YIELD, COMPOSITION, AND NUTRITIVE VALUE OF FORAGE SORGHUM SILAGES: HYBRID AND STAGE OF MATURITY EFFECTS

by

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Introduction

Forage sorghums are important crops in the High Plains Region of the United States. In Kansas, 77,000 hectares of sorghums yielded nearly two million metric tons of forage in 1984. While corn is the most commonly used silage crop in the U.S., sorghum silage production has increased as a result of both increased plantings and increased yields. Sorghums offer silage dry matter (DM) yield potential similar to corn, more drought resistance, lower production costs, and greater latitude of soil fertility (Johnson et al., 1971).

Only limited information is available concerning the effect of stage of maturity at harvest on crop composition and digestibility of improved sorghum hybrids. Variations due to maturity (early to late season), plant height, grain and forage yields, DM content, and crop composition among sorghum hybrids create numerous harvesting and nutritive value combinations.

As maturity advances, digestibility of sorghum silages generally decreases but dry matter intake increases. Fox et al. (1970) and Black et al. (1980) reported decreased digestibility of DM, protein, cellulose, hemicellulose, and lignin as sorghum hybrids matured. However, other research suggests that the effects of maturity on chemical composition and apparent digestibility may not be similar among all forage sorghums (Owens and Webster, 1963; and Cummins, 1981).

The objectives of these experiments were to investigate the effect of stage of maturity at harvest on the yield and chemical composition of forage sorghum hybrids and the nutritive value of the silages made from them.

Chapter 1

REVIEW OF LITERATURE

The Origin of Silage

The practice of silage-making has been traced to 1500 B. C. This method of feed preservation enabled ancient communities to store grain as a reserve for future use, when bad weather reduced yields or when maurauding armies threatened (Woolford, 1984). The word silo is derived from the Greek word siros (a pit for holding grain). From this root word the term silage is used to describe the material held within.

The first modern reference of conserving fresh forage as silage was in the 1780's in Italy, when the conservation of green leaves in wooden casks was noted by John Symonds. The practice of ensiling fresh forage, however, was not introduced into the United States until the late nineteenth century. Since that time, silage has become a major source of stored protein and energy for beef and dairy cattle (McCullough, 1977).

The Silage Fermentation Process

Silage is the product formed when grass or other plant material of sufficiently high moisture content, which is liable to spoilage by aerobic microorganisms, is stored anaerobically (Woolford, 1984). The main objective of silage fermentation is to preserve the crop with a minimum loss of nutrients and obtain a feed of high nutritive value for the animal. In simple terms, the ensiling process can be explained by saying that "carbohydrates are converted to organic acids which lower the pH to approximately 4.0 and preserve the ensiled material". To accomplish this, McCullough (1977) listed two essential items: 1) achieving and maintaining anaerobic conditions and thereby inhibiting the wasteful activities of aerobic microorganisms and oxidative enzymes and 2) inhibiting protein destruction by clostridia under anaerobic conditions.

Many factors contribute to the type, extent, and eventual success of each silage fermentation. McDonald and Edwards (1976) listed five primary factors which control the process: 1) moisture content, 2) buffer capacity, 3) availability of water soluble carbohydrates (WSC), 4) type of bacteria that predominate, and 5) speed of the fermentation. McCullough (1977) stated that an ideal fermentation should occur when a forage is ensiled with a DM content of 28 to 34%, a WSC content of 6 to 8% of the DM, minimum buffering capacity (not more than 450 milliequivalents per kg of DM), and a temperature and degree of compaction suitable for an immediate bacterial explosion. Within these limits, most of the available carbohydrates will be converted to lactic acid.

Silage-making is a dynamic process and not any two silages are expected to be exactly alike. Two fermentation pathways are predominant: 1) homolactic and 2) heterolactic. When silages undergo a homolactic fermentation, theoretically, no DM is lost and 99.3% of the energy in the pre-ensiled material is conserved. When a heterolactic fermentation occurs, DM loss can be as high as 24% of the original DM, although energy recovery is quite high (98.3%). The ability of these two lactic fermentations to conserve nutrients explains the desirability of rapid lactic acid production as the primary means of silage preservation (McCullough, 1977).

High energy losses can occur in silage fermentation, particularly if the pH decline is too slow or if total acid production is too low to inhibit clostridial organisms. These bacteria are classified as being either sarccorolytic (sugar reducing) or proteolytic (protein reducing). In addition to excessive energy and DM losses (up to 51%), proteolysis can also effect the protein quality of the silage. Free amino acids, ammonia, and carbon dioxide increase the buffering capacity of the crop, consequently, higher levels of fermentable carbohydrates are then needed to reduce the pH. In silages that have undergone a clostridial fermentation, high levels of butyric acid will likely be present.

The ensiling process consists of five stages. While some principles of silage fermentation may not yet be fully understood, the actual process of fermentation is well documented.

Stage I. Immediately after chopping or swathing, the plant is still alive and respiring. Once the material is compacted in the silo and a proper seal is in place, only a short time is needed to consume the entrapped oxygen (Sprague, 1974). Through the activity of plant respiratory enzymes and aerobic bacteria, the oxygen and available carbohydrates are converted to carbon dioxide and heat. The desirable temperature of the silage after respiration stops is 27 to 37° C, however if oxygen is not adequately excluded, temperatures in excess of 40° C can result. At temperatures above this, protein may be damaged resulting in a dark brown "carmalized" silage.

Stage II. The production of acetic acid, by facultative anaerobes, consume the remaining trapped oxygen present in the ensiled mass. This process takes place only hours after filling, but can last for 12 to 24 hours. During this time, the pH is dropping to a point that will allow a more favorable environment for the lactic acid bacteria.

Stage III. At this time, lactic acid bacteria predominate within the ensiled material. Although lactic acid producing bacteria may not be present in great numbers on the growing plant, conditions allow for a rapid increase in their population and readily available carbohydrates are converted to predominantly lactic acid.

Stage IV. At this time, the pH is approaching 4.0 and lactic acid bacteria activity is slowing down. Because of the reduction in microbial activity, the temperature also gradually declines.

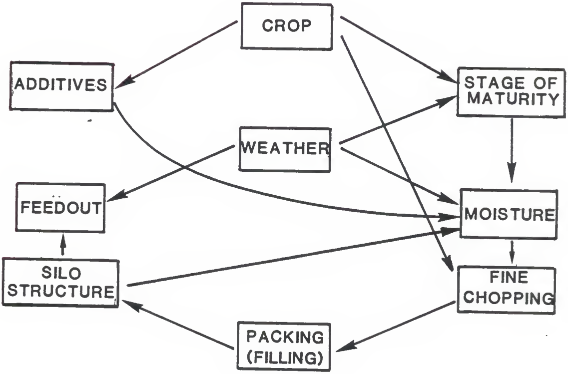
Stage V. The pH is now low enough (3.8 to 4.2) to inhibit further enzyme or microbial action and the silage should be in a static state. However, if during stage III (anaerobic initiation) the pH decline was not adequate and the moisture content was too high, a clostridial fermentation can occur and result in poor quality silage.

After the ensiling process, chemical analyses are often used to characterize the fermentation and evaluate the quality of silages. A good silage should have the following characteristics: a pH value of near 4.0, a lactic acid content of 4 to 8% of the DM, a butyric acid content of less than .1% of the DM, an ammonia-nitrogen content of 5 to 10% of the total nitrogen, and an ensiling temperature that did not exceed 38° C (McCullough, 1977).

Bolsen and Hinds (1984) reported that there are at least nine factors which affect silage quality (figure 1). They state that rather than acting independently, these factors interact and cause silages to be quite unpredictable with regard to repeatable characteristics and nutritrive values. To combat this variability, attention to detail and sound management techniques are essential to consistently produce good quality silages.

The effect of original crop DM content on silage fermentation is of particular importance for forage sorghums. With the large number of cultivars available and their varying season length, DM content at each maturity among cultivars is not constant. Short season cultivars mature more rapidily and through

Figure 1. Nine factors which affect silage quality.



maturation, decrease in moisture content. Conversely, long season forage sorghums generally do not increase in DM content soon enough to avoid the ensiling of extremely wet material.

The primary disadvantages of ensiling forage sorghums at high moisture levels (> 75%) are high conservation losses and reduced animal performance (McDonald, 1981). The critical pH value below which clostridial growth is inhibited varies directly with the moisture content of the crop and, unless WSC levels are exceptionally high, the ensiling of wet forage sorghums can encourage a clostridial fermentation. If this happens, high nutrient losses and a nutritionally inferior silage will result. To compound this loss of nutrients, animal performance is also affected through reduced intake of low DM silages (McDonald, 1981). The effluent from low DM forage sorghums not only carries with it high amounts of soluble nutrients, but it is an environmental pollutant, due to its very high biological oxygen demand. Drier crops are also preferred because they are easier to handle and a higher quantity of crop DM can be transported per trailer load.

There are three principle methods of increasing forage DM content: field wilting, applying desiccants, or allowing the plant to mature. Since virtually all forage sorghums are grown in rows and direct-cut, the option of increasing plant maturity is the only realistic choice.

Silage as a Method of Crop Conservation

There are several advantages inherent to silage as a method of crop conservaton. First, a reduction of weather damage at harvest. As crop DM increases, field losses increase (Zimmer, 1977). Direct-cut harvesting ensures minimum field loss. Second, silage systems allow for total mechanization which will reduce labor inputs. Third, silage permits harvesting maximum nutrients per land unit. Buice et al. (1981) noted that whole-plant grain sorghum harvested and fed as silage produced about one-third more cattle gain per hectare than harvesting and feeding only the grain portion. Fourth, silage enables a producer to multiple crop and, thereby, more effectively use land and capital investments. Finally, silage offers the potential of providing uniform quality forage throughout the year.

Silage, as a method of feed conservation, is not without disadvantages. The practice of silage-making can lead to high losses of nutrients. However, the unavoidable minimum loss from fermentation and its related processes are low (table 1). Unfortunately, the amount of losses through improper techniques can reach 40% or more of the pre-ensiled material. Zimmer (1980) reported that under poor management, losses of DM and gross energy can reach 50 and 30%, respectively, before the silages are consumed by livestock. Because it contains much more water than hay and it spoils when exposed to air, silage is difficult to move as a saleable feedstuff in normal market channels.

Table 1. Factors responsible for losses in silages.

Process	Classified as	Aprox. losses (%)	Causing factors
Residual respiration	Unavoidable	1 - 2	Plant enzymes
Fermentation	Unavoidable	2 - 4	Micro-organisms
Effluent or	Mutual	5 - >7	DM content
		or	
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 (heating)	Avoidable	0 - >15	As above, DM content silage, unloading technique, season
	Total	7 - >40	

Sorghum Morphology

The following is a categorization of the growth stages of the sorghum plant as described by Vanderlip (1979).

Stage 0. Emergence is defined as when the coleoptile breaks through the soil surface. This usually takes place in 3 to 10 days post-planting. This time period may be altered by either soil temperature, moisture, or their interaction. There is no variation among varieties in producing viable seed, but differences can occur in seed development or subsequent handling (Wilson and Eastin, 1982). The sorghum seed reaches maximum germination ability before physiological maturity and follows the usual pattern of decreasing germination ability over time, with increased temperatures, and with high moisture levels. Sorghum seeds can tolerate low moisture levels, but rapid water uptake will lead to reduced stands. This problem can be lessened by a moisture treatment prior to planting to gradually increase the moisture content of the seed.

Germination (and emergence) are affected not only by the characteristics of the seeds but also by the soil environment in which they are sown (Wilson and Eastin, 1982). Past research has mostly pertained to growth in high latitudes. Interest has been in behavior due to a shorter growing season and lower temperatures. Studies dealing with upper temperature limitation have not been as thorough, possibly because of the origin of the sorghum plant. Past studies suggest that shoot elongation was greater at higher temperatures.

Soil moisture associations with germination are much more complex due to the seed-soil moisture relationship involving the dynamic properties of the soil, ie., potential water in the soil, ground water conductivity, and physical contact of the seed with the soil. The variation of soil type within a given field make this area of research difficult.

Stage 1. At this stage of growth, the growing point of the plant is still below ground level and plant growth is mainly dependent on temperature. This stage can be identified when the first three leaves can be seen without tearing the plant apart (Vanderlip, 1979). This stage usually takes place approximately 10 days after emergence and is the first step in developing a optimum leaf area index. Leaf area is the basis of growth and yield (Wilson and Eastin, 1982). The stem at this stage is not prominant and does not contribute until after head emergence. Rooting at this time of development is predominately by seminal roots and is controlled by the soil complex and seed bed preparation.

Stage 2. This is the period in plant development that the potential for plant growth is determined. Because the growing point of the plant still remains below the soil surface, excessive leaf loss will not kill the plant, however, regrowth will not be as vigorous as at the three-leaf stage. The plant is most susceptible to competition from outside sources such as weeds, drought or nutrition stress. Such deficiencies will greatly reduce potential yields if not corrected. This stage occurs when there are five leaves visible on the plant and takes place approximately 21 days after emergence. At this time the plant is entering its "grand period of growth" (Vanderlip, 1979). The accumulation of DM is relatively linear from this point through plant maturity. While leaf expansion is genetically influenced, sorghums are also strongly dependent on temperature. Stem elongation is not prominant in this stage.

Stage 3. At this time, the plant is changing from vegetative growth (leaf producing) to reproduction (head producing). This stage usually occurs about 30 days after emergence. Total leaf number has already been determined, however, only approximately one-third of the total number of leaves is present at this time. Following this growth point differentation, rapid leaf and culm elongation occur. Adequate water and nutrients are essential to attain maximum growth. This period is approximately the first one-third of the plants growth cycle (maximum DM deposition). Weed control from this point on is maintained due to this rapid stage of growth, high levels of nutrient uptake, and decreasing soil surface sunlight.

Stage 4. This period is classified by the presence of the final leaf commonly called the "flag leaf". It is visible at the uppermost point of the whorl. At this time, head development and nutrient uptake are continuing at a rapid pace. Optimum leaf area index is approaching maximum interception at this stage to supply the plant with a canopy capable of intercepting 95% of the available sunlight for this period of rapid growth.

Stage 5. This stage is evident when the head is enclosed in the flag leaf sheath and is called the boot stage. By pressure from the peduncle, the head will be exposed, however potential head size and seed number have previously been determined. Dry matter deposition is now increasing in the head at a linear rate. While vegatative plant growth is now almost complete, severe stress from drought or herbicides may result in insufficient exposure of the peduncle from the flag leaf to allow adequate pollination. Hulquist (1979) indicated that seed production was influenced mostly by water stress at this stage of peduncle and panicle rachis elongation.

Stage 6. Following the boot stage, the elongation of the peduncle allows the pollination process to begin. This stage of growth is known as half-bloom. The sorghum plant blooms from the top of the peduncle downward. Individual plants are at half-bloom when half of the heads are flowering. The blooming process usually takes between 4 to 9 days. Dry matter accumulation is now only half complete. In the remaining one-third of the plant's growing season, the remaining DM must be deposited to reach maximum DM accumulation. A linear DM accumulation was noted by Dickinson (1976) in the first 2 to 3 days prior to blooming. Compared to corn, that is 8 to 9 days later. High temperatures will influence subsequent grain production and is most critical 6 to 9 days after flowering. This depositing of DM continues until approximately 2 days before the black layer (physiological grain maturity) (Wilson and Eastin, 1982). After the end of anthesis, the sorghum caryopsis will attain its maximum volume and is commonly referred to as the milk stage. This stage varies from 8 to 18 days (Newton et al., 1983). At the onset of the milk stage, the sorghum endosperm will have completely replaced the nucleus.

Stage 7. This period is noted by the accumulation of approximately 50% of the grain DM and is known as the soft-dough stage (Vanderlip, 1979). This stage can be noted by crushing the sorghum berry and observing a pastey material with only small traces of milk present. This period usually takes about 15 days after the milk stage. Total DM yield is determined by the rate and length of time available for deposition. Therefore, a later maturing variety will yield more than an early season hybrid if frost, high temperatures or water stress during flowering do not occur.

Stage 8. Immediately following soft-dough, the grain head accumulates an additional 25% of its final dry weight. At this time, the kernel is still readily broken but its appearance is somewhat chalky with no visible signs of milk. Nutrient uptake is now virtually complete and leaf loss may be evident (Vanderlip, 1979). During this time, extremely low temperatures will result in lighter test weights.

Stage 9. At this time, maximum grain dry weight has occurred and it is the last stage of maturity of the sorghum plant. This period is noted by the accumulation of a black layer on the side opposite the embryo, and the plant is considered physiological mature (Vanderlip, 1979). It has been speculated that defering the expansion of the embryo will possibly increase grain size by delaying the means of closing off the phloem parenchyma by mucilage and pectin accumulation (Giles et al., 1975). During this period, grain moisture ranges from 25 to 35 percent. Because the sorghum plant is a perennial, the possibility of further growth by shoots at the leaf nodes is possible if temperature and moisture are adequate. Maximum forage yield is highest at this stage. However, if the moisture content is too high to properly ensile, delaying the harvesting will result in leaf loss and reduced yields. A combination of physiological maturity and optimum DM content will produce the highest yields.

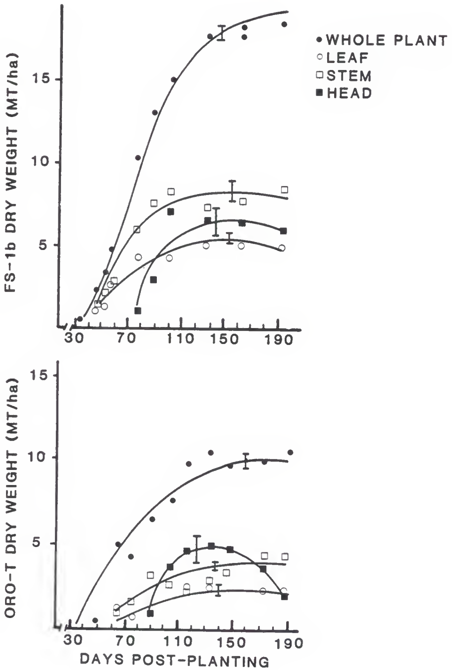
Yield of Forage Sorghum Silages

The ability of the sorghum plant to accumulate DM over a long period of time was documented by Webster (1963) who monitored weekly DM yields of Rox Orange and Atlas forage sorghums. During a 7 week period following first-bloom, the accumulated yield increases were 27, 41, 59, 72, 76, 97, and 104% of that of the first-bloom yield. In a similar study, Marshall et al.(1966) harvested NK 310 grain sorghum at two stages of maturity, milk-to-dough stage (early, 23% DM) and hard-seed (late, 42% DM), and reported a 30% increase in DM yield for hard-seed.These data indicate that maximum DM yields are obtained by delaying the harvest of sorghums until physiological maturity.

As the sorghum plant develops and DM yield increases, the proportion of heads, blades, and sheaths decrease (Thurman, 1960). Schake et al., (1982) studied the contribution of leaves, stems, and heads to total sorghum plant DM and crude protein when harvested at 10 stages of maturity. Although their results suggests that the two cultivars (ORO-T, a tall grain sorghum and FS-1b, an medium season forage sorghum) followed similar trends in accumulating DM the contribution made by the head was more pronounced in grain sorghum, and the contribution by the stems was more pronounced in forage sorghum (figure 2). The stems contained the lowest amount of total plant crude protein in both the grain and forage sorghum and, consequently, stem growth was responsible for the reduction in total protein as the cultivars matured.

Although sorghums continue to deposit DM over time, there is a tendency for varieties to be unstable among years. For a specie to be stable, it must be adaptable to a wide range of growing conditions, produce above average yields, and have a below average variance across all environments. Because sorghums differ dramatically in grain production and maturity, many cultivars produce

Figure 2. Dry matter deposition of two sorghum cultivars with advancing maturities.



satisfactorily in a given year, but prove unstable on the average across several years.

Shown in table 2 are silage and grain yields, DM content, and plant height for nine forage sorghum hybrids or cultivars which were grown at four Kansas locations (Walter, 1984). Within location, all hybrids and cultivars were planted on the same day and harvested when the latest maturing entry reached the soft-dough stage. All four measurements were affected by location and management practice. Because harvests were not made at the same stage of maturity, direct comparisons between hybrids or cultivars are not possible. Early and medium season forage sorghums were allowed to increase in DM content and reach maximum yield potential. The occurence of freezing weather during anthesis, or shortly thereafter, halted grain development in several of the forage sorghums. This can be a major disadvantage, particulary when the planting of late season cultivars is delayed.

Shown in table 3 are the average results for eight hybrids or cultivars which were grown at the Northeastern Kansas Agricultural Experiment Station from 1981 to 1984 (Walter, 1984). Four-year averages showed that silage yields ranged from 33 to 60 metric tons per ha for Rox Orange and T-E Silomaker, respectively. Grain yield measured within hybrids or cultivars ranged from low to high, plant height from 203 to 274 cm, and days to half bloom from 58 to 85 days. These data illustrate the wide range of yields and agronomic chacteristics which are possible when forage sorghums are grown under similar environments.

Saied and Francis (1983) studied genotype stability for early, medium, and late maturing cultivars of grain sorghum. Genotypes were classified by the mean number of days from planting to physiological maturity. Average days needed to reach maturity were: 107, 117, and 127 for the early, medium, and late genotypes,

Table 2. Forage sorghum test results for nine cultivars grown at four Kansas locations.[1]

Brand	Hybrid or cultivar	DM, %	Grain yield[2]	Silage yield, tons/ha[3]	Height, cm
Buffalo	Canex	32-39	M-H	25-52	163-210
Conlee	Cow Vittles	30-36	M	27-59	163-231
Funk's	HW 5574 Exp	24-31	O-M	20-79	135-282
Growers	G5A 1586F	25-31	O-M	22-79	140-287
Paymaster	FS 455	28-35	O-H	20-69	117-206
Triumph	Super S1620	27-32	L-M	20-71	137-282
	Early Sumac	31-42	L-M	25-56	160-221
	Atlas	26-35	L-M	22-59	175-249
	Rox Orange	27-36	L-M	25-56	185-249

[1]Location and management practice represented are:
1 - Southwestern, irrigated.
2 - Northcentral, fallowed.
3 - Southeastern, dryland.
4 - Northeastern, dryland.

[2]Grain yields were estimated (0=none; L=low; M=medium; and H=high).

[3]Silage yields adjusted to 30% dry matter.

Table 3. Four-year (1981-1984) average results for eight forage sorghum cultivars grown at the Northeastern Kansas Agricultural Experiment Station.

Brand	Hybrid or cultivar	DM, %	Grain yield[1]	Days to half bloom	Height, cm	Silage yield, tons/ha[2]
Buffalo	Canex	36	M	58	221	47
Conlee	Cow Vittles	29	L	84	274	56
Golden Acres	T-E Silomaker	30	H	71	226	60
Warner	Sweet Bee	33	M	61	246	49
Warner	2-way	32	M	85	239	56
	Early Sumac	33	L	64	221	38
	Rox Orange	35	L	64	203	33
	Atlas	34	M	69	251	42

[1]Grain yields were estimated (0=none; L=low; M=medium; and H=high).

[2]Silage yields adjusted to 30% dry matter.

respectively. The authors concluded that the early and medium cultivars were more stable than late maturing cultivars.

<u>Composition of Forage Sorghums</u>

The influence of stage of maturity on chemical composition of present-day sorghum cultivars is not well defined and previous studies show conflicting results. Although maturity at harvest is a major factor in determining the plant composition, there is evidence of composition differences among hybrids at the same growth stages.

As the sorghum plant develops, a gradual decrease occurs in plant moisture. Although differences in DM yield are observed among sorghum hybrids, similar patterns of DM accumulation can be seen over the range of maturities. When compared with corn, the sorghum plant is often 8 to 10% lower in DM percentage at the stage of maximum DM accumulation (Cummins, 1981).

The effect of maturity on cell components is complex and varies among species of forage plants. The forage constituents affected most by advancing maturity are protein, soluble and structural carbohydrates, and lignin (Danley and Vetter, 1973). The proximate analyses of silages from various forage sorghum cultivars and different stages of maturity at harvest are presented in table 4. Owen (1962), Nordquist and Rumery (1967), and Black et al., (1980) reported increases in DM and decreases in crude protein percentages as maturity advanced. Crude protein appears more variable in the early stages across cultivars than when the plant reaches later maturities. Owen (1962) and Black et al.,(1980) reported increases in nitrogen-free extract with advancing maturity, and this was due largely to the increased formation of starch in the kernel.

Owen and Webster (1963) recorded the changes in crude protein,

Table 4. Proximate analyses of silages from various forage sorghum cultivars and stages of maturity.

Reference	Stage of maturity	% DM	CP	CF	NFE	EE	Ash
			-------- % of the DM -----				
Owen[2] (1962)	milk	21.3	9.3	31.7	46.7	3.7	8.6
	soft-dough	24.0	7.8	26.9	52.6	3.3	8.2
	medium-dough	26.5	7.4	26.3	55.0	3.2	8.1
	mature	28.2	7.5	26.4	55.2	3.2	7.7
Lance et al. (1964)	early-dough	25.4	6.8	23.9	56.7	6.3	6.2
		22.1	9.7	26.0	55.0	2.6	6.7
Nordquist and Rumery[3] (1967)	hard-dough	26.8	7.8	24.9	54.3	2.9	10.1
	hard-dough	25.6	6.7	31.1	48.8	3.3	9.1
	hard-dough	25.8	6.5	26.6	55.0	3.4	8.5
Ward and Smith (1968)	Sterile hard-dough	27.1	7.1	27.8	55.2	2.4	7.5
Bolsen et al. (1973)	dough	32.6	5.2	27.9	—	—	—
Black et al. (1980)	early-bloom	19.8	9.2	32.4	50.6	2.8	5.1
	bloom	23.2	8.3	32.9	52.0	2.1	4.7
	milk	23.7	7.7	32.6	53.0	2.3	4.4
	early-dough	27.4	7.2	26.3	59.2	2.2	5.1
	dough	27.6	7.1	28.5	57.0	2.3	5.1
	mature	32.3	7.4	25.0	60.2	2.7	4.6
McCullough et al. (1981)	early-bloom	18.0	6.7	36.9	50.1	2.2	4.1
	early-bloom	24.0	8.2	31.5	51.9	2.7	5.7

[1]Values of three experiments.
[2]Values of two experiments.
[3]Mean of 3 years.

nitrogen-free extract, and crude fiber of Rox Orange and Atlas forage sorghums from bloom to mature-seed stages. Crude protein and crude fiber decreased 15 and 18 percentage units, respectively, while nitrogen-free extact increased 16 percentage units.

The most common analysis of animal feedstuffs since the middle of nineteenth century has been the proximate analyses. However, it does not adequately determine the crude fiber or nitrogen-free extract portion of forages. Shown in figure 3 is a comparison of the proximate and Van Soest analyses. The ability of the Van Soest analyses to separate hemicellulose and alkali-soluble lignin from the nitrogen-free extract portion of the proximate system produces a better separation of the fiberous components of forages.

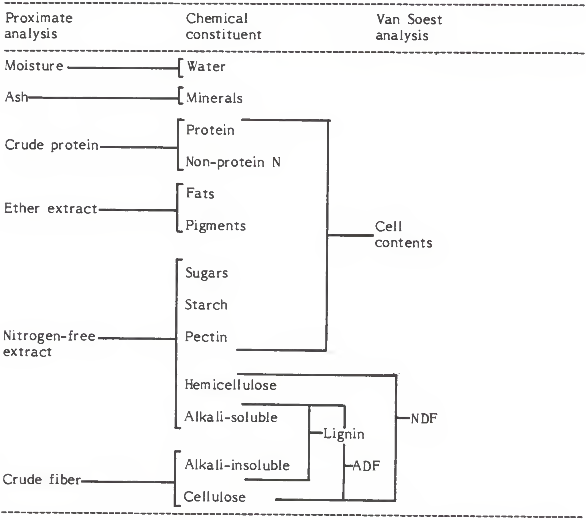
The fibrous portion of the Van Soest analyses consists of both carbohydrates (cellulose and hemicellulose) and noncarbohydrates (lignin). Cellulose, which is the major skeletal carbohydrate in plants, is very insoluble and is digested only by microbial action. Its availability as a nutrient is highly variable and depends upon its association with lignin and other noncarbohydrate constituents.

Hemicellulose digestion is very similar to cellulose, in that it may be covalently linked with lignin. However, if liberated, hemicellulose becomes water soluble and completely digestible.

Lignin is the noncarbohydrate fraction of the plant cell wall. Essentially indigestable, it adds rigidity to the cell wall and protects carbohydrates from biological attack. The lignin in grasses appears to be esters of hemicellulose.

The Van Soest analysis for silages made from forage sorghum cultivars harvested at different stages of maturity are presented in table 5. Conflicting results were obtained by Danley and Vetter (1973) who worked with Pioneer 931

Figure 3. Two systems for estimating chemical constituents of forages.



ADF = Acid detergent fiber.

NDF = Neutral detergent fiber.

Table 5. Van Soest analyses of silages from various forage sorghum cultivars.

			% of DM			
References	Stage of maturity	NDF	Hemi-Cellulose	ADF	Cellulose	Lignin
Danley and Vetter (1973)	70 DPE[1]	57.2	17.2	40.0	33.9	4.0
	100 DPE	64.3	24.1	40.2	32.8	4.1
	130 DPE	59.6	15.6	44.0	37.1	4.6
	160 DPE	73.4	20.3	53.2	44.6	5.7
	190 DPE	70.0	19.1	50.9	41.4	6.2
Black et al. (1980)	early-bloom	72.4	37.1	35.3	29.6	5.8
	bloom	71.5	34.6	36.9	30.2	6.4
	milk	72.8	34.3	38.5	31.1	7.0
	early-dough	65.2	30.8	34.4	28.6	6.5
	dough	66.2	28.8	37.4	30.7	6.5
	mature	64.6	30.2	34.4	27.6	6.5

[1] DPE means days post-emergence (ie. 70 = pre-seed and 190 = post-frost).

(a nonheading cultivar) and Black et. al (1980) who worked with DeKalb FS 24 (a grain producing cultivar). Black reported a decrease of 11% in NDF, as maturity advanced, while Danley and Vetter reported an increase of 22 percent. This was primarily due to the lack of grain and its starch component in the Pioneer 931. The ADF and cellulose content of Pioneer 931 increased with advancing maturity, but maturity did not affect the structural carbohydrate content of DeKalb FS 24.

Digestibility of Forage Sorghum Components

The ultimate feeding value of a silage depends upon the amount of it consumed by livestock, the digestibility of its nutrient components and subsequent animal performance (Bolsen, 1981). Presented in table 6 are digestibilties of the nutrient components of various forage sorghum cultivars harvested at different stages of maturities. In general as maturity advances, the digestibility of sorghum silage decreases, but DM intake increases (Browning and Lusk, 1967; Owen, 1967; Fox et al., 1970; Johnson et al., 1971). Fox et al. (1970) working with steers, reported lower digestibilities of DM, cellulose, and protein in mature stage versus soft-dough stage, bird-resistant grain sorghum silages. Similarly, Black et al. (1980) conducted a lamb digestion trial with DeKalb FS 24 forage sorghum silages made at six stages of maturity. They found that the highest yields of gross and digestible energy (Mcal/ha) were obtained at the late-milk to early-dough stages. Digestibility of all components decreased rapidily at the later two harvests. In contrast, Johnson et. al (1971) reported a slight increase in DM digestibility and a large increase in crude protein digestability (38 to 54.1%) when Pioneer 931 was harvested after frost. Owen and Kuhlman (1967) cited a decrease of 15 and 20% in DM and crude protein digestibilities, respectively, from the milk to the hard-dough stage in Atlas forage sorghum, but virtually no change with advancing maturity in Rox Orange.

Table 6. Digestibilities of the nutrient components of various forage sorghum cultivars harvested at different stages of maturity.

Reference	Cultivar and stage of maturity	--- Digestibility coefficients --- DM	CP	NDF	ADF	Cellulose
Owen and Kuhlman (1967)	Atlas forage sorghum					
	milk	61.4	56.0	—	—	—
	soft-dough	55.8	56.6	ND	ND	ND
	hard-dough	52.1	45.1	ND	ND	ND
	Rox Orange					
	milk	66.6	60.5	ND	ND	ND
	soft-dough	67.1	58.5	ND	ND	ND
	hard-dough	65.8	63.3	ND	ND	ND
Fox et al. (1970)	Bird-resistant grain sorghum					
	soft-dough	57.8	40.9	ND	ND	47.8
	mature	51.0	27.2	ND	ND	39.8
Johnson et al. (1971)	Pioneer 931 forage sorghum					
	milk	59.4	55.7	ND	ND	53.5
	early-dough	60.0	40.9	ND	ND	43.8
	late-dough	58.7	38.0	ND	ND	30.9
	post-frost	64.6	54.1	ND	ND	37.1
Black et al. (1980)	DeKalb FS 24 forage sorghum					
	early-bloom	65.2	52.8	65.9	57.6	64.6
	bloom	57.8	42.6	57.6	51.4	57.6
	milk	56.9	39.8	56.6	49.1	56.6
	early-dough	57.7	34.6	52.1	42.8	52.1
	dough	50.3	15.1	44.9	39.7	44.9
	mature	52.1	14.8	43.2	38.1	43.2

Along with variation in nutrient digestibilities among forage sorghums, variation within cultivars have also been reported. Helm and Leighton (1960) observed a decline in the digestibility of crude fiber, nitrogen-free extract, and protein in Tracy forage sorghum from milk to mature-seed stages. Maximum TDN (65%) was reached at the soft-dough stage. In contrast, studies conducted by Ramsey et al. (1961) with Tracy showed no decline in energy or DM digestibilities at stages ranging from late-flowering to mature-seed.

Because cellulose digestibility adversely affects total plant digestibility, low grain containing cultivars may not be as digestible to the ruminant as high grain cultivars. Anthony et. al. (1961) reported a decrease in cellulose digestibility of 30% (64 to 45%) in Sart sorghum from pre-heading to full-head stage, however no differences were found in sugar or starch digestibilities. In high grain producing sorghums, the presence of the readily digestible starch fraction in the kernel may compensate for the declining digestibility of the structured carbohydrate fraction in the forage as the plant matures.

Phillips et al. (1954) suggested that the decrease in digestibility and subsequent decrease in nutrient value with advancing maturity was due to an increase in fiber and lignin and a decrease in crude protein. However, results of Danley and Vetter (1973) indicated that this was not entirely true, as they reported a decrease in digestibility even though lignin remained relatively constant.

The indigestible portion of the cell wall represented by the cell wall constituents (CWC) should be an indicator of digestibility. When the CWC reaches 60% of the DM, digestibility decreases rapidly (Van Soest and Wine, 1967). This inverse relationship between CWC and in vitro digestible dry matter (IDDM) is exhibited for two sorghum cultivars, Pioneer 931 (Pio 931) and Rudy Patrick (RP

30F) and two corn cultivars, Cargill 1089 (SCN) and Cargill HS-50 (HSCN), (Danley and Vetter, 1973). The intersection of IDDM and CWC occurs at 55 to 60% for all cultivars, but at different maturities (figure 4). The authors suggest that for CWC to be a valid indicator of digestibility, the IDDM-CWC intersection should occur at an early growth stage rather than at late stages, where other components have become more indigestible.

Lignin is also responsible for decreases in digestibility. Shown in figure 5 is the relationship of lignin as a percent of CWC and IDDM. Danley and Vetter (1973) reported that an inverse relationship exists between lignin as a percent of CWC and IDDM (r = - .95) in forage sorghum, however a positive relationship exists for corn (r = .51). The authors suggest that this was possibly due to an increased availability of hemicellulose fraction in corn.

The effects of lignin were also shown to be closely related the lignin-cellulose ratio (Van Soest, 1968). The lignin content of the ADF exhibits a closer relationship of maturity to digestibility (figure 6). This relationship exists for both forage sorghum and corn cultivars (r = - .88 and r = - .51, respectively). A greater decrease in digestibility for forage sorghums compared to corn can be explained, because with advancing maturities, the percent lignin present in the ADF increases, whereas, in corn the amount in immature plants is relatively high and does not change dramatically over time (10 to 12%).

Figure 4. The relationship of in vitro digestible dry matter (IDDM) and cell wall constituents (CWC) of corn and sorghum cultivars with advancing maturity.

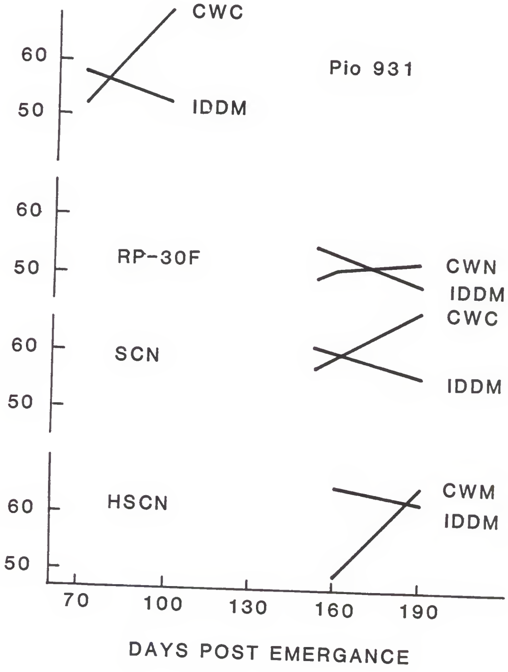


Figure 5. The relationship of lignin expressed as a percent of cell wall constituents (CWC), and in vitro dry matter digestibility (IDDM) in corn and sorghum.

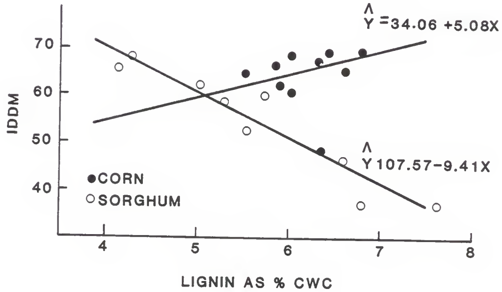
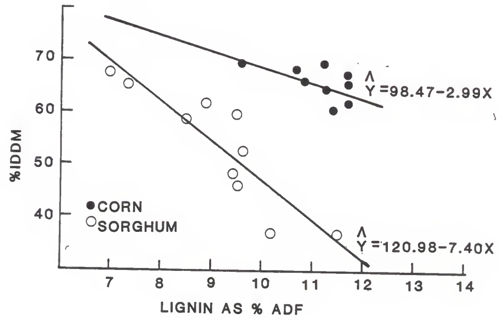


Figure 6. The relationship of lignin expressed as a percent of acid detergent fiber (ADF), and in vitro dry matter digestiblity (IDDM) in corn and sorghum.



Animal Performance from Forage Sorghum Silages

Sorghums are dependable yielding silage crops, especially in areas which receive variable rainfall such as the High Plains. Unlike corn, sorghum can adapt to environmental stress and compensate when conditions improve. Also, sorghums are ideal to incorporate into double cropping systems and they promote maximum yield of forage DM per ha, if harvested as silage after small grain cereals. However, in high silage diets, corn silages are regarded as nutritionally superior to forage sorghums, particularly when fed to growing cattle (table 7).

Brethour (1967) reported 23% more gain from corn silage than forage sorghum silage in wintering steer calves consuming similar amounts of dry matter. Fox et al. (1970) and McCullough et al. (1981) also reported higher gains and better feed efficiencies in steers consuming corn silages. The relative feeding values of forage and grain sorghums and corn were determined by Bolsen and Smith (1984). They fed three whole-crop silages to growing calves: DeKalb FS-25A; a late season, moderate grain producing forage sorghum; Ferry-Morse 81 grain sorghum; and Ferry-Morse 3020 corn. Both the grain sorghum and corn silages had higher grain content than the forage sorghum and increased cattle performance by 30 and 50%, respectively, over the forage sorghum silage. Reduced DM intake was largely responsible for the forage sorghum's lower nutritive value.

When measured as fat corrected milk (FCM) production and milk fat percentage in dairy cows consuming diets containing either corn or forage sorghum silages, the superiority of corn silage has been less pronounced than when measured as rate of gain (table 8). In three separate experiments, Owen et al. (1957) reported significant advantages in FCM production and body weight change

Table 7. Performance of growing cattle consuming forage sorghum or corn silage diets.

Reference	Silage	Average daily gain, kg	DM/kg of gain, kg	Daily DM intake, kg
Brethour (1967)	corn	.98	6.2	6.1
	sorghum	.72	7.8	5.9
Fox et al. (1970)	corn	1.00	5.9	5.9
	sorghum	.73	9.4	6.9
McCullough (1981)	corn	.69	7.1	4.9
	sorghum	.55	9.2	5.0
Bolsen and Smith (1984)	corn	1.22	6.2	6.6
	sorghum	1.03	6.8	7.0
	sorghum	.69	7.7	5.3

Table 8. Performance of dairy cows consuming forage sorghum or corn silage diets.

References	Silage	FCM yield, kg	Milk fat %	Weight change
Owen et al. (1957)	corn	12.2	NR	.18
	sorghum	11.1	NR	-.20
	corn	13.6	NR	.03
	sorghum	12.2	NR	-.27
	sorghum	12.4	NR	-.15
	corn	12.4	NR	.29
	sorghum	11.4	NR	-.07
	sorghum	10.7	NR	-.36
Lance et al. (1964)	corn	18.6	NR	.06
	corn	15.1	NR	.33
	sorghum	17.3	NR	.35
	sorghum	12.3	NR	.18
Nordquist and Rumery[1] (1967)	corn	20.3	3.5	.26
	sorghum	21.2	3.9	.22
	sorghum	19.2	3.9	-.13
	sorghum	21.3	3.9	.13
Browning and Lusk (1967)	corn	16.1	4.6	.01
	sorghum	15.1	4.5	.00

[1]Mean of two experiments.

in favor of corn silage over each cultivar of sorghum silage. Lance et al. (1964) also reported higher FCM production from dairy cows consuming corn silage in two separate experiments. However, Nordquist and Rumery (1967) noted that dairy cows were capable of producing equal or higher amounts of milk and milk fat than cows consuming corn silage. These two authors concluded that excellent milk production could be obtained from either corn or forage sorghum silage diets.

The variabilities in silage feeding value among sorghum cultivars are shown in table 9. The range of daily gains (.24 to 1.10 kg) and subsequent feed conversions (6.0 to 14.9 kg of DM/kg of gain) typify the inconsistent results with forage sorghums. When comparisons are made among sorghum cultivars, differences in animal performance and DM intake arise not only from the amount of grain contained in the silage, but also from the stage of maturity and DM content. Smith et al. (1984) compared the feeding value of three sorghum hybrids with varying grain to forage ratios: Funk's G-1990 (a nonheading forage sorghum); Pioneer 947 (a moderate grain producing forage sorghum); and DeKalb E 67 grain sorghum. The authors reported that the nonheading forage sorghum produced the lowest average daily gain and DM intake and the highest feed conversion when fed to growing cattle. Relative feeding values for the Funk's G-1990 and DeKalb E 67 were reported as 65 and 108% of that for Pioneer 947. Brethour (1978) compared the performance of steers fed Pioneer 931 (nonheading) and DeKalb FS4 forage sorghum silages. Results indicated that the nonheading was inferior to the grain containing hybrid when fed to steers. However, inconsistencies were apparent, since Brethour (1977) reported much narrower differences between Pioneer 931 and DeKalb FS4 (table 9).

Brethour (1966) simulated varying levels of grain to forage ratios by adding rolled sorghum grain with and without water to nonheading forage sorghum. The

Table 9. Performance of beef cattle fed silage-based diets containing various forage sorghum cultivars.

Reference	Stage of maturity	Average daily gain, kg	DM/kg of gain, kg	Daily DM intake, kg
Boren et al. (1962)	milk	.24	14.9	3.6
	hard-dough	.73	6.9	5.1
	sterile	.54	7.7	4.1
Boren et al. (1965)	hard-dough	.60	7.8	4.7
Smith et al. (1966)	sterile	.73	6.0	4.5
Brethour (1966)	sterile	.64	8.7	8.3
Brethour (1971)	dough	.95	8.7	8.3
Bolsen et al. (1973)		.83	8.0	6.6
Bolsen et al. (1977)		.80	7.7	6.2
Brethour (1977)	dough	.95	7.9	7.5
	sterile	.88	7.3	6.7
Brethour (1978)	dough	.70	11.3	7.9
	nonheading	.40	15.2	6.1
Bolsen et al. (1983)	soft-dough	1.1	8.6	9.1
	soft-dough	1.1	8.2	8.6
	soft-dough	.81	7.7	6.2

nonheading diet, although consumed as readily as the diet with added grain and water, produced 20% slower daily gain. When grain was added alone (32.0% DM) a 16 and 34% increase in DM intake and daily gain, respectively, were obtained. Although diet DM contents were not identical (25.7 and 29.4% for the nonheading and nonheading plus rolled sorghum grain and water), it was not believed to be an important factor. In this experiment, the sorghum grain was rolled and may have been more completely digested than whole kernels in silage made from cultivars that produce grain.

By allowing sorghums to mature, the contribution of the grain to total diet DM can be maximized, however Owen (1962) suggested that grain content alone should not be used as a criterion to evaluate forage sorghums. By allowing Tracy forage sorghum to mature (hard-seed) the author reported no significant increases in FCM production and milk fat percentage in dairy cows when compared with a nonheading cultivar. However, when Tracy was harvested at the early-dough stage, cows produced significantly lower fat corrected milk. In contrast, Browning and Lusk (1967) reported no significant increases in milk production when cows were fed diets containing a different cultivar (RS 610 grain sorghum) harvested at three stages of maturity (milk stage with 25% DM; dough stage with 27% DM; and hard-seed stage with 35% DM).

Forage Quality

Forage quality is an expression of the potential of livestock to produce meat, milk, and other products from forage through the utilization of its available nutrients. Quality is a function of the level of forage intake, the rate and extent of its digestion, and the efficiency of utilization of its specific nutrients (Barnes and Merten, 1979).

The determination of forage quality of silages not only requires analysis of the pre-ensiled material but also the silage after the fermentation process. Through the loss of fermentable carbohydrates, the content of intact fractions (ADF, NDF, cellulose, and lignin) will increase as a percentage of the total DM in the material. This increase may be substantial in low DM forages, due to high total fermentation acid production.

Of the components that are present in the pre-ensiled material, DM percent is the only characteristics which can be manipulated. Either by wilting or plant maturation, the DM content of the crop and resulting silage can be increased to improve intake and, subsequently, animal performance. In the case of forage sorghum, season length is potentially the largest factor affecting DM content. Late season cultivars, which mature after early or middle season ones, are not able to "dry down" to an optimum moisture for ensiling.

Studying the effects of DM content of silages on intake by ruminants, Ward et al. (1966) estimated correlation coefficients between silage DM intake and silage DM content using lactating cows and beef calves. After adjusting for concentrate additions, coefficients of .95, .93, and .93 were reported for lactating cows, beef heifers, and beef steers, respectively. These results emphasize the necessity for comparing silages at the same moisture content for feed intake and animal production measurements.

The differences in performance between sorghums and corn silages when fed to ruminants can be explained by the difference among species for several agronomic and quality measurements. Schmid et al. (1976) studied the relationships among agronomic characteristics of corn and sorghum cultivars and silage quality. Twenty-three corn and 26 sorghum silages were compared (table 10). Quality measurements reported indicate large differences in favor of corn for ADF, DDM, ADG, and DM intake. In both corn and sorghum, percent stem and percent ears

Table 10. Correlations among agronomic and quality measurements of 23 corn and 26 sorghum silages fed to sheep.

Corn

Agronomic measurements	Quality measurements*				Agronomic measurements			
	ADF	DDM	DMI	ADG	Leaves	Stems	Ears	Height
					%			
Leaves (%)	0.78	-0.63	-0.73	-0.68				
Stems (%)	0.90	-0.67	0.71	0.65	0.89			
Ears (%)	-0.87	0.67	0.73	0.68	-0.97	-0.97		
Height	0.35	-0.11	-0.26	-0.34	0.20	0.47	-0.35	
Yield	0.10	-0.11	-0.15	-0.26	-0.08	0.15	-0.04	0.76

*Significant correlation at P 0.05 = ± 0.40.

Sorghum

Agronomic measurements	Quality measurements*				Agronomic measurements			
	ADF	DDM	DMI	ADG	Leaves	Stems	Heads	Height
					%			
Leaves (%)	0.13	0.05	-0.25	-0.12				
Stems (%)	0.76	-0.61	-0.89	-0.61	0.12			
Heads (%)	-0.72	0.51	0.88	0.58	-0.50	-0.92		
Height	0.87	-0.90	-0.80	-0.63	0.07	0.74	-0.62	
Yield	0.34	-0.19	-0.48	-0.24	0.16	0.50	-0.50	0.36

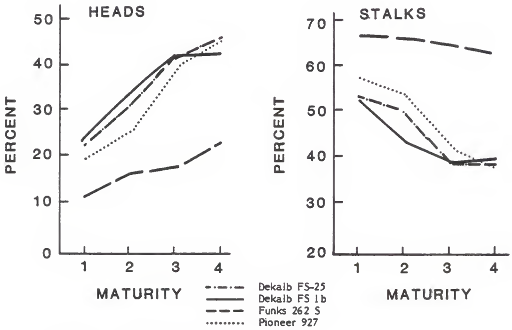
*Significant correlation at P 0.05 = ± 0.39.

and heads were the agronomic characteristics most highly and consistently related to quality measurements. The authors reported high correlations between percent leaves and quality measurements in corn and hypothesized that this was due to the high correlation (r = .89) between percentages of leaves and stems. The taller and higher yielding corn cultivars had higher leaf and stem percentages, while the early maturing, shorter cultivars had higher ear percentages. Height and yield were not highly correlated with quality measurements in the corn cultivars (table 10). However, in sorghums, height was highly negatively correlated with quality measurements. The explanation given was the highly positive correlation of low quality stems with height and the highly negative correlation of high quality heads with height.

When measuring silage quality, large differences were reported which favored corn (table 10). Schmid et al. (1976) reported mean daily gains for sheep fed corn silages of 65 g, which was three times higher than the daily gains for sheep consuming sorghum silages (18 g). The authors suggested that the reduced gains of sheep fed sorghum diets was primarily due to the low digestible DM intakes (DDMI). A linear regression analysis of daily gain and DDMI after maintenance fulfillment shows that .209 g gain resulted from each gram of DDMI for sheep consuming corn silage compared with .202 g gain when sheep were fed sorghum diets.

Cummins (1981) compared four forage sorghum hybrids determining head, leaf, and stem contribution to total plant DM and their in vitro digestibilies. The author reported that the hybrids differed in DM distribution among components, with the major differences being lower head and higher stem proportion from DeKalb FS-25 when compared with the other hybrids (Figure 7). In vitro DDM results indicated that Dekalb FS-25 grain heads were of lower quality with

Figure 7. Dry matter distribution expressed as a percent of total dry matter of four forage sorghum cultivars with advancing maturity.



Maturity: 1 = Late-milk
2 = Early-dough
3 = Dough
4 = Hard-dough

advancing maturity. This is in agreement with Schmid et al. (1976) who reported a high negative correlation with heads and height (r = - .62). However, Cummins (1981) reported that digestibility was significantly higher in Dekalb FS-25 stalks when compared with other hybrids. This does not agree with Schmid et al. (1976) who reported a highly positive correlation of low quality stems with height (r = .74).

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Chapter II

EFFECTS OF HYBRID AND STAGE OF MATURITY AT HARVEST ON THE YIELD, COMPOSITION, AND NUTRITIVE VALUE OF FORAGE SORGHUM SILAGES.

Experimental Procedures

Experiment 1. Two forage sorghums [*Sorghum bicolor* L. (Moench)], DeKalb FS-25A+ (a late maturity and moderate grain producing hybrid) and Funk's G-1990 (a late maturity and nonheading hybrid) were seeded on June 9, 1983 and grown under dryland conditions near Manhattan. Harvests were made at six stages of crop maturity for the DeKalb 25A: boot (I), anthesis (II), early-milk (III), late-milk to early-dough (IV), late-dough (V), and post-freeze, hard-grain (VI). Due to the absence of a grain head, Funk's G-1990 was harvested on the same d as DeKalb 25A. Days post-emergence (DPE) for the six harvests were: 81, 93, 100, 110, 114, 160 for stages I through VI, respectively. Whole-crop yield was determined by harvesting two rows which were each 141 m long (approximately 254 m^2). Fresh material weights and samples were taken immediately after harvest.

At each harvest six, 208 l, metal drum, pilot silos lined with 4 mm plastic were filled with approximately 100 to 105 kg of fresh material from each hybrid. Silos were stored at ambient temperature (18 to 26 C) for at least 100 d prior to opening. Initial and final weights were recorded for each silo and silage samples were taken at three levels from the geometric center as the silos were emptied. The DM content of the pre-ensiled material and silages was determined by drying for 72 h at 55 C in a forced-draft oven, with no correction for volatile losses.

The dried samples were composited by silo and ground in a Wiley mill to pass through a 1 mm screen. Proximate analyses were determined for the ground samples by AOAC (1984) methods and cell wall constituents and hot water insoluble-nitrogen, as described by Goering and Van Soest (1975).

A portion of the pre-ensiled material samples not dried was analyzed for pH and a portion of the silage samples not dried was analyzed for pH, lactic acid, and volatile fatty acids (VFA). A 25 g aliquot was extracted in 100 ml of distilled water for 1 h and pH determined using an Orion 700 meter. Another 25 g aliquot was extracted in 200 ml of .2N H_2SO_4 for 2 d and the supernate strained through four layers of cheesecloth from the mixture and retained for further analyses. From the supernate, lactic acid was measured by colorimetric determination (Barker and Summerson, 1941) and VFAs, by gas chromatography. The VFAs were separated on a 91.4 cm by 3.2 mm glass column packed with Chromosorb 101 (80 to 100 mesh) using a flash vaporization inlet, hydrogen flame detection, and an oven temperature of 180 C (isothermal). The carrier gas was nitrogen.

Twenty-four crossbred wether lambs (avg wt, 39 kg) were allotted by weight to the 12 silages (two lambs per silage) for three digestion trial periods. All diets were 90% of the appropriate silage and 10% supplement on a 100% DM basis. Diets were formulated to 11.5% CP and supplied equal amounts of minerals and vitamins (table 1). At the end of periods one and two, all lambs were weighed and randomly re-assigned to the 12 silage diets.

Each 24 d period was divided into a 10 d pre-feeding, 5 d voluntary intake, 2 d diet intake adjustment, and 7 d fecal collection phases. During the diet adjustment and collection phases, all lambs received 85% of their previously established ad libitum intake.

Lambs were fitted with a canvas harness equipped with a fecal collection bag and fed individually in metal digestion crates. Daily fecal collections were weighed and a 10% aliquot was retained for DM determination. Diet component samples were taken daily during the 7 d collection phase and composited to determine diet DM content. At the end of each period the diet and feces samples were composited, mixed, subsampled, and processed for chemical analyses.

Diet components and feces were dried for 72 h at 55 C and ground through a Wiley mill to pass through a 1 mm screen. The diet and feces samples were analyzed for proximate components and cell wall constituents using AOAC (1984) and Goering and Van Soest (1975) methods, respectively.

Experiment 2. Three forage sorghum hybrids were seeded on June 14, 1984 and grown under dryland conditions near Manhattan. Hybrids were: Acco Paymaster 351 (medium maturity and high grain producing), DeKalb FS-25E (late maturity and moderate grain producing), and Funk's G-1990. Harvests were made at three stages of kernel development for the Acco 351 and DeKalb 25E: late-milk to early-dough (IV), late-dough (V), and post-freeze, hard-grain (VI). The Funk's G-1990 was harvested on the same d as DeKalb 25E which occurred at 102, 116, and 127 DPE for stages IV, V, and VI, respectively. Whole-crop yield was determined by harvesting three rows which were each 127 m long (approximately 350 m^2). Fresh material weights and samples were taken and DM and pH determinations made as described in Exp. 1.

At each harvest for each hybrid, fresh material was ensiled, stored, weighed, and sampled as presented in Exp. 1. Silos were opened at approximately 75 d post-filling and the preparation and analyses of samples were identical to Exp. 1.

Twenty-seven crossbred wether lambs (avg wt, 33 kg) were allotted by weight to the nine silages (three lambs per silage) for two periods. All diets were

90% of the appropriate silage and 10% supplement on a 100% DM basis. Diets were formulated to 11.5% CP and supplied equal amounts of vitamins and minerals (table 1). Period and phase length, re-assignment between periods, collection techniques, preparation of samples, and chemical analyses were similar to those described in Exp. 1.

Experiment 3. Six forage sorghum hybrids were seeded on June 25, 1984 and grown under dryland conditions near Manhattan. Hybrids were selected to represent a range of sorghum pedigrees which included variations in maturity, plant height, and grain and forage yields. The hybrids were: Buffalo Canex and Warner Sweet Bee (early maturity); Pioneer 947 and Golden Acres T-E Silomaker (medium maturity); and Conlee Cow Vittles and DeKalb FS-25E (late maturity). Each hybrid was harvested at three stages of kernel development: late-milk to early-dough (IV); late-dough (V); and hard-grain (VI). The experimental design was a split-plot with four replications. Stages of maturity at harvest were main plots and hybrids were subplots.

The soil type was a silty clay loam, which was uniformly cropped with corn the previous year. Anhydrous ammonia (110 kg per ha) and a broadcast pre-emergence herbicide spray (Ramrod-atrazine) were applied before seeding. Soil tests indicated phosphorus and potassium were adequate. Furadan insecticide was placed in the furrows at seeding and Cygon insecticide spray was applied July 31 for greenbug control. Each plot consisted of 6 rows, 9.2 m in length with 76 cm between rows. Approximately 2 wk after emergence, the plots were thinned to 85, 378 plants per ha (15 cm between plants).

Data collected on each plot included: d to half bloom, plant height, lodging, whole-crop DM yield, and grain yield. Days to half bloom measured maturity as the number of d between seeding date and the date half of the main heads had some florets. 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 6.0 m length from each of the two center rows with a modifed one-row forage harvester. Chopped material from the two rows was composited, weighed, sampled for DM determination, and collected for silage-making. An additional 500 g sample of pre-ensiled material was analyzed as in Exp. 1. Grain yield was determined for each plot by hand clipping the heads from 6.0 m of one of the remaining inside rows. The heads were then partially dried and threshed in a stationary thresher.

Silage was made from the fresh material from each plot in a 20 l capacity, plastic, laboratory silo as described by Hinds (1983). The silos were made air-excluding by a lid fitted with a rubber O-ring seal and Bunsen valve. All fresh material was treated with Pioneer Brand 1177 silage inoculant (.5 g per kg).

The laboratory silos were opened at approximately 100 d post-filling and samples from each silo were analyzed as described in Exp. 1.

Statistical analyses. Data from Exp. 1 and 2 were analyzed using analysis of variance of a two-way treatment structure (Snedecor and Cochran, 1981). Since the block elements (lambs) were randomized to treatment combinations in each block, a conservative approach was taken to treat both Exp. 1 and 2 as randomized complete block designs with six blocks. Data collected from the pilot silos were not statistically analyzed because the samples were considered repeated measures from a single whole plot. In Exp. 3 statistical analysis was by analysis of variance of a split-plot design. Treatments were evaluated using a protected F test (Snedecor and Cochran, 1981). If mean differences were significant, separation was by the Least Significant Difference method (Cochran and Cox, 1980).

Results

Experiment 1. Harvest dates, DM contents, and whole-crop DM yields for the two forage sorghum hybrids are shown in table 2. The increase in DM content with advancing maturity was similar for the two hybrids. Both reached their maximum DM yield at an intermediate harvest stage; DeKalb 25A at stage III and Funk's G-1990 at stage IV. DeKalb 25A outyielded Funk's G-1990 at the three earlier harvest stages, but at stages IV and V, DM yields were similar.

Chemical analyses for the 12 forage sorghum silages are shown in table 3. The CP content was similar for both hybrids, with the lowest CP occurring at harvest stage VI. The fiber fractions (NDF, ADF, and hemicellulose) were higher at all harvest stages for Funk's G-1990 silages than DeKalb 25A. Harvest stage did not affect the fiber fractions of either hybrid at stages I through VI, however all fractions, except cellulose, declined at stage VI.

Nitrogen constituents and fermentation end products for the 12 forage sorghum silages are presented in table 4. All silages were well preserved and had undergone lactic acid fermentations. They had very low pH values, high lactic acid contents, and negligible amounts of butyric acid. The lactic acid content did not appear to be related to harvest stage in either hybrid. Acetic and total fermentation acids increased with advancing maturity in the Funk's G-1990 silages, but not in DeKalb 25A. The Funk's G-1990 silages had consistently lower hot water insoluble nitrogen values than DeKalb 25A.

Results for voluntary intake and apparent digestibility are shown in table 5. Since there were no significant hybrid x harvest stage interactions, only data for the main effects are given. Hybrid did not affect intakes or digestibilities of DM, organic matter (OM), or crude protein. Only NDF and ADF digestibilities were significantly affected by hybrid; being higher for the Funk's G-1990 silages. Voluntary intakes were higher ($P<.05$) for the stage V silages than stage I silages. The DM and OM digestibilities were higher ($P<.05$) for the stages II and III silages than stage VI silages. Crude protein digestibilities were lowest ($P<.05$) for the stage I silages. The NDF and ADF digestibilities were numerically highest for the stage II silages, but lowest for stage VI silages.

Experiment 2. Harvest dates, DM contents, and whole-crop DM yields for the three forage sorghum hybrids are shown in table 6. All three hybrids increased in DM content as maturity advanced, with Acco 351 being consistently highest at each harvest stage. The DM yield was lowest for all three hybrids at harvest stage IV; Acco 351 and Funk's G-1990 reached maximum yields at stage VI and DeKalb 25E at stage V.

Chemical analyses of the nine forage sorghum silages are shown in table 7. The CP contents were unusually low for all three hybrids and were not influenced by harvest stage. The fiber fractions followed very consistent patterns. Acco 351 silages had the lowest NDF, ADF, and cellulose values; Funk's G-1990 silages had the highest values. Most fiber fractions decreased at the last harvest stage, particularly for Acco 351 and DeKalb 25E silages.

Nitrogen constituents and fermentation end products for the nine forage sorghum silages are presented in table 8. All silages were well preserved and had undergone lactic acid fermentations. Differences due to hybrid or harvest stage were not significant. Acco 351 silages, which had higher DM contents than DeKalb 25E or Funk's G-1990, also had the highest pH values, lowest total fermentation acids, and highest hot water insoluble nitrogen levels. The DeKalb 25E silages had the lowest pH values and the highest total acids. Acetic acid content increased and lactic:acetic acid ratio decreased with advancing maturity for all three hybrids.

Results for voluntary intake and apparent digestibility are shown in table 9. Since no significant hybrid X harvest stage interactions occurred, only data for main effects are given. The Acco 351 silages were consumed in greater amounts (P<.05) than DeKalb 25E or Funk's G-1990 silages. The three hybrids had similar DM and OM digestibilities. Crude protein and ADF digestibilities were highest (P<.05) for the Funk's G-1990 silages; ADF digestibility was lowest (P<.05) for the Acco 351 silages. Harvest stage did not influence voluntary intakes or digestibilities of DM, OM, and crude protein.

Experiment 3. The effect of hybrid on d to half bloom, plant height, and lodging for the six forage sorghums is shown in table 10. Canex was the earliest maturing hybrid, while DeKalb 25E, Cow Vittles, and Silomaker were the latest (P<.05) maturing. Sweet Bee was the tallest (P<.05) hybrid and it also had the highest (P<.05) lodging percent. Silomaker, the shortest (P<.05) hybrid, along with Canex, Pioneer 947, and DeKalb 25E had the lowest (P<.05) lodging percent.

The effect of hybrid on whole-crop DM and CP contents, whole-crop DM and grain yields, and grain to forage ratios for the six forage sorghums is shown in table 11. Since significant hybrid X harvest stage interactions occurred for whole-crop DM content (P<.0001) and whole-crop yield (P<.0003), only main effect significance levels for the remaining variables are presented. Pioneer 947 had the highest grain yield and grain to forage ratio (P<.05), while DeKalb 25E had the lowest (P<.05). Pioneer 947 also had the numerically highest CP content.

The effect of harvest stage on whole-crop DM and CP contents, whole-crop and grain yields, grain to forage ratios, and lodging for the forage sorghums is shown in table 12. Pioneer 947, Silomaker, and DeKalb 25E had higher (P<.05) CP content at all three stages than Canex or Sweet Bee. Silomaker, Pioneer 947, and Sweet Bee produced more ($P<.05$) grain at stages IV and V than Cow Vittles or DeKalb 25E. DeKalb 25E also had the lowest ($P<.05$) grain to forage ratios at stages V and VI. No consistent trends were observed in whole-crop DM yields. Three different hybrids had numerically highest yield at each harvest stage; DeKalb 25E, Silomaker, and Sweet Bee at stages IV through VI, respectively. Sweet Bee had the highest ($P<.05$) lodging percent at stages V and VI.

The effect of harvest stage within hybrid on whole-crop DM and CP contents, whole-crop and grain yields, grain to forage ratios, and lodging is shown in table 13. Canex, Sweet Bee, and Pioneer 947 had their lowest DM content at stage IV; their highest, at stage VI. Silomaker and Cow Vittles had their highest DM content at stage V; DeKalb 25E, at stage IV. Silomaker and Cow Vittles yielded less ($P<.05$) DM at stage VI than stage IV.

The effect of hybrid and harvest stage on whole-crop DM and CP contents, whole-crop and grain yields, grain to forage ratios, and lodging is shown in appendix table 3.

The effect of hybrid on Van Soest constituents for the six forage sorghum silages is shown in table 14. A significant hybrid X harvest stage interaction occurred for all variables except hemicellulose. Hemicellulose content did not differ among hybrids, as all were within 1.5 percentage units.

The effect of harvest stage on Van Soest constituents for the forage sorghum silages is shown in table 15. Pioneer 947, Silomaker, and DeKalb 25E were higher ($P<.05$) in hemicellulose content than Cow Vittles at stage IV. However, no differences were observed at stage V and Cow Vittles was higher ($P<.05$) than Silomaker at stage VI.

The effect of harvest stage within hybrid on Van Soest constituents for the forage sorghum silages is shown in table 16. Canex, Sweet Bee, Pioneer 947, and Silomaker were highest in NDF and cellulose content at Stage IV. Sweet Bee was lower in ADF and cellulose content at stage VI. Pioneer 947 was higher ($P<.05$) in NDF content at stage IV than V. Silomaker was highest ($P<.05$) at stage IV. In contrast, Cow Vittles was highest ($P<.05$) in NDF and cellulose content at stage VI and higher ($P<.05$) in ADF content at stage VI and IV.

The effect of hybrid and harvest stage on Van Soest constituents for the forage sorghum silages is shown in appendix table 4.

The effect of hybrid on nitrogen constituents and fermentation end products for the six forage sorghum silages is shown in table 17. A significant hybrid X harvest stage interaction occurred for acetic acid content and lactic to acetic acid ratios, consequently no significance levels for main effects are given. All silages underwent lactic acid fermentations, characterized by low pH values, high lactic acid contents, and negligable amounts of butyric acid. Pioneer 947 silages had higher ($P<.05$) pH than DeKalb 25E silages. Lactic acid content was higher ($P<.05$) in Canex than Pioneer 947 silages. Total fermentation acids were higher ($P<.05$) in Canex, Sweet Bee, and DeKalb 25E than in Pioneer 947 silages.

The effect of harvest stage on nitrogen constituents and fermentation end products for the forage sorghum silages is shown in table 18. Pioneer 947 silages had higher pH ($P<.05$) than Sweet Bee, Cow Vittles, or DeKalb 25E silages at stages IV and V, and Cow Vittles and DeKalb 25E at stage VI. Silomaker silage was higher ($P<.05$) in lactic acid content than Pioneer 947 and DeKalb 25E silages at stage IV. Canex and DeKalb 25E silages had higher ($P<.05$) lactic acid than Pioneer 947 at stage VI. Total fermentation acids were not affected by harvest stage until stage VI, where DeKalb 25E and Canex silages were higher ($P<.05$) than Sweet Bee and Pioneer 947 silages.

The effect of harvest stage within hybrids on nitrogen constituents and fermentation end products for the forage sorghum silages is shown in table 19. Sweet Bee stage VI silage was lowest ($P<.05$) in acetic acid content. Canex and Pioneer 947 stage IV silages were higher ($P<.05$) than stage VI and V, respectivley. However, Cow Vittles was lowest ($P<.05$) at stage IV and Silomaker was lower ($P<.05$) at stages IV and VI. Canex produced the most ($P<.05$) lactic acid per unit of acetic acid at stage VI, whereas Silomaker had the highest ($P<.05$) ratio at stage IV.

The effect of hybrid and harvest stage on nitrogen constituents and fermentation end products for the forage sorghum silages is shown in appendix table 5.

Discussion

Experiments 1 and 2. Planting dates differed only 5 d between experiments, but the number of d to post-freeze, hard grain maturity (stage VI) was 33 d longer in Exp. 1. A freeze on September 25, 1984 ended the growing season 27 d earlier than 1983. In Exp. 1, 4 d elapsed between harvests of late-milk to early-dough (IV) and late-dough (V), while 15 d elapsed between late-dough and post-freeze, hard grain (VI). In Exp. 2, these same harvest stages were separated by 14 and 11 days. The differences among years was mainly due to misjudgement of the stage IV maturity in Exp. 1. Although measurements were not taken in either experiment, the grain producing hybrids appeared to increase in grain content with advancing harvest. Results from Exp. 3 as well as those from previous research (Browning and Lusk, 1967; Johnson et al., 1971) substantiate this observation. Whole-plant DM yield is maximized by delaying the harvest of sorghums until physiological maturity (Webster, 1963; Marshall et al., 1966).

The decrease in CP content of the silages as maturity advanced is in agreement with other reports for sorghums (Johnson et al., 1971; Danley and Vetter, 1973; Schake et al., 1982). The low CP contents of silages in Exp. 2 exemplify the variability of forage sorghums among years (Saied and Francis, 1983).

Van Soest constituents were highest in both experiments for the nonheading Funk's G-1990. This agrees with other research which indicate that the dilution of fiberous components is negatively correlated to starch formation in the kernel as maturity advances (Owen, 1962; Owen and Webster, 1963; Black et al., 1980).

Hybrid affected DM intake, particularly where wide ranges in silage DM content were observed. This is in agreement with Ward et al. (1966) who reported a high correlation between sorghum silage DM intake and silage DM content. The decreases in component digestibility in experiments 1 and 2 agree with numerous research findings (Browning and Lusk; 1967; Owen and Kuhlman, 1967; Fox et al., 1970; Johnson et al., 1971; and Black et al., 1980). Results from both experiments suggest that grain content influenced ADF digestibility. The grainless Funk's G-1990 silages had significantly higher ADF digestibility which may have resulted from increased retention time in the rumen. Although cellulose digestibility was not measured, the percent of whole-crop DM coming from the grain portion in the grain producing hybrids may have contributed to their lower ADF digestibilities. Under this premise, DM digestibility would not be affected (Phillips et al., 1957; Anthony, 1961). However, the ranges of cellulose content in the silages in these experiments suggest the involvement of other factors.

The increase in CP digestibility with advancing maturity was consistent in both experiments. This agrees with results of Johnson et al. (1971) who observed a large increase in CP digestibility (38 to 54%) when Pioneer 931 was harvested after frost. However,it is not in agreement with other reports in the literature that showed CP digestibility decreased with advancing maturity (Owen and Kuhlman, 1967; Fox et al., 1971; Black et al., 1980). This discrepancy could be due to variation among hybrids.

Stage of harvest did not affect apparent digestibilities among hybrids, however DM intake was greatest for Acco 351 silages at all harvests. These results suggest that factors other than component digestibility need to be evaluated before a decision on the stage of maturity to harvest forage sorghums for silage can be made. Because of the wide ranges in silage DM content, the low digestible OM intake from the later maturing forage sorghums could lead to decreased animal performance. Consequently, forage sorghums should be evaluated and managed on the basis of desired or expected performance.

Experiment 3. Differences among forage sorghum hybrids in d to half bloom were quite evident. Twenty-six additional d were needed to reach anthesis for the latest maturing hybrid compared with the earliest maturing. The differences in plant height, although genetically predetermined, were also influenced by environmental factors. A freeze on September 25 restricted plant height and grain production of the later maturing hybrids. The percent of plants that lodged also was quite variable, but appeared to be related to plant height and composition. Visually taller hybrids had the fewest leaves and smallest stem diameters, along with above average grain production. The added weight supplied by the grain in the head might have increased lodging.

Plant composition and subsequent silage fermentation characteristics were not similar for all hybrids. Highly significant hybrid X harvest stage interactions occurred for many of the variables measured. Although there is little evidence of this in the literature when comparing findings of other authors, conflicting trends are noted (Thurman et al., 1960; Webster, 1963; Schake et al., 1982; Saied and Francis, 1983; Walter, 1984).

Season length differnces among the forage sorghums was the factor responsible for the hybrid X harvest stage interaction in whole-crop DM yields. The earlier maturing hybrids attained their maximum DM production at the post freeze, hard grain stage. These results agree with Browning and Lusk (1967) who 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. However, the later maturing hybrids tended to decrease in whole-crop DM yields with advanced maturity. Leaf loss and reduced grain yields which resulted from the early freeze were likely responsible for this reduction. A similar maturity effect was reported by Black et al. (1980). These authors reported that DM yields for DeKalb FS 24 were highest at the late-milk to early-dough stage and declined at later stages of maturity. Whole-crop DM content also followed similar patterns. The failure of the late maturing hybrids to increase in DM content at advanced harvest stages may have resulted from the release of cell contents after freezing.

Whole-crop CP content differed among hybrids, but similar patterns were observed as maturity advanced. Other authors have also reported a negligable effect on CP content within hybrids at different harvest stages (Danley and Vetter, 1973; Black et al., 1980). However, there are reports in the literature which contradict these findings (Owen, 1962; Nordquist and Rumery, 1967).

The effect on Van Soest constituents as maturity advanced was not well defined, however, a pattern was observed for season length. The later maturing hybrids, Cow Vittles and DeKalb 25E, were primarily responsible for the interactions observed. The increasing grain content that Cow Vittles exhibited increased whole-crop neutral detergent fiber content, while other hybrids decreased at the later harvest stages. No explanation can be given for the consistency of lignin content, as Danley and Vetter (1973) reported that lignin was one of the forage constituents most affected by maturity.

Silages made from the forage sorghum hybrids at all three stages of maturity were well preserved and had acceptable quality. Less extensive fermentations occurred for most hybrids as they were harvested at more advanced maturity. The effect of maturity on pH and lactic and total fermentation acid contents was greatest for Pioneer 947. 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 higher pH values and lower fermentation acids. However, results from Exp. 1 and 2 do not support this observation, as silages with similar DM content differed considerably in total fermentation acids. This suggests that other factors, including management practices, may be responsible for the fermentation profile of silages. No explanation can be given for the decreased efficiency of Silomaker to produce lactic acid as maturity advanced. Although the epiphytic microflora was not quantified in this experiment, the proximity of the hybrids suggests that it would likely be similar.

In summary, results from Exp. 3 suggest that forage sorghums differ in agronomic characteristics and plant composition, and they have the potential to offer high whole-crop DM yields at harvest stages ranging from late-milk to hard-grain. As noted in Exp. 1 and 2, component digestibilities were not adversely affected by harvesting at advanced maturities. However, the wide range in DM contents of silages made from these six forage sorghum hybrids could lead to large differences in DM intake and animal performance among the hybrids, even when harvested at similar maturities.

The ability of the sorghum plant to produce excellent whole-crop DM yields in marginal rainfall areas in the High Plains region could have a tremendous impact on the livestock industry. However, the variability among hybrids suggests that not any one hybrid is likely to be suited for all livestock production systems.

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

Ingredient	Exp. 1				Exp. 2	
	A[1]	B[2]	C[3]	D[4]	E[5]	F[6]
	% on a DM basis					
Grain sorghum, rolled (IFN 4-20-893)	—	10.0	26.0	75.0	—	--
Soybean meal (IFN 5-20-637)	78.3	67.0	51.0	1.0	75.1	73.4
Urea (IFN 5-05-070)	8.7	8.8	8.8	8.8	10.5	12.0
Limestone (IFN 6-02-632)	5.3	6.5	6.3	5.4	6.0	6.1
Dicalcium phosphate (IFN 6-01-080)	3.5	3.8	4.1	5.6	3.8	3.9
Salt (IFN 6-04-152)	2.5	2.5	2.5	2.5	2.5	2.5
Tallow (IFN 4-00-409)	1.0	1.0	1.0	1.0	1.0	1.0
Trace mineral premix[a]	.3	.3	.3	.3	.3	.3
Vitamin and antibiotic premix[b]	.4	.4	.4	.4	.8	.8

[1]Fed with DeKalb 25A stage IV, V, and VI silages.
[2]Fed with DeKalb 25A stage II and III and Funk's G-1990 stage VI silages.
[3]Fed with DeKalb 25A stage I and Funk's G-1990 stage II, III, IV and V silages.
[4]Fed with Funk's G-1990 stage I silage.
[5]Fed with all Acco 351 and DeKalb 25E silages.
[6]Fed with all Funk's G-1990 silages.

[a]Contained 11% Ca, 10% Mn, 10% Fe, 10% Zn, 1% Cu, .3% I, and .1% cobalt.
[b]Formulated to supply 3,000 IU of vitamin A, 300 IU of vitamin D, 3 IU of vitamin E, and 20 mg of aureomycin/lamb/day.

TABLE 2. HARVEST DATES AND WHOLE-CROP DRY MATTER CONTENTS AND YIELDS FOR THE TWO FORAGE SORGHUM HYBRIDS CUT AT SIX HARVEST STAGES IN EXP. 1

Hybrid and harvest stage	Harvest date	DM at harvest	Whole-crop DM yield[1]
	1983	%	
DeKalb 25A			
I	Aug. 29	20.4	13.3
II	Sept. 9	25.1	14.5
III	Sept. 16	26.2	15.4
IV	Sept. 26	28.7	14.7
V	Sept. 30	28.8	14.3
VI	Nov. 15	29.1	12.7
Funk's G-1990			
I	Aug. 29	20.2	11.6
II	Sept. 9	23.4	11.6
III	Sept. 16	24.1	13.8
IV	Sept. 26	27.6	14.7
V	Sept. 30	27.6	14.2
VI	Nov. 15	29.2	14.3

[1]Metric tons per hectare.

TABLE 3. PROXIMATE ANALYSES AND VAN SOEST CONSTITUENTS FOR THE 12 FORAGE SORGHUM SILAGES IN EXP. 1

		Chemical component[1]							
Hybrid and harvest stage	DM	CP	ash	EE	NDF	ADF	hemi-cellulose	cellulose	lignin
	%	% of the silage DM							
DeKalb 25A									
I	19.1	7.19	7.9	2.6	64.2	39.6	24.7	31.4	5.3
II	23.0	7.22	8.0	2.3	67.9	38.8	29.5	29.6	5.5
III	23.4	7.38	8.7	3.4	63.1	37.3	25.9	27.5	5.9
IV	25.5	7.12	8.8	4.3	64.0	38.0	25.4	28.0	6.1
V	26.5	6.62	8.8	2.5	62.7	38.2	24.5.	30.6	3.8
VI	28.0	6.17	8.2	2.5	56.5	38.1	18.5	33.2	3.8
Funk's G-1990									
I	21.1	7.33	8.5	2.7	67.4	41.3	26.1	33.8	4.9
II	22.1	6.81	8.3	3.6	68.9	41.5	27.2	32.3	5.6
III	23.6	6.76	7.9	3.0	70.5	40.8	29.8	26.9	6.7
IV	25.7	7.20	8.7	3.1	67.4	39.6	27.7	30.3	5.1
V	25.7	6.84	8.9	2.8	67.2	41.4	25.8	31.5	5.4
VI	26.8	6.15	9.0	2.4	62.6	40.9	21.7	32.7	3.8

[1]DM = dry matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fiber, ADF = acid detergent fiber.

TABLE 4. NITROGEN CONSTITUENTS AND FERMENTATION END PRODUCTS FOR THE 12 SORGHUM SILAGES IN EXP. 1

Hybrid and harvest stage	DM	pH	Total N	HWIN	Fermentation acids Lactic	Acetic	Total	Lactic: acetic
	%		% of the silage DM					
DeKalb 25A								
I	19.1	3.71	1.15	.50	8.7	2.5	11.2	3.6
II	23.0	3.90	1.16	.58	6.8	1.4	8.2	4.9
III	23.4	3.75	1.18	.60	8.4	2.4	10.6	4.0
IV	25.5	3.89	1.14	.68	6.6	2.5	9.2	2.7
V	26.5	3.82	1.06	.63	7.5	2.7	10.3	2.7
VI	28.0	3.95	.99	.51	5.3	2.4	7.7	2.2
Funk's G-1990								
I	21.1	3.79	6.8	1.3	8.1	5.4	11.7	5.2
II	22.1	3.85	7.2	1.4	8.6	5.2	10.9	4.7
III	23.6	3.81	5.7	2.5	8.1	2.3	10.8	4.3
IV	25.7	3.88	6.3	3.7	9.9	1.7	11.5	5.9
V	25.7	3.75	7.0	3.2	10.2	2.2	10.9	6.0
VI	26.8	3.77	7.0	3.2	10.2	2.2	9.8	4.2

TABLE 5. EFFECTS OF FORAGE SORGHUM HYBRID AND HARVEST STAGE ON DIET VOLUNTARY INTAKE AND APPARENT DIGESTIBILITY IN EXP. 1[1]

Hybrid and harvest stage	VI g DM/d	VI g DM/kg body wt$^{.75}$	Digestibility, % DM	OM	CP	NDF	ADF
Hybrid							
DeKalb 25A	581	40.0	58.8	51.1	68.8	48.4^{f}	44.7^{f}
Funk's G-1990	578	42.3	56.7	52.1	70.2	52.2^{e}	49.9^{e}
Harvest stage							
I	510^{h}	34.3^{i}	55.5^{gh}	51.3^{gh}	64.5^{h}	51.8^{h}	49.6^{gh}
II	601^{gh}	39.5^{hi}	57.8^{g}	53.4^{g}	70.3^{g}	58.2^{g}	55.2^{g}
III	605^{gh}	44.0^{gh}	58.1^{g}	53.5^{g}	69.3^{g}	50.1^{hi}	49.0^{ghi}
IV	580^{gh}	41.8^{gh}	56.5^{gh}	51.7^{gh}	71.0^{g}	48.8^{hi}	44.6^{hi}
V	625^{g}	47.1^{g}	55.0^{gh}	50.1^{gh}	69.7^{g}	48.9^{hi}	43.3^{hi}
VI	557^{gh}	39.9^{hi}	54.6^{h}	49.6^{h}	72.1^{g}	44.1^{hi}	42.1^{i}

[1] VI = voluntary intake, DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber.

[e,f] Means in the same column with different superscripts differ (P<.05).

[g,h,i] Means in the same column with different superscripts differ (P<.05).

TABLE 6. HARVEST DATES AND WHOLE-CROP DRY MATTER CONTENTS AND YIELDS FOR THE THREE FORAGE SORGHUM HYBRIDS CUT AT THREE HARVEST STAGES IN EXP. 2

Hybrid and harvest stage	Harvest date	DM at harvest	Whole-crop DM yield[1]
	1984	%	
Acco 351			
IV	Sept. 21	29.2	12.3
V	Oct. 4	33.1	12.4
VI	Oct. 19	36.7	13.4
DeKalb 25E			
IV	Sept. 24	23.3	13.9
V	Oct. 8	26.2	16.2
VI	Oct. 19	26.5	14.8
Funk's G-1990			
IV	Sept. 24	24.9	13.3
V	Oct. 8	25.2	11.9
VI	Oct. 19	25.3	14.4

[1]Metric tons per hectare.

TABLE 7. PROXIMATE ANALYSES AND VAN SOEST CONSTITUENTS FOR THE NINE FORAGE SORGHUM SILAGES IN EXP. 2

Hybrid and harvest stage	DM	Chemical component[1]							
		CP	ash	EE	NDF	ADF	hemi-cellulose	cellulose	lignin
	%	% of the silage DM							
Acco 351									
IV	27.8	5.57	8.7	2.3	60.0	38.2	21.8	27.2	5.9
V	32.5	5.62	8.6	1.9	59.8	36.9	22.5	24.4	7.1
VI	35.3	5.88	8.6	1.8	53.5	38.1	15.5	27.1	6.1
DeKalb 25E									
IV	22.7	6.34	8.3	2.9	63.0	41.1	23.0	30.5	6.0
V	24.6	6.10	8.1	2.0	66.7	41.5	25.7	31.3	6.4
VI	24.4	6.41	8.6	1.9	56.8	39.7	17.1	28.3	7.1
Funk's G-1990									
IV	23.4	4.55	8.6	2.1	68.1	45.0	23.2	34.5	6.7
V	24.6	4.44	8.8	1.8	68.3	45.8	22.5	35.8	6.5
VI	24.6	4.25	9.1	1.8	65.2	48.4	16.8	35.6	8.6

[1]DM = dry matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fiber, ADF = acid detergent fiber.

TABLE 8. NITROGEN CONSTITUENTS AND FERMENTATION END PRODUCTS FOR THE NINE FORAGE SORGHUM SILAGES IN EXP. 2

Hybrid and harvest stage	DM	pH	Total N	HWIN	Fermentation acids Lactic	Acetic	Total	Lactic: acetic
	%		% of the silage DM					
Acco 351								
IV	27.8	3.95	.88	.50	6.0	2.2	8.2	2.8
V	32.5	3.99	.90	.50	6.1	2.4	8.5	2.6
VI	35.3	4.08	.94	.49	5.6	2.8	8.4	2.1
DeKalb 25E								
IV	22.7	3.81	1.01	.47	7.9	2.3	10.1	3.7
V	24.6	3.84	.98	.48	7.4	3.0	10.4	2.5
VI	24.4	3.79	1.03	.42	6.7	3.2	9.9	2.1
Funk's G-1990								
IV	23.4	3.85	.73	.33	6.7	2.9	9.5	2.4
V	24.6	3.94	.71	.34	5.9	3.5	9.4	1.8
VI	24.6	3.92	.68	.55	6.0	3.3	9.4	1.9

TABLE 9. EFFECTS OF FORAGE SORGHUM HYBRID AND HARVEST STAGE ON DIET VOLUNTARY INTAKE AND APPARENT DIGESTIBILITY IN EXP. 2[1]

Hybrid and harvest stage	VI g DM/d	VI g DM/kg body wt$^{.75}$	Digestibility, % DM	OM	CP	NDF	ADF
Hybrid							
Acco 351	639^{d}	48.0^{d}	57.1	55.9	68.1^{e}	53.2	34.2^{f}
DeKalb 25E	547^{e}	42.7^{e}	55.9	54.3	67.3^{e}	50.2	41.7^{e}
Funk's G-1990	527^{e}	40.8^{e}	56.7	55.3	70.5^{d}	55.2	48.7^{d}
Harvest stage							
IV	584	44.0	56.9	55.8	68.0	58.2^{g}	42.8^{g}
V	552	42.9	56.3	54.8	68.2	51.5^{gh}	38.7^{h}
VI	577	44.6	56.6	55.0	69.6	48.9^{h}	43.0^{g}

[1] VI = voluntary intake, DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber.

[d,e,f] Means in the same column with different superscripts differ (P<.05).

[g,h] Means in the same column with different superscripts differ (P<.05).

TABLE 10. EFFECT OF FORAGE SORGHUM HYBRID ON DAYS TO HALF BLOOM, PLANT HEIGHT, AND LODGING IN EXP. 3

Hybrid	Days to half bloom	Plant height, cm	Lodging, %
Canex	55[c]	217[b]	6.3[c]
Sweet Bee	62[bc]	237[a]	31.3[a]
Pioneer 947	68[b]	205[c]	3.6[c]
Silomaker	76[a]	177[d]	5.8[c]
Cow Vittles	79[a]	213[bc]	15.1[b]
DeKalb 25E	81[a]	207[c]	0[c]
LSD (P<.05)[1]	7	8	6.7
SE	.4	4.8	2.4

[1]The LSD is valid across all means.

TABLE 11. EFFECT OF FORAGE SORGHUM HYBRID ON WHOLE-CROP DRY MATTER AND CRUDE PROTEIN CONTENTS, WHOLE-CROP AND GRAIN YIELDS, AND GRAIN TO FORAGE RATIOS IN EXP. 3

Hybrid	Whole-crop		DM yield[1]		Grain: forage
	DM, %	CP, % (DM basis)	Whole-crop	Grain	
Canex	27.4	6.57[c]	12.85	.45[b]	.26[b]
Sweet Bee	27.4	6.84[c]	13.34	.52[b]	.30[b]
Pioneer 947	34.7	8.97[a]	13.23	.64[a]	.41[a]
Silomaker	29.2	8.42[ab]	13.63	.47[b]	.26[b]
Cow Vittles	25.5	7.84[b]	13.23	.31[c]	.17[c]
DeKalb 25E	25.4	8.08[b]	14.09	.10[d]	.04[d]
[2]H X HS (P<)	.0001	—	.0003	—	—
[3]LSD (P<.05)	—	.75	—	.07	.06
SE	.3	.19	.26	.03	.02

[1]Metric tons per hectare.

[2]H X HS means hybrid by harvest stage interaction.

[3]LSD is valid across all means.

TABLE 12. EFFECT OF HARVEST STAGE ON WHOLE-CROP DRY MATTER AND CRUDE PROTEIN CONTENTS, WHOLE-CROP AND GRAIN YIELDS, GRAIN TO FORAGE RATIOS, AND LODGING FOR THE FORAGE SORGHUM HYBRIDS IN EXP. 3

Harvest stage	Hybrid	Whole-crop DM, %	Whole-crop CP, % (DM basis)	DM yield[1] Whole-crop	DM yield[1] Grain	Grain: forage	Lodging, %
IV	Canex	27.2	7.1^{c}	12.0	.33^{ab}	.20^{ab}	0.0^{b}
	Sweet Bee	24.8	6.9^{c}	12.1	.42^{a}	.26^{a}	15.8^{a}
	Pioneer 947	30.5	9.1^{a}	12.3	.45^{a}	.28^{a}	.8^{b}
	Silomaker	27.0	8.2^{ab}	13.7	.38^{a}	.20^{ab}	3.0^{b}
	Cow Vittles	24.5	8.1^{b}	13.9	.21^{b}	.10^{bc}	6.0^{ab}
	DeKalb 25E	26.9	8.3^{ab}	14.7	.09^{c}	.04^{c}	0.0^{b}
V	Canex	25.8	5.7^{d}	13.0	.50^{b}	.30^{b}	7.5^{b}
	Sweet Bee	26.8	6.8^{c}	13.4	.54^{b}	.31^{b}	34.3^{a}
	Pioneer 947	31.7	8.7^{a}	13.3	.76^{a}	.51^{a}	2.8^{b}
	Silomaker	30.5	8.5^{ab}	14.5	.57^{b}	.30^{b}	2.0^{b}
	Cow Vittles	26.0	7.7^{ab}	13.5	.33^{c}	.16^{c}	10.8^{b}
	DeKalb 25E	24.7	7.9^{ab}	13.9	.11^{d}	.05^{d}	0.0^{b}
VI	Canex	29.2	6.8^{cd}	13.6	.51^{bc}	.28^{b}	11.5^{cd}
	Sweet Bee	30.4	6.7^{d}	14.5	.59^{ab}	.31^{b}	44.0^{a}
	Pioneer 947	41.9	9.1^{a}	14.1	.71^{a}	.44^{a}	7.3^{cd}
	Silomaker	30.1	8.6^{ab}	12.7	.46^{c}	.28^{b}	12.3^{c}
	Cow Vittles	25.8	7.7^{bc}	12.2	.39^{c}	.24^{b}	28.5^{b}
	DeKalb 25E	24.7	8.1^{b}	13.6	.10^{d}	.04^{d}	0.0^{d}
	[1]H x HS (P<)	.0001	--	.0003	--	--	--
	[2]LSD (P<.05)	--	.9	--	.12	.10	11.7
	SE	.5	.32	.5	.04	.04	4.1

[1]Metric tons per hectare.

[2]H x HS means hybrid by harvest stage interaction.

[3]The LSD is valid only within harvests.

TABLE 13. EFFECT OF HARVEST STAGE WITHIN HYBRID ON WHOLE-CROP DRY MATTER AND CRUDE PROTEIN CONTENTS, WHOLE-CROP AND GRAIN YIELDS, GRAIN TO FORAGE RATIOS, AND LODGING FOR THE FORAGE SORGHUM HYBRIDS IN EXP. 3

Hybrid	Harvest stage	Whole-crop DM, %	Whole-crop CP, % (DM basis)	DM yield[1] Whole-crop	DM yield[1] Grain	Grain: forage	Lodging, %
Canex	IV	25.8^{c}	7.1	12.0^{b}	.33	.20	0.0
	V	27.2^{b}	5.7	13.0^{ab}	.50	.30	7.5
	VI	29.2^{a}	6.8	13.6^{a}	.51	.28	11.5
Sweet Bee	IV	24.8^{c}	6.9	12.1^{a}	.42	.26	15.8
	V	26.8^{b}	6.8	13.4^{ab}	.54	.31	34.3
	VI	30.4^{a}	6.7	14.5^{a}	.59	.31	44.0
Pioneer 947	IV	30.5^{c}	9.1	12.3^{b}	.45	.28	.8
	V	31.7^{b}	8.7	13.3^{ab}	.76	.51	2.8
	VI	41.9^{a}	9.1	14.1^{a}	.71	.44	7.3
Silomaker	IV	27.0^{b}	8.2	13.7^{a}	.38	.20	3.0
	V	30.5^{a}	8.5	14.5^{a}	.57	.30	2.0
	VI	30.1^{a}	8.6	12.7^{b}	.46	.28	12.3
Cow Vittles	IV	24.5^{b}	8.1	13.9^{a}	.21	.10	6.0
	V	26.0^{a}	7.7	13.5^{ab}	.33	.16	10.8
	VI	25.8^{a}	7.7	12.2^{b}	.39	.24	28.5
DeKalb 25E	IV	26.9^{a}	8.3	14.7	.09	.04	0.0
	V	24.7^{b}	7.9	13.9	.11	.05	0.0
	VI	24.7^{b}	8.1	13.6	.10	.04	0.0
[2]LSD (P<.0)		.82	—	1.3	—	—	—
SE		.5	.32	.45	.04	.04	4.1

[1]Metric tons per hectare.

[2]LSD is valid within hybrids.

TABLE 14. EFFECT OF HYBRID ON VAN SOEST CONSTITUENTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Hybrid	ADF	NDF	Hemi-cellulose	Cellulose	Lignin
	% of the silage DM				
Canex	27.6	47.1	19.5	20.9	4.2
Sweet Bee	32.7	53.3	20.6	24.1	5.0
Pioneer 947	31.9	52.8	20.8	23.5	4.8
Silomaker	30.9	51.8	20.9	23.1	4.5
Cow Vittles	33.5	52.4	19.8	25.5	4.8
DeKalb 25E	34.6	55.4	20.7	26.4	4.9
[1]H x HS (P<)	.0007	.01	—	.0005	.008
[2]LSD (P<.05)	—	—	2.49	—	—
SE	.45	.82	.87	.41	.15

[1]H x HS means hybrid by harvest stage interaction.
[2]The LSD is valid among all hybrids.

TABLE 15. EFFECT OF HARVEST STAGE ON VAN SOEST CONSTITUENTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Harvest stage	Hybrid	ADF	NDF	Hemi-Cellulose	Cellulose	Lignin
		% of the silage DM				
IV	Canex	27.9	48.1	20.1[ab]	20.8	4.6
	Sweet Bee	34.6	54.9	20.3[ab]	26.1	5.8
	Pioneer 947	32.9	55.7	22.8[a]	23.9	5.0
	Silomaker	31.6	55.9	23.4[a]	23.8	4.2
	Cow Vittles	31.5	49.8	18.3[b]	24.0	4.6
	DeKalb 25E	33.1	55.9	22.8[a]	25.4	4.6
V	Canex	28.4	47.2	18.7	21.5	4.6
	Sweet Bee	32.9	51.7	18.8	23.3	5.2
	Pioneer 947	31.8	50.5	18.7	23.3	5.2
	Silomaker	30.8	49.7	18.8	22.4	5.4
	Cow Vittles	33.4	50.7	17.4	25.1	5.1
	DeKalb 25E	36.1	54.5	17.8	26.9	5.5
VI	Canex	26.3	46.0	19.7[ab]	20.5	3.2
	Sweet Bee	30.5	53.3	22.8[ab]	22.9	3.9
	Pioneer 947	30.9	52.3	21.1[ab]	23.3	4.1
	Silomaker	30.4	50.0	19.5[b]	23.0	4.1
	Cow Vittles	35.6	56.8	23.9[a]	27.5	4.6
	DeKalb 25E	34.4	55.8	21.3[ab]	26.8	4.5
[1]H x HS (P<)		.0007	.01	—	.01	.008
[2]LSD (P<.05)		—	—	4.32	—	—
SE		.78	1.42	1.52	.71	.26

[1]H x HS means hybrid by harvest stage interaction.
[2]The LSD is valid only within harvests.

TABLE 16. EFFECT OF HARVEST STAGE WITHIN HYBRID ON VAN SOEST CONSTITUENTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Hybrid	Harvest stage	ADF	NDF	Hemi-Cellulose	Cellulose	Lignin
		% of the silage DM				
Canex	IV	27.9	48.1	20.1	20.8	4.6
	V	28.4	47.2	18.7	19.7	4.6
	VI	26.3	46.0	19.7	20.5	3.2
Sweet Bee	IV	34.6[a]	54.9	20.3	26.1[a]	5.8
	V	32.9[ab]	51.7	18.8	23.3[b]	5.2
	VI	30.5[b]	53.3	22.8	22.9[b]	3.9
Pioneer 947	IV	32.9	55.7[a]	22.8	23.9	5.0
	V	31.8	50.5[b]	18.7	23.3	5.2
	VI	30.9	52.3[ab]	21.1	23.3	4.1
Silomaker	IV	31.6	55.9[a]	24.3	23.8	4.2
	V	30.8	49.7[b]	18.8	22.4	5.2
	VI	30.4	50.0[b]	19.5	23.0	4.1
Cow Vittles	IV	31.5[b]	49.8[b]	18.3	24.0[b]	4.6
	V	33.4[ab]	50.7[b]	17.4	25.1[b]	5.1
	VI	35.6[a]	56.8[a]	23.9	27.5[a]	4.6
DeKalb 25E	IV	33.1[b]	55.9	22.8	25.4	4.6
	V	36.1[a]	54.5	17.8	26.9	5.5
	VI	34.4[ab]	55.8	21.3	26.8	4.5
[1]LSD ($P<.05$)		2.46	4.52	—	2.07	2.27
SE		.78	1.42	1.52	.71	.26

[1]The LSD is valid only within hybrid.

TABLE 17. EFFECT OF HYBRID ON NITROGEN CONSTITUENTS AND FERMENTATION END PRODUCTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Hybrid	pH	Total N	HWIN	Fermentation acids Lactic	Acetic	Total	Lactic: acetic
	% of the silage DM						
Canex	3.95^{ab}	1.05	.48^{bc}	9.00^{a}	3.05	12.05^{a}	2.95
Sweet Bee	3.92^{ab}	1.10	.54^{a}	7.67^{ab}	2.99	10.68^{a}	2.57
Pioneer 947	4.18^{a}	1.43	.55^{a}	6.15^{b}	2.21	8.40^{b}	2.78
Silomaker	4.02^{ab}	1.35	.49^{ab}	8.50^{ab}	2.54	11.10^{ab}	3.35
Cow Vittles	3.83^{ab}	1.26	.41^{c}	8.44^{ab}	3.38	11.82^{ab}	2.50
DeKalb 25E	3.77^{b}	1.29	.39^{d}	8.71^{ab}	3.74	12.45^{a}	2.33
[1]H x HS (P<)	—	—	—	—	.0001	—	.01
[2]LSD (P<.05)	.39	—	.07	2.79	—	3.45	—
SE	.15	--	.02	.98	.13	1.01	.45

[1]H x HS means hybrid by harvest stage interaction.
[2]LSD is valid across all means.

TABLE 18. EFFECT OF HARVEST STAGE ON NITROGEN CONSTITUENTS AND FERMENTATION END PRODUCTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Harvest stage	Hybrid	pH	Total N	HWIN	Fermentation acids Lactic	Acetic	Total	Lactic: acetic
			% of the silage DM					
IV	Canex	3.81^{ab}	1.14	$.48^{ab}$	7.56^{ab}	3.60	11.16	2.10
	Sweet Bee	3.75^{b}	1.11	$.53^{a}$	9.05^{ab}	3.19	12.25	2.84
	Pioneer 947	4.10^{a}	1.45	$.55^{a}$	6.03^{b}	2.6	8.63	2.32
	Silomaker	3.85^{ab}	1.31	$.44^{a}$	11.52^{a}	2.02	13.61	5.70
	Cow Vittles	3.75^{b}	1.30	$.36^{c}$	9.46^{ab}	2.59	12.05	3.65
	DeKalb 25E	3.72^{b}	1.32	$.40^{bc}$	6.66^{b}	3.28	9.95	2.03
V	Canex	3.92^{ab}	.96	$.45^{ab}$	8.02	3.11	11.13	2.58
	Sweet Bee	3.84^{b}	1.00	$.52^{a}$	7.58	3.66	11.25	2.07
	Pioneer 947	4.14^{a}	1.39	$.55^{a}$	7.53	1.81	9.44	4.16
	Silomaker	4.05^{ab}	1.36	$.51^{a}$	6.32	2.73	9.13	2.32
	Cow Vittles	3.81^{b}	1.23	$.45^{ab}$	7.92	3.78	11.70	2.10
	DeKalb 25E	3.79^{b}	1.27	$.35^{b}$	8.34	4.01	12.36	2.08
VI	Canex	4.12^{ab}	1.10	$.51^{a}$	11.41^{a}	2.45	13.86^{a}	4.66
	Sweet Bee	4.17^{ab}	1.08	$.57^{a}$	6.38^{bc}	2.10	8.56^{b}	3.04
	Pioneer 947	4.30^{a}	1.46	$.54^{a}$	4.89^{c}	2.21	7.14^{b}	2.21
	Silomaker	4.16^{ab}	1.37	$.52^{ab}$	7.68^{abc}	2.86	10.57^{ab}	2.69
	Cow Vittles	3.93^{bc}	1.24	$.42^{b}$	7.94^{abc}	3.75	11.70^{ab}	2.12
	DeKalb 25E	3.80^{c}	1.29	$.42^{b}$	11.12^{ab}	3.93	15.04^{a}	2.83
[1]H x HS (P<)		—	—	—	—	.0001	—	.01
[2]LSD (P<.05)		.29	—	.11	4.83	—	4.99	—
SE		.15	—	.05	1.70	.23	1.75	.78

[1]H x HS mean hybrid by harvest stage interaction.
[2]The LSD is valid only within harvest stage.

TABLE 19. EFFECT OF HARVEST STAGE WITHIN HYBRID ON NITROGEN CONSTITUENTS AND FERMENTATION END PRODUCTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Hybrid	Harvest stage	pH	Total N	HWIN	Fermentation acids Lactic	Acetic	Total	Lactic: acetic
			% of the silage DM					
Canex	IV	3.81	1.14	.48	7.56	3.60[a]	11.16	2.10[b]
	V	3.92	.96	.45	8.02	3.11[ab]	11.13	2.58[b]
	VI	4.12	1.10	.51	11.41	2.45[b]	13.86	4.66[a]
Sweet Bee	IV	3.75	1.11	.53	9.05	3.19[a]	12.25	2.84
	V	3.84	1.00	.52	7.58	3.66[a]	11.25	2.07
	VI	4.17	1.08	.57	6.38	2.10[b]	8.56	3.04
Pioneer 947	IV	4.10	1.45	.55	6.03	2.60[a]	8.63	2.32
	V	4.14	1.39	.55	7.53	1.81[b]	9.44	4.16
	VI	4.30	1.46	.54	4.89	2.21[ab]	7.41	2.21
Silomaker	IV	3.85	1.31	.44	11.52	2.02[b]	13.61	5.70[a]
	V	4.05	1.36	.51	6.32	2.73[ab]	9.13	2.32[b]
	VI	4.16	1.37	.52	7.68	2.86[a]	10.57	2.69[b]
Cow Vittles	IV	3.75	1.30	.36	9.46	2.59[b]	12.05	3.65
	V	3.81	1.23	.45	7.92	3.78[a]	11.70	2.10
	VI	3.93	1.24	.42	7.94	3.75[a]	11.70	2.12
DeKalb 25E	IV	3.72	1.32	.40	6.66	3.28	9.95	2.03
	V	3.79	1.27	.35	8.34	4.01	12.36	2.08
	VI	3.80	1.29	.42	11.12	3.93	15.04	2.83
[1]LSD (P<.05)		—	--	--	--	.74	—	2.04
SE		.15	--	--	1.70	.23	1.75	.78

[1]The LSD is valid only among hybrids.

APPENDIX

APPENDIX TABLE 1. EFFECTS OF FORAGE SORGHUM HYBRID AND HARVEST STAGE ON DIET VOLUNTARY INTAKE AND APPARENT DIGESTIBILITY IN EXP. 1

Hybrid and harvest stage	VI		Digestibility, %				
	g DM/d	g DM/kg body wt$^{.75}$	DM	OM	CP	NDF	ADF
DeKalb 25A							
I	513	34.4^{c}	56.1^{abc}	52.4^{abc}	64.3^{c}	51.5^{ab}	52.8^{ab}
II	561	38.4^{abc}	55.1^{c}	50.3^{bc}	67.2^{bc}	58.6^{a}	55.2^{a}
III	620	40.6^{abc}	56.5^{abc}	51.6^{abc}	67.1^{bc}	46.1^{bc}	44.2^{abcd}
IV	579	41.7^{abc}	57.0^{abc}	52.1^{abc}	70.7^{ab}	46.5^{bc}	40.4^{cd}
V	645	46.3^{ab}	55.7^{abc}	50.7^{bc}	69.9^{ab}	47.3^{bc}	38.5^{cd}
VI	571	38.4^{abc}	54.3^{c}	49.5^{c}	73.6^{a}	40.6^{c}	37.0^{d}
Funk's G-1990							
I	507	34.1^{c}	54.9^{c}	50.3^{bc}	64.7^{c}	52.0^{ab}	46.3^{abcd}
II	642	40.7^{abc}	60.4^{a}	56.4^{a}	73.5^{a}	57.8^{a}	55.3^{a}
III	589	47.5^{ab}	59.7^{ab}	55.3^{ab}	71.4^{ab}	54.2^{ab}	53.8^{ab}
IV	581	42.0^{abc}	55.9^{abc}	51.2^{bc}	71.4^{ab}	51.0^{ab}	48.9^{ab}
V	606	48.0^{a}	54.4^{c}	49.4^{c}	69.5^{ab}	50.6^{ab}	48.1^{abc}
VI	544	41.4^{abc}	55.0^{c}	49.7^{c}	70.6^{ab}	47.5^{bc}	47.2^{abc}

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

APPENDIX TABLE 2. EFFECTS OF FORAGE SORGHUM HYBRID AND HARVEST STAGE ON DIET VOLUNTARY INTAKE AND APPARENT DIGESTIBILITY IN EXP. 2[1]

Hybrid and harvest stage	VI g DM/d	VI g DM/kg body wt$^{.75}$	Digestibility, % DM	OM	CP	NDF	ADF
Acco 351							
IV	641^{ab}	45.9^{abc}	57.2^{a}	56.3^{a}	66.6^{bc}	66.3^{a}	37.4^{bc}
V	624^{ab}	48.1^{ab}	57.5^{a}	56.2^{a}	69.7^{ab}	49.7^{ab}	29.1^{c}
VI	652^{a}	50.1^{a}	56.6^{ab}	55.3^{ab}	67.8^{bc}	43.5^{c}	36.0^{bc}
DeKalb 25E							
IV	554^{bc}	43.2^{bc}	57.4^{a}	56.0^{a}	67.9^{abc}	53.2^{ab}	42.7^{abc}
V	532^{c}	41.4^{bc}	54.3^{c}	52.5^{b}	65.1^{c}	48.0^{ab}	38.5^{bc}
VI	565^{bc}	43.5^{abc}	55.9^{ab}	54.5^{ab}	68.9^{abc}	49.3^{ab}	43.8^{ab}
Funk's G-1990							
IV	558^{bc}	42.9^{bc}	56.1^{ab}	54.9^{ab}	69.7^{ab}	55.1^{ab}	48.4^{a}
V	509^{c}	39.4^{c}	56.9^{ab}	55.8^{a}	69.9^{ab}	56.6^{ab}	48.4^{a}
VI	516^{c}	40.1^{c}	57.1^{a}	55.1^{ab}	72.1^{a}	54.0^{ab}	49.2^{a}

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

APPENDIX TABLE 3. EFFECTS OF HYBRID AND HARVEST STAGE ON WHOLE-CROP DRY MATTER AND CRUDE PROTEIN CONTENTS, WHOLE-CROP AND GRAIN YIELDS, GRAIN TO FORAGE RATIOS, AND LODGING FOR THE FORAGE SORGHUMS IN EXP. 3

Hybrid	Harvest stage	Whole-crop DM, %	Whole-crop CP, % (DM basis)	DM yield[1] Whole-crop	DM yield[1] Grain	Grain: forage	Lodging, %
Canex	IV	25.8[gh]	7.1	12.0[i]	.33	.20	0.0
	V	27.2[e]	5.7	13.0[fg]	.50	.30	7.5
	VI	29.2[d]	6.8	13.6[cde]	.51	.28	11.5
Sweet Bee	IV	24.8[hi]	6.9	12.1[i]	.42	.26	15.8
	V	26.8[efg]	6.8	13.4[def]	.54	.31	34.3
	VI	30.4[c]	6.7	14.5ab	.59	.31	44.0
Pioneer 947	IV	30.5[c]	9.1	12.3[hi]	.45	.28	.8
	V	31.7[b]	8.7	13.3[ef]	.76	.51	2.8
	VI	41.9[a]	9.1	14.1[bc]	.71	.44	7.3
Silomaker	IV	27.0[ef]	8.2	13.7[cde]	.38	.20	3.0
	V	30.5[c]	8.5	14.5[ab]	.57	.30	2.0
	VI	30.1[cd]	8.6	12.7[gh]	.46	.28	12.3
Cow Vittles	IV	24.5[i]	8.1	13.9[cd]	.21	.10	6.0
	V	26.0[fg]	7.7	13.5[def]	.33	.16	10.8
	VI	25.8[gh]	7.7	12.2[hi]	.39	.24	28.5
DeKalb 25E	IV	26.9[ef]	8.3	14.7[a]	.09	.04	0.0
	V	24.7[i]	7.9	13.9[cd]	.11	.05	0.0
	VI	24.7[i]	8.1	13.6[cde]	.10	.04	0.0
[2]LSD (P<.0)		1.0	—	.58	—	—	—
SE		.5	.32	.45	.04	.04	4.1

[1]Metric tons per hectare.

[2]The LSD is valid across all means.

APPENDIX TABLE 4. EFFECTS OF HYBRID AND HARVEST STAGE ON VAN SOEST CONSTITUENTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Hybrid	Harvest stage	ADF	NDF	Hemi-Cellulose	Cellulose	Lignin
		% of the silage DM				
Canex	IV	27.9^{jk}	48.1^{fgh}	20.1	20.8^{jk}	4.7^{ab}
	V	28.4^{j}	47.2^{gh}	18.7	19.7^{hij}	4.6^{ab}
	VI	26.3^{k}	46.0^{h}	19.7	20.5^{k}	3.2^{b}
Sweet Bee	IV	34.6^{bc}	54.9^{ab}	20.3	26.1^{bc}	5.8^{a}
	V	32.9^{efg}	51.7^{de}	18.8	23.3^{efgh}	5.2^{ab}
	VI	30.5^{hi}	53.3^{bcd}	22.8	22.9^{gh}	3.9ab
Pioneer 947	IV	32.9^{efg}	55.7^{ab}	22.8	23.9^{ef}	5.0^{ab}
	V	31.8^{fgh}	50.5^{ef}	18.7	23.3^{efgh}	5.2^{ab}
	VI	30.9^{hi}	52.3^{cde}	21.1	23.3^{efgh}	4.2^{ab}
Silomaker	IV	31.6^{ghi}	55.9^{ab}	24.3	23.8^{efg}	4.2^{ab}
	V	30.8^{hi}	49.7^{efg}	18.8	22.4^{hi}	5.2^{ab}
	VI	30.4^{i}	50.0^{ef}	19.5	23.0^{fgh}	4.1^{ab}
Cow Vittles	IV	31.5^{hi}	49.8^{ef}	18.3	24.0^{e}	4.6^{ab}
	V	33.4^{cde}	50.7^{de}	17.4	25.1^{d}	5.1^{ab}
	VI	35.6^{ab}	56.8^{a}	23.9	27.5^{a}	4.6^{ab}
DeKalb 25E	IV	33.1^{def}	55.9^{a}	22.8	25.4^{cd}	4.6^{ab}
	V	36.1^{a}	54.5^{abc}	17.8	26.9^{ab}	5.6^{a}
	VI	34.4^{bcd}	55.8^{ab}	21.3	26.8^{ab}	4.5^{ab}
[1]LSD (P<.05)		1.40	2.62	—	.96	2.18
SE		.78	1.42	1.52	.71	.26

[1]The LSD is valid across all means.

APPENDIX TABLE 5. EFFECTS OF HYBRID AND HARVEST STAGE ON FERMENTATION END PRODUCTS FOR THE FORAGE SORGHUM SILAGES IN EXP. 3

Hybrid	Harvest stage	pH	Fermentation acids: Lactic	Acetic	Total	Lactic: acetic
			% of the silage DM			
Canex	IV	3.81	7.56	3.60[abc]	11.16	2.10[fg]
	V	3.92	8.02	3.11[de]	11.13	2.58[defg]
	VI	4.12	11.41	2.45[fgh]	13.86	4.66[b]
Sweet Bee	IV	3.75	9.05	3.19[cd]	12.25	2.84[de]
	V	3.84	7.58	3.66[ab]	11.25	2.07[g]
	VI	4.17	6.38	2.10[hi]	8.56	3.04[d]
Pioneer 947	IV	4.10	6.03	2.60[fg]	8.63	2.32[efg]
	V	4.14	7.53	1.81[i]	9.44	4.16[bc]
	VI	4.30	4.89	2.21[ghi]	7.41	2.21[fg]
Silomaker	IV	3.85	11.52	2.02[i]	13.61	5.70[a]
	V	4.05	6.32	2.73[ef]	9.13	2.32[efg]
	VI	4.16	7.68	2.86[def]	10.57	2.69[def]
Cow Vittles	IV	3.75	9.46	2.59[fg]	12.05	3.65[c]
	V	3.81	7.92	3.78[a]	11.70	2.10[fg]
	VI	3.93	7.94	3.75[a]	11.70	2.12[fg]
DeKalb 25E	IV	3.72	6.66	3.28[bcd]	9.95	2.03[g]
	V	3.79	8.34	4.01[a]	12.36	2.08[g]
	VI	3.80	11.12	3.93[a]	15.04	2.83[de]
[1]LSD (P<.05)		—	—	.42	—	.60
SE		.15	1.70	.23	1.75	.78

[1]The LSD is valid across all means.

YIELD, COMPOSITION, AND NUTRITIVE VALUE OF FORAGE SORGHUM SILAGES: HYBRID AND STAGE OF MATURITY EFFECTS

by

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Abstract

Two experiments were conducted to determine the effects of hybrid and stage of maturity at harvest on the yield and nutritive value of forage sorghum silage. A third experiment measured the effect of hybrid and stage of maturity on yield, composition, and silage quality of six forage sorghums. In Exp. 1, harvests were made at six stages: boot (I); anthesis (II); milk (III); early-dough (IV); late-dough (V); and post-freeze, hard-grain (VI). Only stages IV, V and VI were harvested in Exp. 2. Each silage was fed to lambs in digestion trials. Silage dry matter (DM) content increased with advancing maturity, but did not exceed 28% for either DeKalb 25A, DeKalb 25E, or Funk's G-1990 in either experiment. However, Acco 351 silages had the highest DM at all three stages in Exp. 2 and Acco 351 also had the highest ($P<.05$) silage DM intake in Exp. 2. Silage DM intake generally increased as harvest stage advanced. Digestibilities of DM and organic matter were not affected by hybrid. Van Soest constituents were highest in both experiments for the non heading hybrid (G-1990). Crude protein (CP) digestibility increased with advancing maturity in both experiments. In the third experiment, six forages sorghum hybrids were each harvested at stages of maturity indentical to those in Exp. 2. Chopped material from each of four sub-plots was collected and ensiled in laboratory silos. Canex was the earliest ($P<.05$), and DeKalb 25E, Cow Vittles, and Silomaker were latest ($P<.05$) maturing hybrids. The earlier-maturing hybrids were lower ($P<.05$) in CP content than intermediate maturing-hybrids. Grain yield and grain to forage ratio were highest ($P<.05$) for Pioneer 947; lowest ($P<.05$) for DeKalb 25E. The whole-crop DM yields were not consistently affected by hybrid or harvest stage. Sweet Bee harvested at stage VI had the highest ($P<.05$) percentage of plants lodged. The higher grain-containing silages were highest in acid detergent fiber content at stage IV. Lignin content did not differ ($P<.05$) among hybrids or harvest stages. The higher DM

Pioneer 947 silages had the highest pH and lowest lactic and total fermentation acids. Data from the 10 hybrids used in these experiments showed only small changes in nutrient content with advancing maturity. However, there were large variations among the hybrids in DM content at similar harvest dates. Thus, proper management must be exercised in matching the selection of forage sorghum hybrids with expected animal performances.