Harvest Timing and Byproduct Addition Effects on Corn and Forage Sorghum Silage Grown Under Water Stress

Bulletin 799

Mark A. Marsalis*, Sangu Angadi, Francisco E. Contreras-Govea, Rex E. Kirksey[1]

Agricultural Experiment Station • College of Agricultural, Consumer and Environmental Sciences

Department of
Extension Plant Sciences

ABSTRACT

Reduced irrigation may limit yield and nutritional value of forage sorghum (FS) [*Sorghum bicolor* (L.) Moench] and corn (*Zea mays* L.) in large-scale silage systems, and byproduct additions may improve feeding value of ensiled low-quality crops when harvest is delayed. A 2-yr study was conducted to investigate effects of harvest timing on corn, conventional forage sorghum (C-FS), and brown midrib forage sorghum (BMR-FS) production when irrigated at a restricted level and effects of byproduct additions on silage quality. Irrigation was applied at 33 mm wk^{-1}. Crops were harvested at two dry matter (DM) concentrations: optimum for ensiling (350–400 g kg^{-1}) and late for ensiling (410–500 g kg^{-1}). Cheese industry byproduct additions were 4.0 and 7.5% of actual harvest moisture content. Conventional FS produced more DM than corn and BMR-FS when harvested at optimum stage (C-FS, 21.1 Mg ha^{-1}; corn, 18.2 Mg ha^{-1}; BMR-FS, 16.9 Mg ha^{-1}); however, yields for C-FS and corn were similar at late harvest. Net energy for lactation (NE_L) was reduced at late harvest for all crops, and NE_L of both FS was lower than that of corn. Forage sorghum maintained greater neutral detergent fiber digestibility (NDFD) than corn. Byproduct addition improved NE_L of silage only in corn and BMR-FS at late harvest.

INTRODUCTION

Declining underground water levels in the Ogallala Aquifer in eastern New Mexico and West Texas are threatening the sustainability of highly productive agriculture in these areas. Producers are facing limited or no water for irrigation and are forced to grow crops that are highly efficient water users. The decline in water resources is further exacerbated by increasing demand for good quality forages in the region by the seventh largest and fastest growing dairy industry and the largest concentration of beef cattle in the country (Cabrera and Hagevoort, 2006). Dairy cow numbers are increasing at a rate greater than 5% per year (2000–2005) in New Mexico due to recent influxes of dairy operations from other parts of the U.S. It appears that large numbers of cattle will continue to be a principal component of crop marketing for area producers. Therefore, water conservation and improving water use efficiency of forage crops are high priorities.

Corn (*Zea mays* L.) silage is used extensively for lactating dairy cows that require feed with a high energy content for maximum milk production. However, corn requires large amounts of water (up to 770 mm yr^{-1}; Howell et al., 2008; Howell et al., 1997; New and Dusek, 2005; Gowda et al., 2007) in order to be high yielding and of adequate nutrition for the dairy industry. One option to maintain forage production under declining water resources is to replace corn with more water use-efficient crops such as forage sorghum [FS; *Sorghum bicolor* (L.) Moench]. Sorghum is better suited than corn to semi-arid conditions for several reasons, including lower transpiration ratios, slower leaf and stalk wilting, recovery after

---

*Corresponding author: Agricultural Science Center at Clovis, New Mexico State University, 2346 SR 288, Clovis, NM 88101; 575-985-2292 (tel); 575-985-2419 (fax); marsalis@nmsu.edu

[1] Respectively, Extension Agronomy Specialist, Agricultural Science Center at Clovis; Crop Physiologist, Agricultural Science Center at Clovis; Agronomist, Agricultural Science Center at Artesia; and Superintendent/Agricultural Economist, Agricultural Science Center at Clovis, all of New Mexico State University.

drought, and tillering (Martin, 1930). In general, sorghum requires 25% less water than corn (Martin et al., 1976), and FS has been shown to have 27% lower evapotranspiration (ET) than corn (Howell et al., 2008). In addition, regional research has indicated that FS tested over many varieties can be 25% more productive with the same amount of water applied through irrigation (Bean and McCollum, 2006). Further, it has been documented in other areas of the U.S. that FS has the potential to produce as much, and in some cases more, dry matter (DM) than corn when grown with the same amount of water (Anderson and Guyer, 1986; Teutsch, 2002). Preliminary results from research conducted at Bushland, TX, indicate that FS maintains lower ET rates throughout the growing season and uses less cumulative water (Howell et al., 2008). Even at similar ET rates, corn tends to use more water than sorghum in the Southern High Plains because of earlier planting dates and longer growing seasons (Howell et al., 1997). Sorghum has exhibited better potential as an alternative silage crop than other corn types such as popcorn and sweet corn (Kurle et al., 1991).

Historically, sorghum silage energy and digestibility have been lower than that of corn (NRC, 1996, 2001), and its acceptance among dairies and feedlots has been limited. Dairy farmers have been reluctant to utilize sorghum for feeding lactating cows, and many have not explored other, more water use-efficient crops. In recent years, however, sorghum forage quality has improved through extensive breeding efforts and selection of highly nutritious varieties for use as silage. Forage sorghum varieties have exhibited equal or higher quality nutrition than corn in the Texas Panhandle (Bean and McCollum, 2006). In addition, the brown midrib (BMR) trait in sorghum, characterized by reduced lignin concentrations, has significantly improved the digestibility of many varieties to a level close to that of corn (Oliver et al., 2004; Bean and McCollum, 2006; Grant et al., 1995). Lignin concentrations in conventional FS limit DM intake and milk production (Aydin et al., 1999). Popularity of the BMR sorghums is increasing, and questions from growers and dairy producers alike have led to a great need for research involving these varieties, not only for yield data, but for nutritive information as well. Many concerns exist about lodging potential, yield reductions, and overall plant fitness of sorghums with the BMR trait and reduced lignin (Pedersen et al., 2005; Miron et al., 2006; Casler et al., 2003; Beck et al., 2007). If forage quality of sorghum can be maintained at acceptable levels while conserving water and reducing costs associated with irrigation, growers and dairies may be willing to utilize sorghum forages on a larger scale.

Improving sorghum silage nutritive value is another area of interest and necessary research. Feed quality may be improved by additions of high-energy materials, such as corn grain, liquid whey or lactose, molasses, and various other grains, prior to ensiling (Linn et al., 1996). Liquid and dry whey contain high levels of lactose, which provides a source of fermentable carbohydrate that can be utilized by ruminants (Linn et al., 1996). Defrain et al. (2004) indicated that feeding lactose increased DM intake of lactating dairy cows without harming the animals. Moreover, feeding costs were reduced when whey silage was fed compared with corn silage and alfalfa hay (ZoBell and Burrell, 2002).

Many silage crops are harvested by custom harvest operations that provide only a small window of opportunity for each grower to have their crop removed at the proper time. Weather delays or scheduling conflicts can result in significant drying of crops to levels inadequate for suitable ensiling. Adding liquid might provide an increase in moisture content that may improve fermentability of dry sorghum and corn in these delay situations. Although starch content increases with plant maturity, overall corn plant nutritive value may be reduced with increasing DM levels (Browne et al., 2005). In contrast, Bolsen and Sonon (1997) and Darby and Lauer (2002) indicated that, although crude protein (CP) levels declined with advancing corn and FS maturity, neutral detergent fiber (NDF) and acid detergent fiber (ADF) content declined also, while *in vitro* true digestibility (IVTD) increased, potentially leading to greater overall nutritive value of the resultant silage. Whole plant DM content and dry down are variable among hybrids and weather conditions (Ma et al., 2006; Darby and Lauer, 2002), and information on proper DM levels is limited in the Southern High Plains where successful silage crop production is dependent upon supplemental irrigation. It is uncertain what effects restricted irrigation will have on overall performance of corn and sorghum crops with respect to yield and forage nutritive value. Addition of liquid cheese byproduct prior to ensiling may improve energy of sorghum silage to levels commonly associated with traditional corn silage and adequate for high production dairy cows. While moisture additions are not considered the same as the plant's own moisture content, added liquid could be important if sorghum harvest is delayed for weather reasons or custom harvester scheduling as plants dry down to a DM level greater than that required for proper ensiling.

The overall objectives of this research were to compare DM yield and nutritive value of conventional FS (C-FS), brown midrib FS (BMR-FS), and corn at two maturity stages under water restriction, and to assess the effects of adding a cheese byproduct on the energy value of silage of these three crops. Specifically, forage yield and nutritive value of pre- and post-ensiled material from two harvests and three byproduct levels added post-harvest were of interest.

MATERIALS AND METHODS

Crop Production Phase

Research was conducted in 2005 and 2006 at the New Mexico State University Agricultural Science Center at Clovis, NM (103°12' W, 34°35' N, 1,348 m elevation). The region is characterized as semi-arid, and mean annual precipitation is 445 mm. Soil type is an Olton clay loam (Fine, mixed, superactive, thermic Aridic Paleustoll). Treatments were applied in a split plot arrangement and consisted of three crops (main plot) and two harvests (subplot). Crops used were corn (cv. DKC 69-71, RR2/YGCB, Monsanto Co., St. Louis, MO), conventional forage sorghum (cv. FS-5, Monsanto Co.), and brown midrib forage sorghum (cv. BMR 106, Seed Resource Co., Tulia, TX). These crops were considered regional standards for silage crop production at the time of testing and have exhibited high yields and nutritive value in other testing programs in the region (Bean and McCollum, 2006; Kirksey et al., 2005). Plants were seeded in 46.45 m^2 (1.52 m x 30.40 m) plots at typically recommended rates for each crop under limited irrigation conditions: corn, 70,000 seeds ha^{-1}; C-FS, 415,000 seeds ha^{-1}; BMR-FS, 191,000 seeds ha^{-1}. Planting dates were 2 May 2005 and 27 April 2006 for corn and 25 May 2005 and 22 May 2006 for both C-FS and BMR-FS. Harvests included an 'optimum' DM (350–400 g kg^{-1}) cutting and a 'late' DM (410–500 g kg^{-1}) cutting. Forage sorghum was seeded at later dates because of different soil temperature requirements for corn and sorghum. Samples were collected twice per week from adjacent border areas to determine actual whole-plant DM content of each crop. Crops were harvested on the following dates: corn (optimum) – 7 Sept. 2005, 2006; corn (late) – 16 Sept. 2005, 20 Sept. 2006; C-FS (optimum) – 27 Sept. 2005, 2006; C-FS (late) – 16 Nov. 2005, 1 Nov. 2006; BMR-FS (optimum) – 23 Sept. 2005, 20 Sept. 2006; BMR-FS (late) – 14 Nov. 2005, 1 Nov. 2006. Optimum harvest DM was based on regional standards for chopping silage crops and research showing that maximum forage quality is obtained between 300 and 370 g kg^{-1} of DM (Darby and Lauer, 2002).

The study was irrigated with a center pivot system (Zimmatic, Lindsay Corp., Omaha, NE), the most typical method for the region. Limited research on FS in the area has utilized sprinkler application of water (Howell et al., 2008) and none are known to have used center pivot method; therefore, this study is considered appropriate and unique in its scope to add to the literature. Spray heads (Low Drift Nozzle) on drops were fitted with 69-kPa pressure regulators (Senninger Irrigation, Inc., Clermont, FL) and were located 1.5 m apart and 0.45 m above the ground. Pre-season irrigations totaling 76 mm were applied in each year to ensure a full soil profile to a depth of 1.2 m. In-season irrigation set to 33 mm/wk (16.5 mm every 3.5 d) began immediately after planting and simulated a well capacity of 96.5 m^3 hr^{-1} on 48.6 ha, which is considered to be limiting for optimal corn production in the region. Target total seasonal irrigation (regardless of precipitation) was 508 mm. Actual mean 2-yr water amounts applied were 510 mm for corn and 456 mm for both C-FS and BMR-FS. Total seasonal irrigation amounts varied slightly between corn and sorghums due to differences in plant maturities (e.g., longer growing season for corn) and the need for termination of irrigation in order for plants to dry down properly. Forage sorghum dries at a slower rate compared to corn (personal observations), and irrigation termination soon after optimum harvest was deemed necessary. Continuing to irrigate FS to match amounts applied to corn would have likely resulted in prolonged delays in harvest and unnecessary variation due to exacerbated quality decline in the field. Total seasonal (April–November) precipitation averaged 308 mm for the 2-yr study (Figure 1); mean long-term (1929–2007) seasonal precipitation for the area is 381 mm. The research plots received below normal precipitation (2-yr mean) in all seasonal months except August and September. The month of August was exceptionally wet, receiving greater than 125 mm of rainfall in both years, 1.6 times the normal amount.

All plots were fertilized in the spring prior to planting as dictated by soil tests; annual applications consisted of 224 kg N ha^{-1}, 67 kg P_2O_5 ha^{-1}, 22 kg S ha^{-1}, and 11 kg Zn ha^{-1} to all plots except BMR-FS, which received all of the same fertilizers except for a reduced nitrogen rate (112 kg N ha^{-1}). This low rate of nitrogen is recommended for BMR-FS to prevent lodging. Previous research has suggested that high amounts of nitrogen do not necessarily improve yields, but may increase the incidence of FS lodging, particularly in early-released BMR hybrids (Bean et al., 2003). In further support, variety trials conducted at Clovis indicate lower yields of BMR-FS under conditions of equal, non-limiting N application (Kirksey et al., 2005; Marsalis et al., 2007, 2008). Each crop was treated as a separate system with best management practices imposed upon the respective system. Reduced seeding and N fertility rates on BMR-FS are considered best management for the crop. Bicep Lite II Mag herbicide (Syngenta Crop Protection, Inc., Greensboro, NC) was applied at a rate of 3.5 liters ha^{-1} to give 0.454 kg atrazine ha^{-1} (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) and 0.56 kg S-metolachlor ha^{-1} [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-([1S]-2-methoxy-1-methylethyl)] acetamide on all plot areas for weed control immediately after planting of each crop in both years. Twospotted spider mites (*Tetranychus urticae* Koch) and Banks grass mites (*Oligonychus pratensis* Banks) were controlled with Comite insecticide (Chemtura USA Corp., Middlebury, CT) on 12 June 2006 at a rate of 1.75 liters ha^{-1} of propargite [2-(p-tert-butylphenoxy) cyclohexyl 2-propynyl sulfite] active ingredient.

At all harvests, a tractor drawn forage harvester was used to chop plants within each treatment (46.45 m^2) to a particle size of 12.7 mm. Plant material was collected in a basket and weighed to estimate wet yield per ha. A 400-g subsample was taken for estimates of DM concentration and nutritive value. Subsamples were oven dried at 55°C for 48 hr. Once dry, collected material was weighed to estimate yield on a dry basis, ground to 1 mm using a Wiley Mill (Comeau Technique Ltd., Vandreuil-Dorion, Quebec, Canada), and stored at room temperature for further analysis. A subset of wet material from each treatment was collected immediately after chopping to be prepared for the ensiling phase with byproduct additions described below.

Ground forage from harvest was analyzed by near-infrared (NIRSystems, Inc., Silver Spring, MD) absorption techniques at the University of Wisconsin Soil/Forage Analysis Laboratory, Marshfield, WI (National Forage Testing Association certified laboratory for NIR), to predict pre-ensiled levels of NDF, neutral detergent fiber digestibility (NDFD), and CP. Developed equations were based on wet chemistry of annually selected samples (Van Soest et al., 1991; Goering and Van Soest, 1970) of corn and FS and must be within a defined range of means approved by the NIRS Consortium. Non-fiber carbohydrates (NFC) and net energy for lactation (NE_L) were calculated using equations described in NRC (2001).

The crop production phase was a randomized complete block design with a split plot arrangement and four replications (Steel and Torrie, 1981) of crop as the main plot and harvest as the subplot. All forage yield and nutritive value parameters were analyzed using the GLM procedure in SAS that tested main effects of year, crop, harvest, and their interactions (SAS Institute, 1999). Differences among means were separated by the least significant difference test when *F* tests were significant ($P \leq 0.05$; Steel and Torrie, 1981).

Ensiling Phase

At harvest, 136 kg of freshly ground plant material from each crop were collected and prepared for ensiling. Prior to ensiling, material of all crops and from both harvests was mixed with appropriate proportions of cheese byproduct permeate obtained from a regional cheese processing facility. The permeate chosen

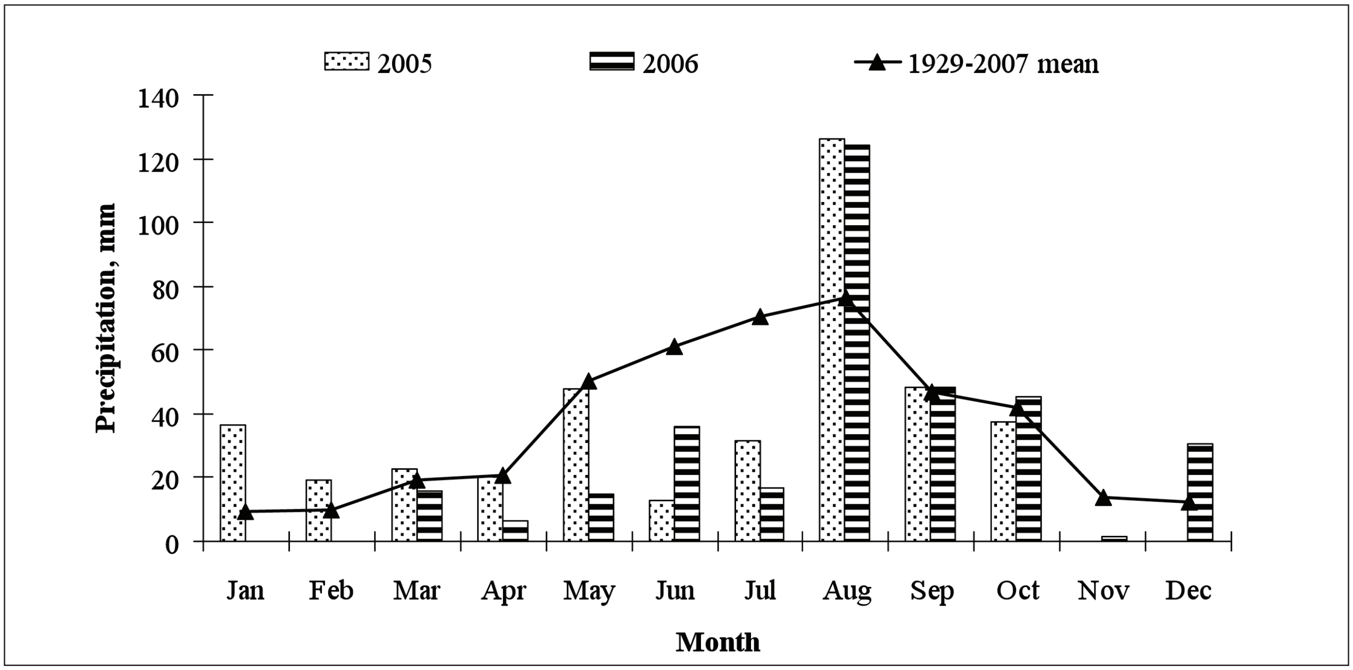

Figure 1. **Mean monthly 2005, 2006, and long-term (1929–2007) precipitation at experiment location near Clovis, NM.**

Table 1. Makeup of Cheese Permeate Byproduct Used for Additions to Harvested Corn and Forage Sorghum (FS) Plant Material Prior to Ensiling

Parameter	As Mixed
	g kg^{-1}
Moisture	908
DM	92
	g kg^{-1} DM
Crude protein	4.70
Calcium	0.50
Phosphorus	0.57
Total fatty acids	0.76
Total sugars	60.90
Other minerals	32.60

Table 2. Average 2-yr Final DM Contents of Corn, Conventional Forage Sorghum (C-FS), and Brown Midrib Forage Sorghum (BMR-FS) Prepared for Ensiling After Two Harvests

	Byproduct addition*		
Harvest	**Control**	**Low**	**High**
Optimum (g kg^{-1})	358	320	287
Late (g kg^{-1})	423	390	352

* Byproduct additions were targeted to achieve 0, 4, and 7.5% of actual harvest moisture on a wt:wt basis for 'control', 'low', and 'high', respectively.

is one that is commonly produced from cheese facilities and frequently used as a livestock feed additive in the region. Makeup of the byproduct is described in Table 1. Byproduct treatments were added to freshly cut material and were based on final total moisture content of the material to be ensiled (Table 2). Treatments consisted of three moisture concentration levels: control, 0%; low, 4%; and high, 7.5%. Immediate determination of plant DM through procedures described by Pitt (1993) was necessary to calculate the appropriate amounts of byproduct to add to each crop (wt:wt basis) at each harvest in order to bring the combinations to the proper final moisture. While moisture levels greater than 700 g kg^{-1} are considered too wet for proper ensiling (McDonald, 1981; Waldo, 1977) due to increases in potential effluent exuded from silos or pits and greater occurrence of undesirable microbes (e.g., *Clostridia* spp.), test final moistures were as high as 730 g kg^{-1} for the 7.5% byproduct addition to optimum harvested crops and were necessary for all treatment combinations. After measuring the weights of byproduct and forage, the forage was sprinkled and mixed thoroughly with liquid byproduct and placed into 18.9-L buckets with lids fitted with rubber seals to prevent air exposure during

Table 3. Analysis of Variance for DM Yield, Crude Protein (CP), Neutral Detergent Fiber (NDF), Non-Fiber Carbohydrates (NFC), Net Energy for Lactation (NE_L), and Neutral Detergent Fiber Digestibility (NDFD) for Two Years (Y), Two Harvests (H), and Three Crops (C)

		Mean squares					
Source	**df**	**DM yield**	**CP**	**NDF**	**NFC**	**NE_L**	**NDFD**
Crop	2	66.94***	8.01***	24.05***	26.08***	0.0141***	631.50***
Error a	6	0.55	0.22	3.38	4.04	0.0004	3.04
Year	1	0.74	10.08***	172.90***	7.84	0.6402***	251.17***
C × Y	2	7.23**	0.15	4.18	6.97*	0.0242***	20.38***
Error b	6	0.55	0.08	3.10	3.56	0.0008*	1.41
Harvest	1	1.05	14.74***	88.29***	222.74***	0.0218***	31.04***
Y × H	1	0.01	0.14	0.09	0.85	0.0035**	10.27*
C × H	2	12.37***	0.35	3.81	1.66	0.0003	1.18
C × Y × H	2	5.75*	0.41	6.31*	7.78*	0.0022**	17.83***
Error c	18	1.07	0.19	1.60	1.86	0.0001	1.32

*Significant at the 0.05 level of probability.
**Significant at the 0.01 level of probability.
***Significant at the 0.001 level of probability.

the ensiling phase. Prior to sealing, fresh forage was packed (250 kg m^3 minimum density) to exclude air contained between individual layers of material. Lids were sealed firmly when buckets were filled completely. An individual 3-mm hole was drilled in the top of each lid to allow gases produced during ensiling to escape. This hole was plugged and sealed with silicone between manual gas release events. Gas was allowed to vent and was released from buckets on a daily basis until gas production ceased. Buckets remained sealed for 42 days and were opened after material was fermented and considered stable (Jones et al., 2004).

Ensiled forage was collected, dried, and ground as described above to determine final DM content and to prepare for nutritive value analyses. All forage quality parameters were analyzed for post-ensiled material and for pre-ensiled material. It is understood that volatile compounds prior to and after ensiling would be volatilized through drying and would not be present for total energy estimation; however, relative comparisons of energy and other nutritive value parameters among the crops tested should not be affected and are appropriate. Sugars constituted the majority of DM in the permeate (Table 1). Therefore, NFC was of interest to estimate to what degree the byproduct additions contributed to overall non-structural carbohydrate content after ensiling.

Table 4. Total Seasonal Dry Matter (DM) Yields of Corn, Conventional Forage Sorghum (C-FS), and Brown Midrib Forage Sorghum (BMR-FS) at Two Harvests in 2005 and 2006 Before Ensiling

	DM yields		
Harvest/Crop	**2005**	**2006**	**2-yr mean**
	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}
Optimum, 358 g kg^{-1} DM			
Corn	17.0 b*	19.4 a	18.2 b†
C-FS	21.5 a	20.7 a	21.1 a
BMR-FS	18.0 b	15.7 b	16.9 c
Late, 423 g kg^{-1} DM			
Corn	20.1 a	19.7 a	19.9 a
C-FS	19.2 a	20.0 a	19.6 a
BMR-FS	16.3 b	15.2 b	15.8 b
SEM‡	0.5	0.5	0.4

*Individual year means within a harvest followed by the same letter are not different according to the LSD test (*P* > 0.05).

†Two-yr means within a harvest followed by the same letter are not different according to the LSD test (*P* > 0.05).

‡SEM = standard error of the mean; n = 4 for each annual mean; n = 8 for each 2-yr mean.

The ensiling phase was a completely randomized design with a split-split plot arrangement and three replications (Steel and Torrie, 1981). Crop represented the main plot, harvest the subplot, and permeate addition the sub-subplot. All post-ensiling nutritive value parameters were analyzed using the GLM procedure in SAS that tested main effects of year, crop, harvest, permeate addition, and all possible interactions (SAS Institute, 1999). Differences among means were separated by the least significant difference test when *F* tests were significant ($P \leq 0.05$; Steel and Torrie, 1981).

RESULTS AND DISCUSSION

Crop Yield

Significant interaction of year x crop x harvest (Table 3) led to interpretation of yield results for each year and harvest date. Ranking of crops at optimum harvest in 2005 was the cause of this interaction; however, variation at late harvest between years was a result of magnitude (Table 4). Therefore, yield results are presented for each year and as means of both years within each harvest. Dry matter contents were similar ($P > 0.05$) for all crops at each harvest and were 358 and 423 g kg^{-1} for optimum and late harvests, respectively (Table 2). In 2005 at optimum harvest, C-FS yielded greater DM than corn and BMR-FS (Table 4); however, in 2006 C-FS and corn were not different and yielded greater DM than BMR-FS. Conventional FS yielded the greatest ($P < 0.05$) amount of DM over two years. This 2006 ranking of optimum yield remained the same for both late harvests regardless of year. Low corn yield in 2005 may have been a result of exceptionally low precipitation in June (< 14 mm) when plant ET was high.

Yields of corn in 2006 and C-FS in both years were considered adequate for the region for the amount of water that was applied (Marsalis et al., 2007, 2008; Bean and McCollum, 2006); however, BMR-FS yields would be considered low. Although typical expectant yields for silage in the region are near 23 Mg ha^{-1} DM, this amount is generally obtained with 762 mm or more of irrigation in addition to precipitation. During the two years of this study, water applied averaged 510 mm (33% less than regional normal) prior to optimum harvest, and C-FS yields were 92% of typical yields. These results further support the relatively high water use efficiency of C-FS compared to corn (Martin et al., 1976; Sanderson et al., 1992; Howell et al., 1997; Howell et al., 2008). While BMR-FS remained lower ($P < 0.05$) in DM produced than the other two crops at late harvest, corn and C-FS did not differ ($P > 0.05$) when harvest was delayed (Table 4). Both FS declined in yield from optimum to late harvest; however, corn increased. It is suggested that this was due to corn grain fill in conjunction with stover stability as the whole plant DM increased to levels beyond 40%. In contrast, FS remained in the field longer in order to achieve late harvest DM targets, and stover (i.e., leaves) proportions were likely reduced to a greater extent because of the extended delay. In addition, grain-to-stover ratios for sorghum, particularly taller forage types, are generally less than those of corn (Prihar and Stewart, 1990; Gourley and Lusk, 1978); therefore, any effects of grain fill on overall plant DM yields would be proportionately less. In both years, FS dry down was slow due to precipitation (Figure 1) and cooling temperatures late in the harvest season. Corn, on the other hand, was more consistent with respect to drying and was less affected by weather. Resultant implications are that corn may be more predictable in the field with respect to harvest timing and scheduling for custom harvesting. At late harvest, corn DM had increased, whereas C-FS and BMR-FS DM had declined from optimum harvest levels, thereby resulting in greater yield for corn (19.9 Mg ha^{-1}) than for BMR-FS (15.8 Mg ha^{-1}) over the two years. Again, this effect was likely exacerbated by the extended delay in dry down of FS. Forage sorghum, whether conventional or BMR, appears to be unpredictable during dry down, but may be able to maintain proper moisture content for ensiling for longer periods of delay. Particularly wet harvest seasons, however, may lead to excessive DM yield losses in FS as a result of slow plant dry down even in situations where field access by harvesting equipment is possible.

Lower yields associated with certain BMR-FS have been reported (Bean et al., 2005; Oliver et al., 2005a; Howell et al., 2008) and were substantiated by the optimum harvest results of this study, when compared with C-FS. Previous research has shown that yield re-

Table 5. Crude Protein (CP), Neutral Detergent Fiber (NDF), Non-Fiber Carbohydrates (NFC), Net Energy for Lactation (NE_L), and Neutral Detergent Fiber Digestibility (NDFD) of Corn, Conventional Forage Sorghum (C-FS), and Brown Midrib Forage Sorghum (BMR-FS) Before Ensiling (values are averages of two years)

Harvest/Crop	CP g kg^{-1}	NDF g kg^{-1}	NFC g kg^{-1}	NE_L Mcal kg^{-1}	NDFD g kg NDF^{-1}
Optimum, 358 g kg^{-1} DM					
Corn	86 a*	501 b	352 c	1.44 a	579 e
C-FS	74 b	525 a	330 d	1.37 b	643 c
BMR-FS	71 b	527 a	332 d	1.39 b	708 b
Late, 423 g kg^{-1} DM					
Corn	72 b	480 c	394 a	1.39 b	601 d
C-FS	62 c	503 b	367 b	1.29 c	654 c
BMR-FS	62 c	489 c	382 a	1.32 c	723 a
SEM†	2	5	5	0.02	4

*Means within a column followed by the same letter are not different according to the LSD test ($P > 0.05$).

†SEM = standard error of the mean; n = 8 for each mean.

duction associated with BMR sudangrasses is variable across environments and is variety-specific (Casler et al., 2003); this may be true of FS as well (Marsalis et al., 2008; late harvest date variation between years in this study). New, improved varieties of BMR-FS may help to alleviate low yields associated with older germplasms (Oliver et al., 2005a). Likewise, the development of more drought-tolerant corn varieties will lead to better competitiveness with C-FS in limited water situations, and the expansion of silage-specific corns may contribute to larger harvest windows and less quality reduction caused by harvest delays (Ma et al., 2006).

Nutritive Value Before Ensiling

Significant interactions of year x crop x harvest (Table 3) led to analysis of pre-ensiled nutritive value results for each year and harvest date; however, the source of variation was a result of magnitude from year 1 to year 2. Therefore, results are presented as means of both years within each harvest date (Table 5). None of the nutritive value parameters exhibited a crop x harvest interaction (Table 3). Means are described across both harvests accordingly.

It has been reported that sorghum silage and sorghum grain frequently contain comparable or higher CP than corn (NRC, 1996, 2001; Marsalis et al., 2008). In this study, CP concentrations ranged from 62 to 86 g kg^{-1} and were at least 10 g kg^{-1} greater ($P < 0.05$) for corn than C-FS and BMR-FS, regardless of harvest (Table 5). Crude protein levels declined significantly for all crops from optimum to late harvests. Conventional and BMR-FS did not differ with respect to CP at either harvest even though 112 kg N ha^{-1} less nitrogen were applied to BMR-FS. This indicates that N was extracted efficiently and was likely not limiting to BMR-FS, further supporting previous work showing that N levels higher than 56 to 100 kg ha^{-1} do not necessarily lead to greater N efficiency or improved yields or quality (Beyaert and Roy, 2005; Ketterings et al., 2006), but may exacerbate lodging in BMR-FS (Bean et al., 2003). As a result, the rate of N applied (112 kg ha^{-1}) to BMR-FS was deemed adequate and not the cause of low yields compared to C-FS and corn. Crude protein concentration of corn at optimum harvest was similar to concentrations reported by Marsalis et al. (2008) and NRC (1996, 2001), and CP levels of both FS were similar to those of cv. BMR 106 and cv. FS-5 reported by Bean and McCollum (2006). Although CP in silage forages is not the most important quality parameter to dairy nutritionists, late harvested FS crops exhibited CP levels (< 65 g kg^{-1}; Table 5) that would be considered low for regional silage standards and would be considered inferior to forages with higher CP and similar NE_L (R. Hagevoort, personal communication, 2008).

All crops exceeded 500 g kg^{-1} NDF at optimum harvest (Table 5). Both FS NDF levels were greater than those reported in the literature (Bean and McCollum, 2006; Oliver et al., 2005a). Overall, NDF declined from optimum to late harvest (21 g kg^{-1} or more) for all crops and corresponded inversely to increases in NFC (Table 5). The decline in whole plant NDF supports previous work conducted on corn and FS maturity (Russell et al., 1992; Hunt et al., 1989; Bolsen and Sonon, 1997). Corn NDF at late harvest was lower than that of both FS at optimum harvest. Beck et al. (2007) reported that NDF was lower for BMR sorghum sudangrass hybrids than for non-BMR types at multiple growth stages; however, NDF of BMR-FS was lower than C-FS only at the late harvest in our study. This indicates that the C-FS maintained its structural carbohydrates longer in the field and implies that, even though total fiber concentrations may be similar at optimum harvest maturity (Oliver et al., 2005a), C-FS may have contained potentially more lignin (lignin not measured). As a result, its NDF fraction (22 g kg^{-1} reduction) was more stable than that of BMR-FS (38 g kg^{-1} reduction). Oliver et al. (2005b) showed higher acid detergent lignin contents in wild type grain sorghum stover than in BMR stover harvested at crop maturity.

Non-fiber carbohydrates increased with maturity to late harvest (Table 5) along with decreases in NDF in conjunction with potential increases in grain (i.e., starch levels) proportions. Stem NFC has been shown to increase late in the maturity of sorghum (McBee and Miller, 1993). Leaf sugar content may also increase late in the growing season as temperatures decline and plant respiration rates are reduced. Total NFC was greatest for corn at optimum harvest; however, NFC of corn did not differ from that of BMR-FS at late harvest. This was consistent with the relationship of corn and BMR-FS with respect to NDF and was particularly surprising considering that corn grain constitutes a larger proportion of the total plant weight than does FS grain. It is suggested that the greater degree of structural carbohydrate decline for BMR-FS (3.8%) compared with corn (2.1%) compounded the difference in NFC between the two crops.

Other than CP reductions, decline in NE_L was the only indication of a negative impact of harvest delay on overall forage quality. In contrast to Hunt et al. (1989), all crops were lower ($P < 0.05$) in NE_L when harvested at the high DM level (Table 5). Nevertheless, NE_L values were comparable to those reported for corn and FS grown with unrestricted water in variety trials conducted at Clovis (Marsalis et al., 2007, 2008). Net energy for lactation was greatest for corn at both optimum and late harvests. Despite greater NDFD for BMR-FS, it exhibited only numerically ($P > 0.05$) higher NE_L over C-FS. There seemed to be no direct relationship between NDFD and NE_L, which is supported by previous research conducted by Tine et al. (2001) and Oba and Allen (1999). Decline in NE_L was associated with reduction in total digestible nutrients (TDN) (NRC, 2001; data not shown), but it is uncertain why TDN decreased at late harvest. It is unlikely that less than 1.5% reductions in CP (Table 5) would cause such a decline, especially considering NDF decreased and NFC and NDFD increased. The TDN value is used to calculate NE_L using CP, NFC, and NDF according to the equations described in NRC (2001) (Linn, 2003).

Neutral detergent fiber digestibility was variable across all crops and both harvests (Table 5). On average, BMR-FS NDFD was 6% greater than C-FS and 12% or more greater than corn at both harvests. Greater NDFD of BMR sorghum than non-BMR types is consistent with results reported by Oliver et al. (2004), Beck et al. (2007), and Thorstensson et al. (1992). While rate of NDFD may not have been greater for BMR-FS than for C-FS (Fritz et al., 1990; Thorstensson et al., 1992), extent of BMR-FS NDFD was certainly superior. Although NDF levels declined at late harvest, the extent of digestibility of NDF increased significantly for the corn and BMR-FS crops. Conventional FS NDFD levels did not differ between harvests. This is important as it suggests that, while C-FS may decline in overall NDF with maturity, the relative indigestibility of the NDF remains the same.

It is important to note that even when corn was left in the field beyond optimum DM content (late harvest), it exhibited characteristics similar to or superior to both FS harvested at optimum stage: comparable CP and NE_L levels, lower NDF, and higher NFC (Table 5). These results are in line with conclusions presented by Darby and Lauer (2002) that showed corn's stability with respect to yield and nutritive value with increasing DM (above 420 g kg^{-1}). In contrast, CP and NE_L declined with maturity. Much speculation exists about the suitability of corn productivity and nutritive value compared to FS in limited water situations. Overall, corn maintained forage quality similar to or better than the FS in this study; this is particularly important as the crops were grown with a restricted quantity of water throughout the growing season. At optimum harvest, there is a tradeoff of yield and nutritive value between FS and corn, and producers must assess the need for either a high yielding, lower quality FS or a lower yielding, higher quality corn.

Silage Nutritive Value

Byproduct additions were successful at increasing moisture content of forages to be ensiled (Table 2). Dry matter content of the 'control' byproduct treatment (Table 2) was representative of DM content of all crops at each harvest; ensiling decreased DM concentration only slightly from harvest levels, suggesting fermentation stability in the control treatment.

Non-fiber carbohydrate levels were estimated to determine to what extent byproduct addition contributed to overall sugar content. In general, the effect of byproduct on NFC levels was minimal, but significant at optimum harvest (Figure 2). Non-fiber carbohydrates increased over the control in corn with 'low' and 'high' additions at the optimum harvest. In contrast, byproduct addition had no effect on NFC levels in any crop at late harvest (Figure 2). It is uncertain why byproduct addition had an effect on optimum harvested crops but not late. A low amount of sugars (61.0 g kg^{-1}; Table 1) in the byproduct as mixed and the relatively low quantities added compared to the total mixture of the final product may have had a greater effect on optimum harvested crops that contained lower quantities of NFC (Table 5) to begin with prior to ensiling. Greater additions would have increased NFC more than what resulted in this study, but resultant mixtures would have been too wet for proper ensiling.

Carbohydrate concentrations in C-FS were increased 1.4% ($P < 0.05$) with 'low' addition of permeate, but no further increase in NFC occurred with the 'high' treatment (Figure 2). Adding byproduct had a declining effect on BMR-FS NFC levels at optimum harvest, and the reason for this is uncertain. It is speculated that the decrease in DM concentration with byproduct addition (Table 2), high NDF and low NFC of BMR-FS (Table 5), and perhaps high microbial populations associated with warm temperatures at harvest led to greater microbial activity during fermentation (Muck, 1990; Pitt and Muck, 1995), thereby reducing final NFC concentrations. Low microbial populations may have existed with the onset of cool fall temperatures and were evidenced by the reduction in gas production of late harvested ensiling buckets (data not shown). At optimum harvest, corn NFC for the control increased (corresponding with a decrease in NDF) with ensiling, but the byproduct control for corn NFC remained similar to pre-ensiled levels at late harvest (Tables 5 and 6). In contrast, control NFC for C-FS at both harvests and BMR-FS at late harvest was reduced during the ensiling process. Reduction in NFC and NDFD during ensiling of the crops is consistent with previous research conducted on fresh and ensiled corn hybrids (Cherney et al., 2007).

Net energy for lactation increased over the control for corn at the 'high' level of byproduct addition and at both harvests (Figure 3); at optimum harvest, the effect of byproduct addition on NE_L mirrored that of NFC with corn (Figures 2 and 3). Conventional FS NE_L was not affected by byproduct addition. Increase in NE_L for BMR-FS was significant only at late harvest and was not due to any increase in NFC (Figure 2), but was likely due to an improvement in ensiling environment associated with proper moisture content (648 g kg^{-1}; Table 2). This appears to be the case with corn at late harvest also. Post-ensiling NE_L was reduced from pre-ensiling levels (Tables 5 and 6) for all crops with no byproduct added.

CONCLUSION

Our findings open the possibility of producing high yielding forage with good nutritive value while using lower amounts of water than highly irrigated corn grown traditionally in the Southern High Plains. Future studies should focus on variable irrigation rates to more completely assess the effects of declining water

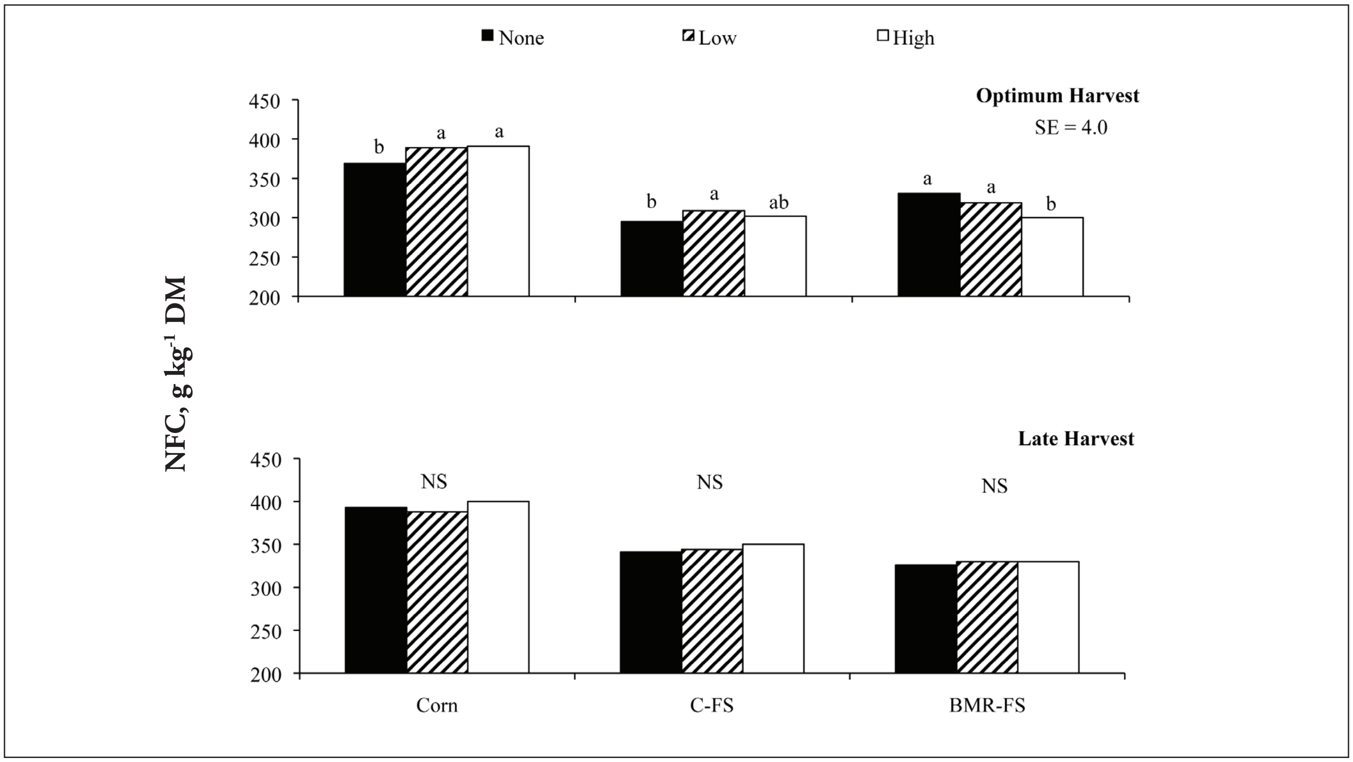

Figure 2. **Post-ensiling non-fiber carbohydrates (NFC) of corn, conventional forage sorghum (C-FS), and brown midrib forage sorghum (BMR-FS) at two harvests and three liquid whey byproduct levels (none, low, and high). Data are means averaged over 2005 and 2006. Means denoted with the same letter within a crop and harvest are not different (*P* > 0.05).**

Table 6. Crude Protein (CP), Neutral Detergent Fiber (NDF), Non-Fiber Carbohydrates (NFC), Net Energy for Lactation (NE_L), and Neutral Detergent Fiber Digestibility (NDFD) of Corn, Conventional Forage Sorghum (C-FS), and Brown Midrib Forage Sorghum (BMR-FS) After Ensiling (control treatment, no byproduct added; values are averages of two years)

Harvest/Crop	CP g kg^{-1}	NDF g kg^{-1}	NFC g kg^{-1}	NE_L Mcal kg^{-1}	NDFD g kg NDF^{-1}
Optimum, 358 g kg^{-1} DM					
Corn	90 a*	472 c	369 a	1.40 a	530 c
C-FS	76 c	549 a	295 c	1.30 b	591 b
BMR-FS	78 b	515 b	331 b	1.28 b	679 a
SEM†	1	4	4	0.01	3
Late, 423 g kg^{-1} DM					
Corn	78 a	469 b	393 a	1.36 a	553 c
C-FS	61 b	534 a	341 b	1.25 b	661 b
BMR-FS	60 b	548 a	326 c	1.25 b	724 a
SEM†	1	4	5	0.01	1

*Means within a column and harvest followed by the same letter are not different according to the LSD test (*P* > 0.05).

†SEM = standard error of the mean; n = 6 for each mean.

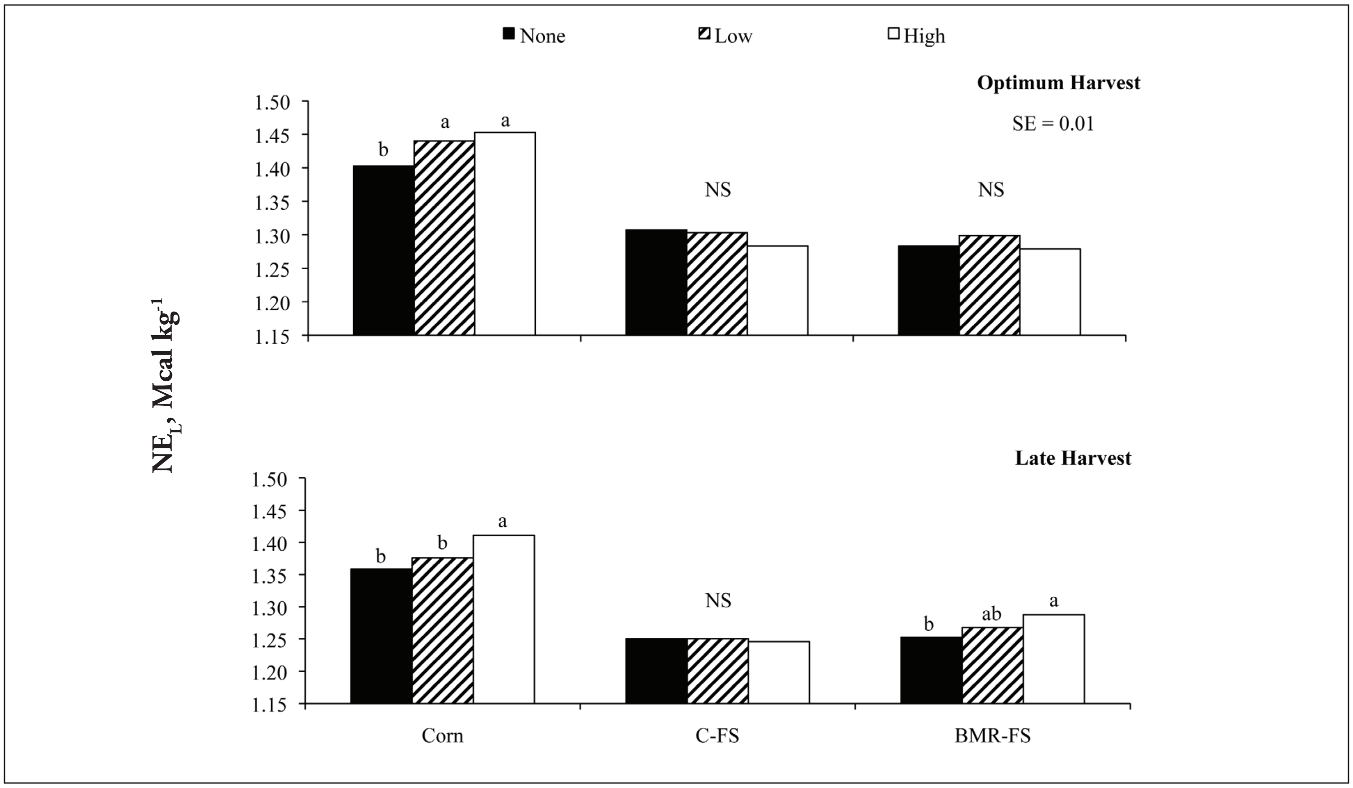

Figure 3. **Post-ensiling net energy for lactation (NE$_L$) of corn, conventional forage sorghum (C-FS), and brown midrib forage sorghum (BMR-FS) at two harvests and three liquid whey byproduct levels (none, low, and high). Data are means averaged over 2005 and 2006. Means denoted with the same letter within a crop and harvest are not different ($P > 0.05$).**

on corn and FS yield and quality. Indications from this study are that, while C-FS will produce more DM when harvested at optimum stage under restricted irrigation, corn may maintain nutritive value longer. While no consistent effect on NFC levels in the crops was evident by adding cheese byproduct, NE$_L$ of corn and BMR-FS was improved by the 'high' additions. However, adding large quantities of the high-moisture byproduct to forage harvested at proper DM levels for ensiling may lead to effluent production and spoilage losses. The rates used in this study would not lead to such conditions in forage harvested at DM levels of 420 g kg^{-1} or higher. It is clear that the feasibility for commercial-scale additions of wet byproduct to chopped forage prior to ensiling requires more research. Transporting liquid and immediate packing of forage may hinder the use of the cheese permeate byproduct as a silage additive.

ACKNOWLEDGMENTS

This research was funded by the New Mexico State University Agricultural Experiment Station. We gratefully acknowledge the technical and field assistance of Gilbert Lucero, Bryan Niece, Kenneth Phipps, Aaron Scott, and Christie Werner.

REFERENCES

Anderson, B., and P. Guyer. 1986. Summer annual forage grasses [NebGuide G74-171A]. Lincoln: University of Nebraska Cooperative Extension.

Aydin, G., R. J. Grant, and J. O'Rear. 1999. Brown midrib sorghum in diets for lactating dairy cows. *Journal of Dairy Science, 82*, 2127–2135.

Bean, B., and T. McCollum. 2006. Summary of six years of forage sorghum variety trials [Pub. SCS-2006-04]. College Station: Texas Cooperative Extension and Texas Agricultural Experiment Station.

Bean, B., T. McCollum, K. McCuistion, E. Hutcherson, J. Robinson, R. VanMeter, and D. Pietsch. 2005. 2004 Texas Panhandle forage sorghum silage trial [Pub. AREC 05-04]. College Station: Texas Cooperative Extension and Texas Agricultural Experiment Station.

Bean, B., T. McCollum, M. Rowland, and K. McCuistion. 2003. Seeding and nitrogen rate effect on forage yield, lodging, and nutrient composition of two brown midrib forage sorghums [Pub. AREC 04-04]. College Station: Texas Cooperative Extension and Texas Agricultural Experiment Station.

Beck, P. A., S. Hutchison, S. A. Gunter, T. C. Losi, C. B. Stewart, P. K. Capps, and J. M. Phillips. 2007. Chemical composition and *in situ* dry matter and fiber disappearance of sorghum × sudangrass hybrids. *Journal of Animal Science, 85*, 545–555.

Beyaert, R. P., and R. C. Roy. 2005. Influence of nitrogen fertilization on multi-cut forage sorghum-sudangrass yield and nitrogen use. *Agronomy Journal, 97*, 1493–1501.

Bolsen, K. K., and R. N. Sonon, Jr. 1997. Effect of cultivar and stage of maturity on agronomic characteristics, chemical composition, and nutritive value of forage sorghum silages. *Advances in Agricultural Research, 5*, 1–17.

Brown, W. F., J. E. Moore, W. E. Kunkle, C. G. Chambliss, and K. M. Portier. 1990. Forage testing using near infrared reflectance spectroscopy. *Journal of Animal Science, 68*, 1416–1427.

Browne, E. M., D. T. Juniper, M. J. Bryant, and D. E. Beever. 2005. Apparent digestibility and nitrogen utilization of diets based on maize silage harvested at three stages of maturity and fed to steers. *Grass and Forage Science, 60*, 274–282.

Cabrera, V. E., and R. Hagevoort. 2006. Importance of the New Mexico dairy industry [Circular 613]. Las Cruces: New Mexico Cooperative Extension Service.

Casler, M. D., J. F. Pedersen, and D. J. Undersander. 2003. Forage yield and economic losses associated with the brown-midrib trait in sudangrass. *Crop Science, 43*, 782–789.

Cherney, D. J. R., J. H. Cherney, and W. J. Cox. 2007. Forage quality differences of corn hybrids as influenced by ensiling [Online]. *Forage and Grazinglands*. doi:10.1094/FG-2007-0918-01-RS

Darby, H. M., and J. G. Lauer. 2002. Harvest date and hybrid influence on corn forage yield, quality, and preservation. *Agronomy Journal, 94*, 559–566.

Defrain, J. M., A. R. Hippen, K. F. Kalscheur, and D. J. Schingoethe. 2004. Feeding lactose increases ruminal butyrate and plasma β-hydroxybutyrate in lactating dairy cows. *Journal of Dairy Science, 87*, 2486–2494.

Fritz, J. O., K. J. Moore, and E. H. Jaster. 1990. Digestion kinetics and cell wall composition of brown midrib sorghum × sudangrass morphological components. *Crop Science, 30*, 213–219.

Goering, H. K., and P. J. Van Soest. 1970. *Forage fiber analysis (apparatus, reagents, procedures, and some applications)* [Handbook 379]. Washington, D.C.: U.S. Department of Agriculture-Agricultural Research Service.

Gourley, L. M., and J. W. Lusk. 1978. Genetic parameters related to sorghum silage quality. *Journal of Dairy Science, 61*, 1821–1827.

Gowda, P. H., R. L. Baumhardt, A. M. Esparza, T. H. Marek, and T. A. Howell. 2007. Suitability of cotton as an alternative crop in the Ogallala Aquifer region. *Agronomy Journal, 99*, 1397–1403.

Grant, R. J., S. G. Haddad, K. J. Moore, and J. F. Pedersen. 1995. Brown midrib sorghum silage for midlactation dairy cows. *Journal of Dairy Science, 78*, 1970–1980.

Howell, T. A., S. R. Evett, J. A. Tolk, K. S. Copeland, P. D. Colaizzi, and P. H. Gowda. 2008, June. Evapotranspiration of corn and forage sorghum for silage. *Wetting Front Newsletter*, *10*(1), 3–11.

Howell, T. A., J. L. Steiner, A. D. Schneider, S. R. Evett, and J. A. Tolk. 1997. Seasonal and maximum daily evapotranspiration of irrigated wheat, sorghum, and corn—Southern High Plains. *Transactions of the ASAE, 40*, 623–634.

Hunt, C. W., W. Kezar, and R. Vinande. 1989. Yield, chemical composition and ruminal fermentability of corn whole plant, ear, and stover as affected by maturity. *Journal of Production Agriculture, 2*, 357–361.

Jones, C. M., A. J. Heinrichs, G. W. Roth, and V. A. Ishler. 2004. From harvest to feed: Understanding silage management [Publication no. 5M6/04acg4674]. College Station: Pennsylvania State University, College of Agricultural Sciences, Agricultural Research and Cooperative Extension.

Ketterings, Q. M., G. Godwin, T. F. Kilcer, P. Barney, M. Hunter, J. H. Cherney, and S. Beer. 2006. Nitrogen, phosphorus, potassium, magnesium and calcium removal by brown midrib sorghum sudangrass in the northeastern USA. *Journal of Agronomy and Crop Science, 192*, 408–416.

Kirksey, R. E., M. A. Marsalis, R. Flynn, M. K. O'Neill, L. M. Lauriault, L. M. English, and D. A. McWilliams. 2005. New Mexico 2004 corn and sorghum performance tests. Las Cruces: New Mexico State University Agricultural Experiment Station. Available from http://aces.nmsu.edu/pubs/variety_trials/perf04.pdf

Kurle, J. E., C. C. Sheaffer, R. K. Crookston, R. H. Peterson, H. Chester-Jones, and W. E. Lueschen. 1991. Popcorn, sweet corn, and sorghum as alternative silage crops. *Journal of Production Agriculture, 4,* 432–436.

Linn, J. G. 2003. Energy in the 2001 Dairy NRC: Understanding the system. *In Proceedings of Minnesota Dairy Health Herd Conference* (pp. 102–110). St. Paul: University of Minnesota, College of Veterinary Medicine.

Linn, J. G., M. F. Hutjens, R. Shaver, D. E. Otterby, W. T. Howard, and L. H. Kilmer. 1996. Feeding the dairy herd [North Central Regional Extension Pub. 346]. St. Paul: University of Minnesota Extension Service.

Ma, B. L., K. D. Subedi, D. W. Stewart, and L. M. Dwyer. 2006. Dry matter accumulation and silage moisture changes after silking in leafy and dual-purpose corn hybrids. *Agronomy Journal, 98*, 922–929.

Marsalis, M. A., R. E. Kirksey, R. Flynn, M. K. O'Neill, L. M. Lauriault, and M. Place. 2007. New Mexico 2006 corn and sorghum performance tests. Las Cruces: New Mexico State University Agricultural Experiment Station. Available from http://aces.nmsu.edu/pubs/variety_trials/perf06.pdf

Marsalis, M. A., R. E. Kirksey, R. Flynn, M. K. O'Neill, L. M. Lauriault, and M. Place. 2008. New Mexico 2007 corn and sorghum performance tests. Las Cruces: New Mexico State University Agricultural Experiment Station. Available from http://aces.nmsu.edu/pubs/variety_trials/07sorghum.pdf

Martin, J. H. 1930. The comparative drought resistance of sorghums and corn. *Journal of the American Society of Agronomy, 22*, 993–1003.

Martin, J. H., W. H. Leonard, and D. L. Stamp. 1976. *Principles of field crop production*. New York: Macmillan Publishing Co., Inc.

McBee, G. G., and F. R. Miller. 1993. Stem carbohydrate and lignin concentrations in sorghum hybrids at seven growth stages. *Crop Science, 33*, 530–534.

McDonald, P. 1981. *The biochemistry of silage*. Chichester, UK: John Wiley & Sons.

Miron, J., R. Soloman, G. Adin, U. Nir, M. Nikbachat, E. Yosef, A. Carmi, Z. G. Weinberg, T. Kipnis, and E. Zuckerman. 2006. Effects of harvest stage and re-growth on yield, composition, ensilage and in vitro digestibility of new forage sorghum varieties. *Journal of the Science of Food and Agriculture, 86*, 140–147.

Muck, R. E. 1990. Dry matter level effects on alfalfa silage quality. II. Fermentation products and starch hydrolysis. *Transactions of the ASAE, 33*, 373–381.

New, L., and D. Dusek. 2005. Ogallala Aquifer 2004 annual report: Crop irrigation and production. Amarillo: Texas Cooperative Extension Service.

NRC. 1996. *Nutrient requirements of beef cattle—Seventh revised edition, 1996*. Washington, D.C.: National Academy Press.

NRC. 2001: *Nutrient requirements of dairy cattle—Seventh revised edition, 2001*. Washington, D.C.: National Academy Press.

Oba, M., and M. S. Allen. 1999. Effects of brown midrib 3 mutation in corn silage on dry matter intake and productivity of high yielding dairy cows. *Journal of Dairy Science, 82*, 135–142.

Oliver, A. L., R. J. Grant, J. F. Pedersen, and J. O'Rear. 2004. Comparison of brown midrib-6 and -18 forage sorghum with conventional sorghum and corn silage in diets of lactating dairy cows. *Journal of Dairy Science, 87*, 637–644.

Oliver, A. L., J. F. Pedersen, R. J. Grant, and T. J. Klopfenstein. 2005a. Comparative effects of the sorghum *bmr*-6 and *bmr*-12 genes: I. Forage sorghum yield and quality. *Crop Science, 45*, 2234–2239.

Oliver, A. L., J. F. Pedersen, R. J. Grant, T. J. Klopfenstein, and H. D. Jose. 2005b. Comparative effects of the sorghum *bmr*-6 and *bmr*-12 genes: II. Grain yield, stover yield, and stover quality in grain sorghum. *Crop Science, 45*, 2240–2245.

Pedersen, J. F., K. P. Vogel, and D. L. Funnell. 2005. Impact of reduced lignin on plant fitness. *Crop Science, 45*, 812–819.

Pitt, R. E. (Ed.). 1993. Forage moisture determination [Pub. NRAES-59]. Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.

Pitt, R. E., and R. E. Muck. 1995. Enumeration of lactic acid bacteria on harvested alfalfa at long and short wilting times. *Transactions of the ASAE, 38*, 1633–1639.

Prihar, S. S., and B. A. Stewart. 1990. Using upper-bound slope through origin to estimate genetic harvest index. *Agronomy Journal, 82*, 1160–1165.

Russell, J. R., N. A. Irlbeck, A. R. Hallauer, and D. R. Buxton. 1992. Nutritive value and ensiling characteristics of maize herbage as influenced by agronomic factors. *Journal of Animal Feed Science and Technology, 38,* 11–24.

Sanderson, M. A., R. M. Jones, J. Ward, and R. Wolfe. 1992. Silage sorghum performance trial at Stephenville: Forage research in Texas [PR-5018]. Stephenville: Texas Agricultural Experiment Station.

SAS Institute. 1999. *SAS user's guide v. 8.0.* Cary, NC: Author.

Steel, R. G. D., and J. H. Torrie. 1981. *Principles and procedures of statistics: A biometrical approach* (2nd ed.). New York: McGraw-Hill.

Teutsch, C. 2002. Warm-season annual grasses for summer forage [Pub. 418-004]. Blacksburg: Virginia Cooperative Extension.

Thorstensson, E. M. G., D. R. Buxton, and J. H. Cherney. 1992. Apparent inhibition to digestion by lignin in normal and brown midrib stems. *Journal of the Science of Food and Agriculture, 59,* 183–188.

Tine, M. A., K. R. McLeod, R. A. Erdman, and R. L. Baldwin. 2001. Effects of brown midrib corn silage on the energy balance of dairy cattle. *Journal of Dairy Science, 84*, 885–895.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, *74*, 3583–3597.

Waldo, D. R. 1977. Suggestions for improving silage. How far with forages for meat and milk production? In *Proceedings of 10th Research-Industry Conference* (pp. 69–91). Columbia, MO: American Forage and Grassland Council.

ZoBell, D. R., and W. C. Burrell. 2002. Producing whey silage for growing and finishing cattle [Pub. AG 514]. Logan: Utah State University Cooperative Extension Service.

September 2009 **Las Cruces, NM**