94.1
pH	4.19	4.34	3.85	4.13	4.39
	% of the silage DM				
Lactic acid	5.92	4.56	5.49	3.58	2.57
Acetic acid	1.54	1.22	3.00	2.04	1.42
Propionic acid	.01	.03	.10	.06	.09
Butyric acid			.07	.08	.05
Total fermentation acids	7.48	5.81	8.70	5.58	4.16
NDF	40.1	45.3	44.8	41.7	41.9
ADF	23.3	23.1	26.6	26.5	21.9
Cellulose	17.3	16.6	19.6	18.7	16.2
Lignin	3.8	4.0	4.3	4.4	3.6
Crude protein	10.9	10.1	10.6	9.8	9.9
	% of the total silage N				
Ammonia-N	6.5	5.2	9.8	6.1	5.2
HWIN	46.8	56.2	33.4	47.3	62.4

TABLE 3. EFFECT OF SILAGE PROCESSING ON STEER PERFORMANCE IN EXP. 1

Item	Nonproc	Proc	SE
No. of steers	40	40	
Initial wt, kg	260	259	2.21
Avg daily gain, kg	.99[b]	1.12[a]	.03
Daily DM intake, kg	8.92	9.13	.17
Feed/gain	9.06[b]	8.15[a]	.21

[a,b]Means with different superscripts differ significantly ($P<.05$).

TABLE 4. EFFECT OF HARVEST STAGE ON STEER PERFORMANCE IN EXP. 1

Item	Late-dough	Hard-grain	SE
No. of steers	40	40	
Initial wt, kg	260	259	2.21
Avg daily gain, kg	1.08	1.04	.03
Daily DM intake, kg	8.81[b]	9.24[a]	.17
Feed/gain	8.22[c]	8.99[d]	.21

[a,b]Means with different superscripts differ significantly ($P<.10$).

[c,d]Means with different superscripts differ significantly ($P<.05$).

TABLE 5. EFFECT OF SILAGE PROCESSING ON DRY MATTER INTAKE AND APPARENT NUTRIENT DIGESTIBILITY IN EXP. 1

Item	Nonproc	Proc	SE
No. of steers	10	10	
Initial wt, kg	257	257	8.72
Daily DM intake, kg	8.16	8.69	.40
	Digestibility, %		
Dry matter	54.5[b]	59.9[a]	1.91
Starch	57.9[d]	72.2[c]	2.58
Crude protein	40.6[b]	47.1[a]	2.64
NDF	56.6	57.7	1.80
ADF	52.7	53.1	2.24
Hemicellulose	61.4	63.1	2.07
Cellulose	61.3	61.0	2.04
Crude fiber	62.1	61.5	1.87

[a,b]Means with different superscripts differ significantly ($P<.10$).

[c,d]Means with different superscripts differ significantly ($P<.05$).

TABLE 6. EFFECT OF HARVEST STAGE ON DRY MATTER INTAKE AND APPARENT NUTRIENT DIGESTIBLITY IN EXP. 1

Item	Late-dough	Hard-grain	SE
No. of steers	10	10	
Initial wt, kg	256	257	8.72
Daily DM intake, kg	8.84	8.01	.40
	Digestibility, %		
Dry matter	57.9	56.5	1.91
Starch	72.0[c]	58.2[d]	2.58
Crude protein	47.2[a]	40.5[b]	2.64
NDF	53.8[d]	60.4[c]	1.80
ADF	49.8[b]	56.0[a]	2.24
Hemicellulose	58.8[d]	65.7[c]	2.07
Cellulose	59.6	62.8	2.04
Crude fiber	58.7[d]	64.9[c]	1.87

[a,b]Means with different superscripts differ significantly (P<.10).

[c,d]Means with different superscripts differ significantly (P<.05).

TABLE 7. EFFECT OF SILAGE PROCESSING ON HEIFER PERFORMANCE IN EXP. 2

Item	Nonproc	Proc	SE
No. of heifers	24	24	
Initial wt, kg	252	252	.99
Avg daily gain, kg	1.04[b]	1.19[a]	.04
Daily DM intake, kg	8.26	8.64	.19
Feed/gain	7.95[b]	7.28[a]	.17

[a,b]Means with different superscripts differ significantly (P<.05).

TABLE 8. EFFECT OF SILAGE PROCESSING ON STEER PERFORMANCE IN EXP. 2

Item	Nonproc	Proc	SE
No. of steers	24	24	
Initial wt, kg	284	282	2.08
Avg daily gain, kg	1.09^b	1.21^a	.03
Daily DM intake, kg	8.83	9.30	.20
Feed/gain	8.12	7.69	.22

^{a,b}Means with different superscripts differ significantly (P<.05).

TABLE 9. EFFECT OF HARVEST STAGE ON HEIFER PERFORMANCE IN EXP. 2

Item	Early-dough	Late-dough	Hard-grain	SE
No. of heifers	16	16	16	
Initial wt, kg	250	251	254	1.21
Avg daily gain, kg	1.12	1.11	1.12	.05
Daily DM intake, kg	8.07^b	8.36^{ab}	8.91^a	.23
Feed/gain	7.19^a	7.59^{ab}	8.07^b	.21

^{a,b}Means with different superscripts differ significantly (P<.05).

TABLE 10. EFFECT OF HARVEST STAGE ON STEER PERFORMANCE IN EXP. 2

Item	Early-dough	Late-dough	Hard-grain	SE
No. of steers	16	16	16	
Initial wt, kg	283	283	282	2.54
Avg daily gain, kg	1.11	1.18	1.16	.04
Daily DM intake, kg	8.76^{d}	8.82^{cd}	9.62^{c}	.24
Feed/gain	7.90^{ab}	7.47^{a}	8.34^{b}	.27

[a,b]Means with different superscripts differ significantly (P<.10).

[c,d]Means with different superscripts differ significantly (P<.05).

TABLE 11. EFFECT OF SILAGE PROCESSING ON DRY MATTER INTAKE AND APPARENT NUTRIENT DIGESTIBILITY IN EXP. 2

Item	Nonproc	Proc	SE
No. of steers	12	12	
Initial wt, kg	400	395	10.89
Daily DM intake, kg	9.19	9.01	.37
	Digestibility, %		
Dry matter	53.2	54.7	1.09
Starch	75.2^{b}	84.1^{a}	1.19
Crude protein	43.9	43.3	1.26
NDF	43.5	41.8	1.97
ADF	39.7	37.8	2.05
Hemicellulose	48.2	46.5	2.47
Cellulose	51.8	49.6	2.16
Crude fiber	52.0	47.9	1.95

[a,b]Means with different superscripts differ significantly (P<.05).

TABLE 12. EFFECT OF HARVEST STAGE ON DRY MATTER INTAKE AND APPARENT NUTRIENT DIGESTIBILITY IN EXP. 2

Item	Early-dough	Late-dough	Hard-grain	SE
No. of steers	8	8	8	
Initial wt, kg	401	400	392	13.34
Daily DM intake, kg	8.63^{b}	8.92^{ab}	9.74^{a}	.45
	Digestibility, %			
Dry matter	55.1	53.8	52.9	1.33
Starch	88.8^{c}	75.0^{d}	75.2^{d}	1.45
Crude protein	50.0^{c}	39.7^{d}	41.1^{d}	2.39
NDF	40.2^{d}	47.6^{c}	40.0^{d}	2.41
ADF	38.0^{ab}	42.6^{a}	35.7^{b}	2.52
Hemicellulose	43.5^{d}	53.5^{c}	45.1^{d}	3.02
Cellulose	49.0^{cd}	56.5^{c}	46.6^{d}	2.65
Crude fiber	47.8	53.3	48.7	1.54

[a,b]Means with different superscripts differ significantly (P<.10).

[c,d]Means with different superscripts differ significantly (P<.05).

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CHAPTER III

EFFECT OF STAGE OF MATURITY AT HARVEST ON YIELD AND COMPOSITION OF HYBRID GRAIN SORGHUM SILAGES

Abstract

Five grain sorghum hybrids and one forage sorghum hybrid were harvested at three stages of kernel development (early-dough, late-dough, and hard-grain) to evaluate the effect of stage of maturity at harvest on silage yield and composition. Field plots were established under dryland conditions in 1984 in split-plot design. Chopped material from each plot was collected and ensiled in laboratory silos. The earliest and latest maturing grain sorghum hybrids differed by only 4 d to half bloom. Plant heights were also similar for all grain sorghums. The forage sorghum was later maturing and taller than the grain sorghums ($P<.05$). The highest whole-crop dry matter (DM) and grain yields for the grain sorghums occurred at the late-dough stage of maturity. Although not significant, whole-crop DM yield for the forage sorghum decreased and grain yield increased as maturity advanced. Grain to forage ratios increased with maturity for both sorghum types. The forage sorghum had higher ($P<.05$) whole-crop DM yields at the early-dough and hard-grain stages, but the two sorghum types had similar whole-crop DM yields at the late-dough stage. Grain yield was higher ($P<.05$) for the forage sorghum at the early-dough stage but higher ($P<.05$) for the grain sorghum at the late-dough stage. Grain to forage ratios were higher ($P<.05$) for the grain sorghum at the late-dough and hard-grain stages. Grain sorghum silages increased ($P<.05$)

in DM content and tended to decrease in crude protein (CP) content with advancing stages of maturity. The forage sorghum showed only a slight change in DM content after the late-dough stage and no change in CP content. Grain sorghum silages were higher in CP content than the forage sorghum silage at all three stages of maturity. Less extensive fermentations occurred as maturity advanced and silage DM content increased. Similar fermentation patterns occurred for the two sorghum types.

Key Words: Grain sorghum, forage sorghum, silage, maturity, yield, composition

Introduction

High production costs and limited water resources in many areas of the United States may favor the use of sorghum as a silage crop rather than corn. Sorghum has more drought resistance and/or avoidance than corn (Beadle et al., 1973) and has a greater ability to recover from drought (Sanchez-Diaz and Kramer, 1971). However, much diversity exists among sorghum types and among varieties within types for both quantity and quality of silage produced.

Grain sorghum (Sorghum bicolor L. Moench) is planted in the United States primarily for grain production, and hybrids are chosen for that purpose. Little attention has been given to potential silage yield and quality of grain sorghum hybrids. Ruff and Schake (1978) proposed that the feeding potential of grain sorghum could be significantly improved by harvesting the whole-crop, because it provides a nearly complete diet for ruminants. Buice et al. (1981) indicated that feeding whole-crop grain sorghum silage could increase beef production per hectare by almost 28% compared with feeding only the grain.

The potential of grain sorghum to yield sufficient quantities of whole-crop DM to support acceptable production per hectare has not been documented. Forage type sorghums usually yield more DM per hectare than grain types; however, forage types generally have a lower grain to forage ratio (Dickerson et al., 1985). Stage of maturity at harvest also influences DM yield and grain to forage ratio. Browning and Lusk (1967) harvested grain sorghum for silage at three stages of maturity and found that as maturity progressed from the milk to early-dough stage to the hard-seed stage, DM yields and grain to forage ratios increased. These authors also reported that crude fiber and crude protein contents of the silages decreased and nitrogen-free extract increased with advanced maturity.

The objectives of this experiment were to determine the effect of stage of maturity at harvest on the yield and composition of grain sorghum hybrids harvested for silage and to compare these grain sorghums to a commonly grown forage sorghum hybrid.

Experimental Procedures

Field plots were established under dryland conditions near Manhattan, Kansas in 1984. Treatments were arranged in a split-plot design with four replications. Main plots were three stages of kernel development at harvest: late-milk to early-dough, late-dough, and hard-grain. Subplots consisted of five grain sorghum hybrids (Asgrow Colt, DeKalb DK-42Y, Funk's G-522DR, Northrup-King 2778, TX 2752 x TX 430), and one forage sorghum hybrid (Pioneer 947). Grain sorghum hybrids were chosen to represent a range of sorghum pedigrees, which included variations in maturity, plant height, and grain and forage yields. Each subplot consisted of six rows, 7.3 m in length, with 76 cm between rows. Plots were seeded on June 1 at a heavy rate and later hand thinned to 84,228 plants/ha (15 cm between plants).

The soil type was a silty clay loam, which was uniformly cropped with corn the previous year. Nitrogen fertilizer was applied uniformly to the experimental site at the rate of 99 kg/ha before the plots were seeded. The growing season was characterized by a wet spring, a hot and dry summer, and a wet autumn.

Data collected on each plot included: days to half bloom, plant height, whole-crop DM yield, and grain yield. Days to half bloom measured maturity, and is defined as number of days between the planting date and the date one-half of the main heads had some florets in bloom. Plant height was measured to the tallest point of the main heads immediately prior to harvest. Whole-crop yield for each plot was determined by harvesting a 6 m length from each of the two center rows with a modified one-row forage harvester. Chopped material from the two rows was combined, weighed, and sampled for DM determination. Grain yield was determined by hand clipping the heads from 6 m of one of the remaining rows. The heads were then partially dried and threshed in a stationary thresher. Grain samples were dried to 100% DM and grain yields were calculated on a DM basis.

The chopped material from the center two rows was collected and ensiled in a 20 l capacity plastic laboratory silo as described by Hinds (1983). Silos were opened at approximately 100 d post-filling and sampled for analyses. Pre-ensiled material and silages were dried in a forced-draft oven at 55 C, and ground in a Wiley mill to pass through a 1 mm screen. Ground silage samples were analyzed for Kjeldahl N (AOAC, 1984), neutral detergent fiber (NDF), acid detergent fiber (ADF), permanganate lignin, and cellulose (Goering and Van Soest, 1975). Wet silage samples were analyzed for pH, lactic acid by colimetry (Barker and

Summerson, 1941), ammonia-nitrogen by the Conway microdiffusion method (Conway, 1957), and volatile fatty acids (VFA) by gas chromatography.

Data were statistically analyzed using a General Linear Models (GLM) procedure (SAS, 1982). Since grain sorghums responded similarly, data for the five grain sorghum hybrids were pooled for analyses. Means for comparing harvest stages were separated by the predicted difference (PDIFF) option of the GLM procedure. A contrast between the five grain sorghums and the forage sorghum was performed to determine the effect of sorghum type (Snedecor and Cochran, 1981).

Results

Agronomic characteristics of the six sorghum hybrids are shown in table 1. The earliest and latest maturing grain sorghum hybrids differed by only 4 d to half bloom. Plant heights were also similar for all grain sorghums. The forage sorghum (Pioneer 947) was later maturing and taller than the grain sorghums ($P<.05$).

The effect of harvest stage on yield of the two sorghum types is presented in table 2. The highest ($P<.05$) whole-crop DM and grain yields for the grain sorghums occurred at the late-dough stage of maturity. Grain yields for two of the five hybrids did not decrease at the hard-grain stage (appendix table 6). Although not significantly different, DM yield for the forage sorghum decreased and grain yield increased as maturity advanced. Grain to forage ratios increased with later maturity for both sorghum types; however, this increase was significant only for the grain sorghums.

The effect of sorghum type on yield at the three harvest stages is presented in table 3. Whole-crop DM yield was higher ($P<.05$) for the forage sorghum at the early-dough and hard-grain stages, with the two sorghum types having similar whole-crop DM yields at the late-dough stage. Grain yield was significantly higher for the forage sorghum at the early-dough stage, significantly higher for the grain sorghums at the late-dough stage, but not different at the hard-grain stage. Grain to forage ratios were similar at the early-dough stage but significantly higher for the grain sorghums at the late-dough and hard-grain stages.

The effect of harvest stage on silage composition of the two sorghum types is shown in table 4. For the grain sorghums, pre-ensiled and silage DM contents were significantly higher with each advancing stage of maturity. Crude protein was highest ($P<.05$) at the early-dough stage. Only one of the grain sorghum hybrids dropped below 9% CP at any stage of maturity (appendix table 8). Acid detergent fiber decreased with advancing maturity; however, only the difference between the early-dough and hard-grain stages was significant. Cellulose also decreased with advancing maturity, with the early-dough stage silage containing significantly more cellulose than silages made at the other two stages. No differences due to maturity were observed in NDF, hemicellulose, or lignin content of the grain sorghum silages. For the forage sorghum, silage DM content followed a similar pattern as the pre-ensiled forage, with the early-dough stage silage having a lower ($P<.05$) DM content than silages made at the two later stages. Hemicellulose was significantly lower in the late-dough and hard-grain stage silages that in the early-dough silage.

The effect of harvest stage on silage fermentation characteristics of the two sorghum types is shown in table 5. For the grain sorghum silages, lactic, acetic, and total acids decreased and pH values increased ($P<.05$) as maturity advanced. The lactic to acetic ratio decreased ($P<.05$) from the early-dough to the hard-grain stage. Ammonia-N was highest ($P<.05$) in the early-dough stage silage. For the forage sorghum silage, lactic acid was significantly higher in the early-dough stage silage than in the late-dough or hard-grain silages. There was a significant difference in total fermentation acids only between the early-dough and late-dough stage silages. The late-dough stage silage had the highest ($P<.05$) pH value. The lactic to acetic ratio tended to decrease with advancing maturity for the forage sorghum.

The effect of sorghum type on silage composition at the three harvest stages is presented in table 6. Grain sorghum silages were significantly lower in DM content at the early- and late-dough stages but the forage sorghum silage had a lower ($P<.05$) DM at the hard-grain stage. Crude protein contents of the grain sorghum silages were higher ($P<.05$) and NDF, ADF, cellulose, and lignin contents were lower ($P<.05$) than the forage sorghum at all three stages of maturity. Hemicellulose was lower ($P<.05$) in the grain sorghum silages at the early-dough stage but lower ($P<.05$) in the forage sorghum silage at the hard-grain stage.

The effect of sorghum type on silage fermentation characteristics at the three harvest stages is given in table 7. Lactic acid content was similar for the two sorghum types except at the late-dough stage, where it was higher ($P<.05$) for the grain sorghum silages. Total acids were significantly higher in the grain sorghum silages than in the forage sorghum silage at the early- and late-dough stages of maturity. Forage sorghum silages had higher ($P<.05$) pH values and lower ($P<.05$) ammonia-N contents than the grain sorghum silages at all three stages of maturity.

Discussion

Differences among grain sorghum hybrids in days to half bloom and plant height were not as great as expected. This probably resulted from the drought and heat encountered during the early stages of growth (Schaffer, 1980). The hot weather that occurred during the later part of the growing season accelerated the rate of maturity for all the hybrids. Schaffer (1980) provided evidence that the grain filling period is temperature dependent and that development will proceed at a faster rate with a rise in temperature. On the average, only 9 d elapsed between successive harvest stages in this experiment.

Whole-crop DM and grain yields of the grain sorghum hybrids were highest ($P<.05$) at the late-dough stage of maturity. Browning and Lusk (1967) harvested grain sorghum for silage at similar stages of maturity and reported an increase in whole-crop DM yields with each advancing stage of maturity. The reduced yields observed at the hard-grain stage in this experiment were related to severe damage by birds in some plots, as well as leaf loss.

Whole-crop DM yields of the forage sorghum tended to decline with advancing maturity. A similar maturity effect was reported by Black et al. (1980). These authors reported DM yields per hectare for DeKalb FS24 were highest at the late-milk to early-dough stage and declined at later stages of maturity. However, the forage sorghum yields in this experiment may have been biased downward because it was not surrounded by a crop of similar height. This was reflected in its higher than expected DM contents, especially at the first two stages of maturity. In a study of this nature, where distinctly different plant heights are expected, possibly more border rows are needed.

Averaged across stages of maturity, the forage sorghum had approximately a 12% higher whole-crop DM yield than the grain sorghums. This difference in whole-crop DM yield between the two sorghum types is considerably less than what was observed by Schake et al. (1982). These authors reported that FS-1b forage sorghum accumulated 60% more DM than ORO-T grain sorghum.

Grain sorghum silages increased in DM content and tended to decrease in CP content with advancing stages of maturity, as previously reported for grain sorghums by Browning and Lusk (1967) and Johnson et al. (1971). In contrast, the forage sorghum showed only a slight change in DM content after the late-dough stage and no change in CP content with advancing maturity. These results are in agreement with those of Danley and Vetter (1973) and Black et al. (1980). Although both of the previously mentioned references found increases in DM content and decreases in CP content from the bloom or pre-seed set stage to the post-frost stage, only slight differences were noted among stages of maturity which were similar to those used in this experiment.

Silages made at all three stages of maturity were well preserved for each of the sorghum hybrids. Less extensive fermentations occurred as maturity advanced and silage DM content decreased, as indicated by the higher pH values and lower lactic and total fermentation acid contents. Other researchers (Jackson and Forbes, 1970; Hinds et al., 1982) have reported that increasing the DM content of the forage restricts silage fermentation and results in silages with a higher pH and lower levels of fermentation acids. The increase in butyric acid content of the grain sorghum silages as maturity advanced cannot be explained. Two hybrids, TX 2752 x TX 430 and Funk's G-522DR, which had uncharacteristically high butyric acid levels at the hard-grain stage of maturity were mainly responsible for this increase (appendix table 9).

In general, results from this experiment suggest that grain sorghums have the potential to produce high whole-crop DM yields in a short period of time.

Although whole-crop DM yields may be lower than for forage sorghum, higher grain to forage ratios and CP contents could offset the reduced DM yields. Higher grain-containing silages generally support faster gains by cattle and higher CP contents mean less supplemental protein would need to be added when diets are formulated. Optimum yields of grain sorghums were obtained by harvesting at the late-dough stage of maturity. However, high quality silages were made at each stage of maturity studied, suggesting that grain sorghum matures at a rate that provides a relatively long harvest season. It has an acceptable DM content over a range of maturities and its yield and nutrient content plateau during the later stages of maturity.

When recovery of DM from the silo and beef gain per kg of silage DM fed are considered (Chapter II) along with DM yield from the field (appendix table 10), optimum beef production per hectare is also obtained at the late-dough stage.

TABLE 1. AGRONOMIC CHARACTERISTICS OF THE SIX SORGHUM HYBRIDS

Hybrid	Sorghum type	Days to half bloom	Plant height[1]
DeKalb DK-42Y	Grain	61.1[a]	109.6[ab]
Northrup-King 2778	Grain	61.3[a]	110.3[ab]
TX 2752 x TX 430	Grain	62.1[b]	108.2[ab]
Funk's G-522DR	Grain	63.1[c]	107.1[a]
Asgrow Colt	Grain	65.2[d]	112.2[b]
Pioneer 947	Forage	71.7[e]	197.7[c]

[1]Centimeters.

[a,b,c,d,e]Means with different superscripts differ significantly ($P<.05$).

TABLE 2. EFFECT OF HARVEST STAGE ON YIELD OF THE TWO SORGHUM TYPES

Sorghum type and item	Harvest stage			SE
	Early-dough	Late-dough	Hard-grain	
Grain sorghums[1]				
Whole-crop DM yield[2]	11.42[b]	12.65[a]	11.39[b]	.18
Grain DM yield[2]	3.67[c]	5.49[a]	5.04[b]	.15
Grain:forage	.481[b]	.785[a]	.817[a]	.04
Forage sorghum				
Whole-crop DM yield[2]	13.59	13.36	12.79	.53
Grain DM yield[2]	4.49	4.60	4.91	.39
Grain:forage	.500	.531	.624	.05

[1]Avg of five hybrids.

[2]Metric tons per hectare.

[a,b,c]Means in the same row with different superscripts differ significantly ($P<.05$).

TABLE 3. EFFECT OF SORGHUM TYPE ON YIELD AT THE THREE HARVEST STAGES

Harvest stage and item	Sorghum type: Grain[1]	Sorghum type: Forage	SE
Early-dough			
Whole-crop DM yield[2]	11.42[b]	13.59[a]	.49
Grain DM yield[2]	3.67[b]	4.49[a]	.36
Grain:forage	.481	.500	.09
Late-dough			
Whole-crop DM yield	12.65	13.36	.49
Grain DM yield	5.49[a]	4.60[b]	.36
Grain:forage	.785[a]	.531[b]	.09
Hard-grain			
Whole-crop DM yield	11.39[b]	12.79[a]	.49
Grain DM yield	5.04	4.91	.36
Grain:forage	.817[a]	.624[b]	.09

[1]Avg of five hybrids.

[2]Metric tons per hectare.

[a,b]Means in the same row with different superscripts differ significantly ($P<.05$).

TABLE 4. EFFECT OF HARVEST STAGE ON SILAGE COMPOSITION OF THE TWO SORGHUM TYPES

Sorghum type and item	Harvest stage			SE
	Early-dough	Late-dough	Hard-grain	
Grain sorghums[1]				
Dry matter:				
Pre-ensiled crop, %	32.9^{a}	41.8^{b}	51.3^{c}	.004
Silage, %	32.2^{a}	40.0^{b}	50.5^{c}	.34
	% of the silage DM			
Crude protein	10.5^{a}	9.7^{b}	9.5^{b}	.10
NDF	48.8	47.1	49.3	.57
ADF	27.8^{b}	26.2^{ab}	25.5^{a}	.40
Hemicellulose	20.6	21.0	23.8	.43
Cellulose	20.5^{b}	18.8^{a}	18.0^{a}	.24
Lignin	4.4	4.5	4.6	.11
Forage sorghum				
Dry matter:				
Pre-ensiled crop, %	39.1^{a}	45.2^{b}	45.5^{b}	.01
Silage, %	37.4^{a}	43.6^{b}	44.8^{b}	1.06
	% of the silage DM			
Crude protein	8.2	8.1	7.9	.18
NDF	55.5	52.1	54.1	1.07
ADF	31.9	31.1	32.6	.81
Hemicellulose	23.6^{b}	20.9^{a}	21.5^{a}	.38
Cellulose	22.8	22.5	23.3	.87
Lignin	5.7	6.1	6.0	.21

[1]Avg of five hybrids.

[a,b,c]Means in the same row with different superscripts differ significantly ($P<.05$).

TABLE 5. EFFECT OF HARVEST STAGE ON SILAGE FERMENTATION CHARACTERISTICS OF THE TWO SORGHUM TYPES

Sorghum type and item	Harvest stage			
	Early-dough	Late-dough	Hard-grain	SE
Grain sorghums[1]	% of the silage DM			
Lactic acid	5.72^{a}	3.97^{b}	2.92^{c}	.18
Acetic acid	2.22^{a}	1.66^{ab}	1.32^{b}	.08
Propionic acid		.01	.02	.01
Butyric acid	$.07^{a}$	$.23^{ab}$	$.59^{b}$	.12
Total acids	8.01^{a}	5.87^{b}	4.86^{b}	.19
pH	4.08^{a}	4.34^{b}	4.78^{c}	.03
Lactic:acetic	2.72^{a}	2.44^{ab}	2.16^{b}	.14
Ammonia-N[2]	8.75^{a}	6.92^{b}	6.78^{b}	.09
Forage sorghum	% of the silage DM			
Lactic acid	5.06^{a}	3.00^{b}	3.22^{b}	.41
Acetic acid	1.78	1.49	2.36	.36
Propionic acid	.01		$<.01$	.003
Butyric acid	.08	$<.01$	.02	.04
Total acids	6.93^{a}	4.50^{b}	5.61^{ab}	.60
pH	4.26^{a}	4.60^{b}	4.21^{a}	.03
Lactic:acetic	2.84^{a}	2.01^{ab}	1.55^{b}	.25
Ammonia-N[2]	5.68	5.62	5.70	.004

[1]Avg of five hybrids.

[2]Expressed as a % of the total N.

[a,b,c]Means in the same row with different superscripts differ significantly ($P<.05$).

TABLE 6. EFFECT OF SORGHUM TYPE ON SILAGE COMPOSITION AT THE THREE HARVEST STAGES

Harvest stage and item	Sorghum type Grain[1]	Forage	SE
Early-dough			
Dry matter:			
Pre-ensiled, %	32.9^{a}	39.1^{b}	.01
Silage, %	32.2^{a}	37.4^{b}	.90
	—— % of the silage DM ——		
Crude protein	10.5^{a}	8.2^{b}	.23
NDF	48.8^{a}	55.5^{b}	1.48
ADF	27.8^{a}	31.9^{b}	1.08
Hemicellulose	20.6^{a}	23.6^{b}	1.08
Cellulose	20.5^{a}	22.8^{b}	.68
Lignin	4.4^{a}	5.7^{b}	.29
Late-dough			
Dry matter:			
Pre-ensiled, %	41.8^{a}	45.2^{b}	.01
Silage, %	40.0^{a}	43.6^{b}	.90
	—— % of the silage DM ——		
Crude protein	9.7^{a}	8.1^{b}	.23
NDF	47.1^{a}	52.1^{b}	1.48
ADF	26.2^{a}	31.1^{b}	1.08
Hemicellulose	21.0	20.9	1.08
Cellulose	18.8^{a}	22.5^{b}	.68
Lignin	4.5^{a}	6.1^{b}	.29
Hard-grain			
Dry matter:			
Pre-ensiled	51.3^{b}	45.5^{a}	.01
Silage, %	50.5^{b}	44.8^{a}	.90
	—— % of the silage DM ——		
Crude protein	9.5^{a}	7.9^{b}	.23
NDF	49.3^{a}	54.1^{b}	1.48
ADF	25.5^{a}	32.6^{b}	1.08
Hemicellulose	23.8^{b}	21.5^{a}	1.08
Cellulose	18.0^{a}	23.3^{b}	.68
Lignin	4.6^{a}	6.0^{b}	.29

[1]Avg of five hybrids.

[a,b]Means in the same row with different superscripts differ significantly ($P < .05$).

TABLE 7. EFFECT OF SORGHUM TYPE ON SILAGE FERMENTATION CHARACTERISTICS AT THE THREE HARVEST STAGES

Harvest stage and item	Sorghum type: Grain[1]	Sorghum type: Forage	SE
Early-dough	— % of the silage DM —		
Lactic acid	5.72	5.06	.47
Acetic acid	2.22	1.78	.26
Propionic acid		.01	.02
Butyric acid	.07	.08	.28
Total acids	8.01[a]	6.93[b]	.53
pH	4.08[a]	4.26[b]	.07
Lactic:acetic	2.72	2.84	.32
Ammonia-N[2]	8.75[a]	5.68[b]	.01
Late-dough	— % of the silage DM —		
Lactic acid	3.97[a]	3.00[b]	.47
Acetic acid	1.66	1.49	.26
Propionic acid	.01		.02
Butyric acid	.23	<.01	.28
Total acids	5.87[a]	4.50[b]	.53
pH	4.34[a]	4.60[b]	.07
Lactic:acetic	2.44	2.01	.32
Ammonia-N[2]	6.92[a]	5.62[b]	.01
Hard-grain	— % of the silage DM —		
Lactic acid	2.92	3.22	.47
Acetic acid	1.32[a]	2.36[b]	.26
Propionic acid	.02	<.01	.02
Butyric acid	.59[a]	.02[b]	.28
Total acids	4.86	5.61	.53
pH	4.78[a]	4.21[b]	.07
Lactic:acetic	2.16	1.55	.32
Ammonia-N[2]	6.78	5.70	.01

[1]Avg of five hybrids.

[2]Expressed as a % of the total N.

[a,b]Means in the same row with different superscripts differ significantly ($P<.05$).

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Appendix A

Procedures for Chromic Oxide Digestion Trials

1. Formulation for chromic oxide pellets:

   % (as-fed basis)

   12.5 chromic oxide (Cr_2O_3)

   62.5 ground corn

   25.0 dry cane molasses

   100.0

2. Determination of chromium intake:

   Each steer was fed 80 g of chromic oxide per day (40 g twice daily), therefore the total collection period intake of pellets was 560 g (80 g x 7 day).

   A composite sample of the chromic oxide pellets wase analyzed and found to contain 9.59% chromium. Therefore, each steer consumed 53.68 g (560 g x .0959) or .1182 lb of chromium during the collection period.

   To determine the percent chromium in the feed, the chromium intake (.1182 lb) was divided by the total DM intake of the animal during the collection period.

3. Calculations for digestion coefficients:

   Once the percent chromium in the feed was determined, a ratio of the percent chromium in the feed and the percent chromium in the feces was then calculated.

   Ratio = % chromium in the feed/% chromium in the feces

   Dry matter digestibility = (1-ratio) x 100

Digestibility coefficients of specific nutrients were calculated in a similar manner. Starch digestibility, for example, was calculated as follows:

$$\text{starch digestibility} = 1 - \frac{\text{ratio} \times \%\ \text{starch in feces}}{\%\ \text{starch in the feed}} \times 100$$

Example:

Chromium intake = .1182 lb

Total DM intake = 175.2 lb

Chromium in the feed, % = (.1182/175.2) x 100 = .0675

Chromium in the feces, % = .1480

Ratio = (.0675/.1480) = .4561

DM digestibility = (1-.4561) x 100 = 54.39

Starch in feed, % = 28.05

Starch in feces, % = 20.29

$$\text{Starch digestibility} = 1 - \frac{.4561 \times 20.29}{28.05} \times 100 = 67.01$$

4. Feces collection schedule

Tuesday	8 am	8 pm
Wednesday	10 am	10 pm
Thursday		12 pm (noon)
Friday	12 am (midnight)	2 pm
Saturday	2 am	4 pm
Sunday	4 am	6 pm
Monday	6 am	8 pm
Tuesday	8 am	

Appendix B

APPENDIX TABLE 1. PERFORMANCE BY STEERS FED THE FOUR SILAGE DIETS IN EXP. 1

Item	Late-dough		Hard-grain		SE
	Nonproc	Proc	Nonproc	Proc	
No. of steers	20	20	20	20	
Initial wt, kg	260	259	259	259	3.13
Avg daily gain, kg	1.02^{ab}	1.14^{a}	0.96^{b}	1.11^{a}	.04
Daily DM intake, kg	8.82^{d}	8.80^{d}	9.03^{cd}	9.46^{c}	.24
Feed/gain	8.69^{d}	7.75^{c}	9.43^{e}	8.54^{d}	.30

^{a,b}Means with different superscripts are significantly different (P<.05).

^{c,d,e}Means with different superscripts are significantly different (P<.10).

APPENDIX TABLE 2. DRY MATTER INTAKE AND APPARENT NUTRIENT DIGESTIBILITY OF THE FOUR SILAGE DIETS FED IN EXP. 1

Item	Late-dough		Hard-grain		SE
	Nonproc	Proc	Nonproc	Proc	
No. of steers	5	5	5	5	
Initial wt, kg	260	252	253	262	12.34
Daily DM intake, kg	8.48	9.21	7.85	8.17	.56
	Digestibility, %				
Dry matter	53.8[b]	61.9[a]	55.1[ab]	57.9[ab]	2.69
Starch	65.0[b]	79.0[a]	50.8[c]	65.5[b]	3.65
Crude protein	42.8[ab]	51.6[a]	38.3[b]	42.6[ab]	3.73
NDF	52.5	55.1	60.6	60.2	2.55
ADF	49.5	50.0	55.9	56.1	3.17
Hemicellulose	56.6	61.0	66.2	65.1	2.93
Cellulose	60.2	59.0	62.5	63.0	2.89
Crude fiber	58.9	58.6	65.4	64.4	2.64

[a,b,c]Means with different superscripts are significantly different ($P<.05$).

APPENDIX TABLE 3. PERFORMANCE BY HEIFERS FED THE SIX SILAGE DIETS IN EXP. 2

Item	Early-dough		Late-dough		Hard-grain		SE
	Nonproc	Proc	Nonproc	Proc	Nonproc	Proc	
No. of heifers	8	8	8	8	8	8	
Initial wt, kg	249^{b}	252^{ab}	251^{ab}	251^{ab}	255^{a}	254^{ab}	1.72
Avg daily gain, kg	1.13^{ab}	1.12^{ab}	0.97^{b}	1.24^{a}	1.03^{ab}	1.20^{a}	.06
Daily DM intake, kg	8.12^{ab}	8.01^{ab}	7.77^{b}	8.95^{a}	8.88^{ab}	8.96^{a}	.33
Feed/gain	7.22^{a}	7.16^{a}	7.98^{ab}	7.20^{a}	8.65^{b}	7.49^{a}	.30

[a,b]Means with different superscripts differ significantly (P<.05).

APPENDIX TABLE 4. PERFORMANCE BY STEERS FED THE SIX SILAGE DIETS IN EXP. 2

Item	Early-dough		Late-dough		Hard-grain		SE
	Nonproc	Proc	Nonproc	Proc	Nonproc	Proc	
No. of steers	8	8	8	8	8	8	
Initial wt, kg	278	289	288	279	287	277	3.59
Avg daily gain, kg	1.06^{b}	1.16^{ab}	1.18^{ab}	1.18^{ab}	1.04^{b}	1.29^{a}	.06
Daily DM intake, kg	8.59^{b}	8.92^{b}	9.04^{b}	8.59^{b}	8.86^{b}	10.38^{a}	.35
Feed/gain	8.13^{cd}	7.67^{cd}	7.66^{cd}	7.29^{c}	8.57^{d}	8.11^{cd}	.38

[a,b]Means with different superscripts differ significantly (P<.05).

[c,d]Means with different superscripts differ significantly (P<.10).

APPENDIX TABLE 5. DRY MATTER INTAKE AND APPARENT NUTRIENT DIGESTIBILITY OF THE SIX SILAGE DIETS FED IN EXP. 2

	Early-dough		Late-dough		Hard-grain		
Item	Nonproc	Proc	Nonproc	Proc	Nonproc	Proc	SE
No. of steers	4	4	4	4	4	4	
Initial wt, kg	405	398	402	399	395	389	18.87
Daily DM intake, kg	8.89^{ab}	8.38^{b}	8.74^{ab}	9.10^{ab}	9.94^{a}	9.54^{ab}	.64
	Digestibility, %						
Dry matter	54.3	55.9	53.7	53.9	51.6	54.3	1.89
Starch	86.1^{cd}	91.5^{c}	71.4^{f}	76.7^{e}	68.2^{f}	82.3^{de}	2.06
Crude protein	49.1^{cd}	50.8^{c}	39.7^{e}	39.6^{e}	43.0^{de}	39.3^{e}	2.18
NDF	39.7^{cd}	40.8^{cd}	49.6^{c}	45.6^{cd}	41.2^{cd}	38.9^{d}	3.40
ADF	36.5^{cd}	39.5^{cd}	44.2^{c}	41.0^{cd}	38.4^{cd}	33.0^{d}	3.56
Hemicellulose	44.1^{cd}	42.8^{d}	55.9^{c}	51.0^{cd}	44.6^{cd}	45.7^{cd}	4.27
Cellulose	47.0^{cd}	51.0^{cd}	58.1^{c}	55.0^{c}	50.3^{cd}	42.8^{d}	3.74
Crude fiber	46.4^{d}	49.2^{cd}	57.1^{c}	49.5^{cd}	52.6^{cd}	44.9^{d}	3.38

^{a,b}Means with different superscripts differ significantly ($P < .10$).

^{c,d,e,f}Means with different superscripts differ significantly ($P < .05$).

APPENDIX TABLE 6. EFFECT OF HARVEST STAGE ON YIELD OF THE SIX SORGHUM HYBRIDS

Hybrid and item	Harvest stage			SE
	Early-dough	Late-dough	Hard-grain	
DeKalb DK-42Y				
Whole-crop DM yield[1]	11.29_{b}	12.01_{a}	11.62_{ab}	.43
Grain DM yield[1]	3.80^{b}	5.17^{a}	4.61^{ab}	.32
Grain:forage	$.513^{a}$	$.761^{a}$	$.652^{ab}$	.07
Northrup-King 2778				
Whole-crop DM yield	10.61_{b}	11.80_{a}	10.90_{a}	.55
Grain DM yield	3.46^{b}	5.44^{a}	4.67^{a}	.32
Grain:forage	$.505^{b}$	$.862^{a}$	$.762^{a}$	.06
TX 2752 x TX 430				
Whole-crop DM yield	11.97_{b}	12.92_{a}	11.66_{a}	.65
Grain DM yield	3.91^{b}	5.78^{a}	5.79^{a}	.23
Grain:forage	$.487^{b}$	$.837^{ab}$	1.053^{a}	.14
Funk's G-522DR				
Whole-crop DM yield	11.77^{b}	13.61^{a}	12.30^{b}	.35
Grain DM yield	3.80^{b}	5.54^{a}	5.55^{a}	.31
Grain:forage	$.487^{b}$	$.710^{ab}$	$.831^{a}$	.08
Asgrow Colt				
Whole-crop DM yield	11.46^{ab}	12.93^{a}	10.45^{b}	.67
Grain DM yield	3.39^{b}	5.50^{a}	4.59^{ab}	.55
Grain:forage	$.414^{b}$	$.753^{a}$	$.785^{a}$	.10
Pioneer 947				
Whole-crop DM yield	13.59	13.36	12.79	.53
Grain DM yield	4.49	4.60	4.91	.39
Grain:forage	.500	.531	.624	.05

[1] Metric tons per hectare.

[ab] Means within a hybrid with different superscripts differ significantly ($P < .05$).

APPENDIX TABLE 7. EFFECT OF HARVEST STAGE ON PRE-ENSILED CROP COMPOSITION OF THE SIX SORGHUM HYBRIDS

Hybrid and item	Harvest stage			SE
	Early-dough	Late-dough	Hard-grain	
DeKalb DK-42Y				
Dry matter, %	32.2^{a}	41.9^{b}	50.9^{c}	.01
	% of the crop DM			
Crude protein	10.9^{a}	10.5^{ab}	10.0^{b}	.20
NDF	55.5	47.4	49.0	3.19
ADF	27.8^{b}	23.8^{a}	25.0^{ab}	.98
Hemicellulose	27.7	23.6	24.0	2.69
Cellulose	19.9^{b}	15.9^{a}	17.6^{ab}	.75
Lignin	4.4^{b}	3.5^{a}	4.9^{b}	.23
Northrup-King 2778				
Dry matter, %	31.4^{a}	41.5^{b}	49.9^{c}	
	% of the crop DM			
Crude protein	10.6^{a}	10.5^{ab}	9.4^{b}	.34
NDF	58.3	52.7	54.5	2.03
ADF	28.4^{b}	24.0^{a}	27.5^{b}	.81
Hemicellulose	29.8	28.8	27.0	2.03
Cellulose	21.4^{b}	17.0^{a}	19.2^{a}	.62
Lignin	4.4	4.3	5.1	.26
TX 2752 x TX 430				
Dry matter, %	35.1^{a}	42.9^{b}	53.1^{c}	.01
	% of the crop DM			
Crude protein	10.8^{a}	10.5^{a}	9.3^{b}	.23
NDF	58.9^{b}	50.5^{a}	56.4^{ab}	2.20
ADF	7.9	23.9	27.4	1.17
Hemicellulose	31.1	26.5	29.0	1.78
Cellulose	20.3	17.6	19.0	.82
Lignin	4.6^{ab}	3.7^{a}	5.1^{b}	.37

APPENDIX TABLE 7 (CONT.)

Hybrid and item	Harvest stage			SE
	Early-dough	Late-dough	Hard-grain	
Funk's G-522 DR				
Dry matter, %	34.2^{a}	43.8^{b}	55.1^{c}	.01
	% of the crop DM			
Crude protein	10.5	10.3	9.4	.34
NDF	55.3^{b}	46.6^{a}	52.7^{ab}	1.98
ADF	27.9	24.6	27.3	1.67
Hemicellulose	27.4^{b}	21.6^{a}	25.4^{ab}	1.32
Cellulose	20.5	17.5	19.1	1.09
Lignin	4.2	4.4	5.4	.75
Asgrow Colt				
Dry matter, %	31.4^{a}	39.2^{b}	47.6^{c}	.01
	% of the crop DM			
Crude protein	10.0	10.1	9.8	.28
NDF	51.7	49.3	51.3	2.01
ADF	27.3	26.5	25.1	1.37
Hemicellulose	24.4	22.8	26.3	1.16
Cellulose	19.8	18.8	18.5	1.05
Lignin	4.2	4.3	4.6	.22
Pioneer 947				
Dry matter, %	39.1^{a}	45.2^{b}	45.5^{c}	.01
	% of the crop DM			
Crude protein	9.4^{a}	8.8^{ab}	8.4^{b}	.19
NDF	53.1	52.0	53.9	1.56
ADF	28.7^{a}	29.2^{a}	31.6^{b}	.64
Hemicellulose	24.5	22.8	22.2	1.06
Cellulose	20.8	21.3	22.4	.56
Lignin	5.0^{a}	5.2^{a}	6.7^{b}	.30

[abc] Means within a hybrid with different superscripts differ significantly ($P<.05$).

APPENDIX TABLE 8. EFFECT OF HARVEST STAGE ON SILAGE COMPOSITION OF THE SIX SORGHUM HYBRIDS

Hybrid and item	Harvest stage			SE
	Early-dough	Late-dough	Hard-grain	
DeKalb DK-42Y				
Dry matter, %	32.1^{a}	40.2^{b}	50.2^{c}	.88
	% of the silage DM			
Crude protein	11.2^{a}	10.0^{b}	9.5^{b}	.16
NDF	48.7	46.6	49.1	2.10
ADF	27.8^{b}	26.5^{ab}	25.0^{a}	.78
Hemicellulose	21.0	20.1	24.2	1.40
Cellulose	19.6^{b}	18.9^{b}	16.8^{a}	.53
Lignin	4.6	4.5	5.1	.36
Northrup-King 2778				
Dry matter, %	30.5^{a}	39.2^{b}	50.0^{c}	.47
	% of the silage DM			
Crude protein	10.4	9.9	10.2	.31
NDF	49.6	47.5	47.7	1.88
ADF	28.9^{b}	25.0^{a}	24.0^{a}	.80
Hemicellulose	20.8	22.5	23.6	1.69
Cellulose	21.1^{b}	18.0^{a}	17.1^{a}	.63
Lignin	4.4	4.1	4.3	.16
TX 2752 x TX 430				
Dry matter, %	34.0^{a}	41.5^{b}	52.7^{c}	.68
	% of the silage DM			
Crude protein	10.4	9.4	9.5	.28
NDF	47.9	47.8	49.4	.98
ADF	25.4	26.1	25.3	1.39
Hemicellulose	20.4^{a}	21.7^{ab}	24.1^{b}	.76
Cellulose	19.9^{b}	18.9^{ab}	18.1^{a}	.48
Lignin	4.4	4.2	4.6	.21

APPENDIX TABLE 8 (CONT.)

Hybrid and item	Harvest stage: Early-dough	Late-dough	Hard-grain	SE
Funk's G-522 DR				
Dry matter, %	33.4^{a}	42.3^{b}	52.8^{c}	.71
	— % of the silage DM —			
Crude protein	10.6^{a}	9.6^{b}	9.4^{b}	.17
NDF	49.0	48.0	48.4	2.39
ADF	28.6	26.7	25.7	1.04
Hemicellulose	20.4	21.3	22.6	1.72
Cellulose	20.6	19.2	18.3	.74
Lignin	4.5	5.2	4.6	.47
Asgrow Colt				
Dry matter, %	30.8^{a}	37.1^{b}	46.8^{c}	.80
	— % of the silage DM —			
Crude protein	9.9^{a}	9.6^{a}	8.7^{b}	.24
NDF	48.7^{ab}	45.7^{a}	51.8^{b}	1.15
ADF	28.5^{b}	26.5^{a}	27.7^{ab}	.50
Hemicellulose	20.2^{a}	19.3^{a}	24.2^{b}	1.08
Cellulose	21.2^{b}	18.9^{a}	19.5^{a}	.43
Lignin	4.1	4.2	4.6	.18
Pioneer 947				
Dry matter, %	37.4^{a}	43.6^{b}	44.8^{c}	1.06
	— % of the silage DM —			
Crude protein	8.2	8.1	7.9	.18
NDF	55.5	52.1	54.1	1.09
ADF	31.9	31.1	32.6	.81
Hemicellulose	23.5^{b}	20.9^{a}	21.5^{a}	.38
Cellulose	22.8	22.5	23.3	.87
Lignin	5.7	6.1	6.0	.21

APPENDIX TABLE 9. EFFECT OF HARVEST STAGE ON SILAGE FERMENTATION CHARACTERISTICS OF THE SIX SORGHUM HYBRIDS

Hybrid and item	Harvest Stage			SE
	Early-dough	Late-dough	Hard-grain	
DeKalb DK-42Y	% of the silage DM			
Lactic acid	5.04^{a}	3.89^{b}	3.81^{b}	.19
Acetic acid	2.01^{a}	1.60^{b}	1.51^{b}	.11
Propionic acid	.00^{a}	.00^{a}	<.01^{b}	.001
Butyric acid	.00	.08	<.01	.05
Total acids	7.05^{a}	5.57^{b}	5.33^{b}	.29
pH	4.12^{a}	4.36^{b}	4.54^{c}	.02
Lactic:acetic	2.49	2.42	2.53	.09
Ammonia-N^{1}	8.13^{a}	6.68^{b}	6.24^{b}	.002
Northrup-King 2778	% of the silage DM			
Lactic acid	5.31^{a}	2.75^{b}	3.58^{ab}	.66
Acetic acid	2.75	1.68	1.42	.44
Propionic acid	.00	.06	.01	.03
Butyric acid	.05	.79	.40	.44
Total acids	8.11^{a}	5.28^{b}	5.41^{b}	.71
pH	4.09^{a}	4.44^{b}	4.68^{b}	.07
Lactic:acetic	2.14	1.53	2.50	.40
Ammonia-N^{1}	9.25^{a}	7.88^{ab}	6.20^{b}	.01

APPENDIX TABLE 9 (CONT.)

Hybrid and item	Harvest stage: Early-dough	Late-dough	Hard-grain	SE
TX 2752 x TX 430	% of the silage DM			
Lactic acid	5.91^{a}	4.41^{a}	1.95^{b}	.53
Acetic acid	2.04^{a}	1.78^{a}	1.00^{b}	.20
Propionic acid	$.00^{a}$	$.00^{a}$	$.05^{b}$	.01
Butyric acid	$.08^{a}$	$<.01^{a}$	1.39^{b}	.31
Total acids	8.04^{a}	6.19^{b}	4.42^{c}	.51
pH	4.08^{a}	4.29^{a}	5.06^{b}	.09
Lactic:acetic	3.03^{a}	2.50^{ab}	1.87^{b}	.22
Ammonia-N[1]	8.82	7.22	7.22	.01
Funk's G-522DR	% of the silage DM			
Lactic acid	5.47^{a}	3.93^{b}	2.02^{c}	.33
Acetic acid	2.06^{a}	1.37^{b}	1.11^{b}	.10
Propionic acid	$.00^{a}$	$<.01^{ab}$	$.03^{b}$	.01
Butyric acid	$.03^{a}$	$.22^{ab}$	1.16^{b}	.32
Total acids	7.56^{a}	5.53^{b}	4.35^{c}	.22
pH	4.12^{a}	4.40^{b}	4.97^{c}	.08
Lactic:acetic	2.68^{ab}	3.14^{a}	1.77^{b}	.42
Ammonia-N[1]	8.88^{a}	6.46^{b}	7.66^{b}	.003

APPENDIX TABLE 9 (CONT.)

Hybrid and item	Early-dough	Late-dough	Hard-grain	SE
	Harvest stage			
Asgrow Colt		% of the silage DM		
Lactic acid	6.89[a]	4.85[b]	3.23[c]	.40
Acetic acid	2.23	1.87	1.54	.23
Propionic acid	.00	.00	.00	.00
Butyric acid	.16[b]	.05[ab]	.01[a]	.04
Total acids	9.28[a]	6.76[b]	4.78[c]	.55
pH	3.99[a]	4.23[b]	4.64[c]	.05
Lactic:acetic	3.26[a]	2.61[ab]	2.13[b]	.32
Ammonia-N[1]	8.64	6.37	7.16	.01
Pioneer 947		% of the silage DM		
Lactic acid	5.06[a]	3.00[b]	3.72[ab]	.41
Acetic acid	1.78	1.49	2.36	.36
Propionic acid	.01	.00	<.01	.003
Butyric acid	.08	<.01	.02	.04
Total acids	6.93[a]	4.50[b]	5.61[ab]	.60
pH	4.26[a]	4.60[b]	4.21[a]	.03
Lactic:acetic	2.84[a]	2.01[ab]	1.55[b]	.25
Ammonia-N[1]	5.68	5.62	5.70	.004

[1]Expressed as a % of the total N.

[abc]Means within a hybrid with different superscripts differ significantly (P<.05).

APPENDIX TABLE 10. ESTIMATED BEEF PRODUCTION PER HECTARE

Item	Harvest stage		
	Early-dough	Late-dough	Hard-grain
Whole-crop DM yield, kg/ha[1]	11420	12650	11390
DM recovery from the silo, %[2]	87.0	92.2	94.1
Silage DM yield, kg/ha	9935.4	11663.3	10718.0
Feed/gain[3]	7.68	7.82	8.61
Kg of beef gain/ha	1293.7	1491.5	1244.8

[1]Avg yield of the five grain sorghum hybrids from table 2.

[2]DM recovery of DK-42Y in Exp. 2.

[3]Avg of heifers and steers in Exp. 2.

YIELD, COMPOSITION, AND NUTRITIVE VALUE OF GRAIN SORGHUM HARVESTED AS SILAGE: STAGE OF MATURITY AND PROCESSING EFFECTS

by

RUSSELL LEON SMITH

B. S., Kansas State University, 1983

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Abstract

Two experiments were conducted to determine the effects of processing (rolling) and stage of maturity at harvest on the nutritive value of grain sorghum silage for growing cattle. A third experiment was conducted to study the effect of stage of maturity at harvest on yield and composition of six sorghum hybrids. In Exp. 1 and 2, harvests were made at the late-dough and hard-grain stages in each of 2 years, with an early-dough harvest added the second year. Each whole-crop silage was fed without further processing and after processing in growth and digestion trials. Dry matter (DM) content and DM recovery from the silos increased and silage crude protein (CP) content decrease with advancing maturity. Processing the silages increased cattle gains and feed efficiencies in both experiments. In Exp. 1, digsestibilities of DM, starch, and CP were significantly improved when the silages were processed. Only starch digestibility was affected (increased) by processing in Exp. 2. Silage DM intake tended to increase; however, feed efficiencies tended to decrease with advancing maturity in both experiments. Neither avg daily gains nor DM digestibilities were affected by stage of maturity at harvest. Starch and CP digestibilities were significantly higher for the late-dough silage in Exp. 1 and highest ($P<.05$) for the early-dough silage in Exp. 2. In the third experiment, five grain sorghum hybrids and one forage sorghum hybrid were each harvested at the early-dough, late-dough, and hard-grain stage of maturity. Chopped material from each plot was collected and ensiled in laboratory silos. The highest whole-crop DM and grain yields for the grain sorghums occurred at the late-dough stage. Whole-crop DM yield for the forage sorghum decreased and grain yield increased as maturity advanced. Grain to forage ratios increased with maturity for both sorghum types. Grain sorghum silages increased in DM content and decreased in CP content as maturity

advanced. The forage sorghum showed only a slight change in DM content and no change in CP content with advancing maturity. Less extensive fermentations occurred in the drier, more mature silages.

The ability of grain sorghums to produce high whole-crop DM yields and to support rates of gain for growing cattle exceeding 1.0 kg per day make it a promising silage crop for the High Plains region.