Management of Forage Sorghum: Nitrogen, Plant Density and Irrigation Effects on Yield and Quality

Matt A. Sanderson*
Ronald M. Jones
Texas A&M Univ. Agric. Res. and Ext. Cent., Rt.2, Box 00, Stephenville, TX 76401
James C. Read
Texas A&M Univ. Agric. Res. and Ext. Cent., 17630 Coit Road, Dallas, TX 75252

ABSTRACT

Increased interest in producing forage sorghum (*Sorghum bicolor* (L.) Moench) for silage has prompted questions on the effects of production inputs on forage sorghum quality. Our objective was to determine how supplemental irrigation, N fertility and plant density affected yield and quality of forage sorghum. Dekalb hybrid FS-25e was overplanted and thinned to three densities (32 300, 50 800 and 66 300 plants acre^{-1}) in 1987 and four densities (15 500, 31 400, 56 900 and 107 300 plants acre^{-1}) in 1988 and 1989 (19 000, 29 200, 54 800 and 79 700 plants acre^{-1}) in rows spaced 3 ft apart. Plots were not irrigated or received supplemental irrigation when water-deficit stress symptoms were apparent. Nitrogen was applied at 0, 160 or 320 lb acre^{-1}. Plots were harvested when grain was at the soft dough stage. Whole plants, leaf blades and stalks were analyzed for in vitro true digestibility (IVTD), acid detergent fiber (ADF), cellulose and acid detergent lignin (ADL, whole plants and stalks only). Under the dryland treatment 160 lb N acre^{-1} increased dry matter yield 2.5 to 3.3 tons acre^{-1}. Supplemental irrigation (15.4 inches) increased yield in one year. Increasing N from 160 to 320 lb acre^{-1} increased dry matter yield about 0.5 to 1 ton acre^{-1}. Dry matter yield increased with increasing plant density up to about 80 000 plants acre^{-1}. Nitrogen at 160 or 320 lb acre^{-1} reduced leaf proportion an average of 32% and increased panicle proportion. Increased plant density increased ADF by 10%, and cellulose concentrations by 29% and reduced IVTD by 3% in leaf blades. Increasing levels of fertilizer N reduced IVTD in leaf blades, stalks and whole plants compared to no N fertilizer. Supplemental irrigation reduced IVTD by 2 to 3% in whole plants and stalks. This study suggests that when considering plant population recommendations for forage sorghum grown for silage (i) differences in plant density have minor effects on forage quality and (ii) yield responses to applied N override the small reductions in IVTD.

KEYWORDS: silage, fertility

The increased size and number of dairies in northcentral Texas has increased the need for high-quality forage in this region. Current dairying practices include drylot feeding systems where no pasture is used and most feeds are purchased. Silage often is used as the wet base ingredient for total mixed rations on many of these dairies. Sorghum frequently is used as a forage crop in the southern U.S. and similar

Accepted 3 Apr 1996. *Corresponding author.

climatic areas around the world because of its drought tolerance, adaptability to late planting after winter crops and high yields (Miller, 1976). A disadvantage of sorghum forage, however, is that its nutritive value often is less than that of other silage crops such as corn (Goodrich and Meiske, 1985).

Research data are available for grain sorghum production in response to irrigation, N fertilizer and plant density (Jensen and Sletten, 1965; Musick and Dusek, 1969), but comparable data are few for silage-type sorghums. Also, grain sorghum data may not be directly applicable to forage sorghums because the entire plant is used in silage production and the genetics of grain and forage sorghums differ (Gourley and Lusk, 1978).

Nitrogen fertility recommendations for the forage sorghums are based on yield responses, amount of N removed by the crop, avoidance of excess nitrate in forage and an adequate concentration of crude protein in the forage (Ball et al., 1991; Schaller, 1980; TAEX, 1989). Plant density recommendations are formulated to control seed costs and optimize forage stands and yield (Martin and Stephens, 1955; Martin et al., 1976).

We conducted a three-year experiment to better understand the interrelationships among N rate, plant density and supplemental irrigation on forage sorghum managed for silage. Specifically, we wanted to determine how these production inputs and their interaction affected yield, morphological composition and forage quality so that we could refine producer recommendations.

MATERIALS AND METHODS

The study was conducted at the Texas A&M University Agricultural Research and Extension Center 2 miles north of Stephenville on a Windthorst fine sandy loam (fine, mixed, thermic Udic Paleustalf) soil in 1987, 1988 and 1989. Available water holding capacity in the surface 8 inches is typically 0.10 to 0.13 inch inch^{-1} and at depths between 8 and 34 inches is 0.14 to 0.17 inch inch^{-1} (Wagner et al., 1973). Permeability is greater than 2 inches h^{-1} in the upper 34 inches. Soil analysis of the surface 6 inches before fertilizer application each year indicated 2 to 10 lb nitrate-N acre^{-1}, 2 to 26 lb P acre^{-1} and 318 to 590 lb K acre^{-1}. Soil pH was 7.3. The previous crop in both 1987 and 1989 was peanut. The same site used in 1987 was used in 1988.

Seedbed preparation consisted of moldboard plowing, two diskings and bedding into rows 3 ft apart. Phosphorus (as triple superphosphate) and K (as muriate of potash) were broadcast at rates of 35 and 33 lb acre^{-1} (elemental form), respectively, in 1987, at 25 and 50 lb acre^{-1} in 1988, and at 35 and 50 lb acre^{-1} in 1989. DeKalb brand FS-25e, a mid- to late-season hybrid of forage sorghum, was used in 1987 and 1988; 'FS-25e+', a greenbug- [*Schizaphis graminum* (Rodani)] resistant hybrid, was used in 1989. Sorghum was planted on 19 Jun 1987, 9 May 1988 and 21 Apr 1989. The late planting date in 1987 was due to an initial seeding failure and inclement weather. Weeds were controlled by broadcast application of 1 quart acre^{-1} of metolachlor which was incorporated with a rolling cultivator within 1 h after planting. A seed safetener was applied to the sorghum seed to protect it from damage due to metolachlor. Chlorpyrifos was applied after planting in 1989 as a granular product at the rate of 1.1 lb acre^{-1} active ingredient in 8-inch bands over each row to control soil-borne insects.

The experimental design was a randomized complete block with treatments arranged in split-split plots with four blocks. Moisture treatments of dryland or supplemental irrigation were main plots, N rates were subplots and plant densities were sub-subplots.

Supplemental irrigation was applied at 0.25 inch h^{-1} through sprinkler heads positioned above the crop canopy when leaf rolling, a symptom of water deficit stress, was observed. Dryland plots were separated from irrigated plots by a 50-ft buffer area. The amount of irrigation water applied was calculated from pressure, nozzle diameter and duration of irrigation. Monthly rainfall and mean temperature were measured at an official weather station one-half mile from the study site and are reported in Table 1 along with irrigation amounts.

Nitrogen (as ammonium nitrate) at rates of 0, 160 and 320 lb $acre^{-1}$ was applied to subplots 2 or 3 weeks before planting and incorporated by disking within 2 h after application.

Plant density sub-subplots were 20 ft long and 9 ft (3 rows) wide. Plant density was adjusted when plants had five leaves with visible collars (growth stage 2 of Vanderlip and Reeves, 1972) to target densities of 14 500, 29 000, 58 000 and 116 000 plants $acre^{-1}$. The high plant density (116 000 plants $acre^{-1}$) was not included in 1987. Actual plant densities at harvest were 32 300, 50 800 and 66 300 in 1987; 15 500, 31 400, 56 900 and 107 300 in 1988; and 19 000, 29 200, 54 800 and 79 700 in 1989. Emergence in 1987 and 1989 was poor in some treatments which precluded their use. Some plant losses (not due to lodging, however) occurred during the season resulting in differences in actual densities each year. In 1987, heavy and frequent rainfall during May and June prevented replanting of the experiment until 19 Jun. No lodging was observed in any of the treatments during the experiment.

Replicates of individual treatments were harvested in 1987 and 1988 when grain had reached the soft dough stage (i.e., treatments were harvested at different dates but at similar maturity). In 1989 all treatments were harvested on the same date. All treatments reached soft dough stage within a 1-wk period each year. Plants from 10 ft of the middle row of sub-subplots were cut 4 inches above ground. Fresh weights were recorded and six random plants were chopped with a garden-type chipper/shredder. One lb of this chopped plant material was used for dry matter determination. An additional four plants from each sub-subplot were separated into leaf blades, stalks and panicles. Leaf sheath was included with the stalk. Plant components were weighed, chopped and subsampled for dry matter determination. Subsamples of whole plants and plant components were weighed fresh, dried at 131°F for 48 h and reweighed to determine dry matter percentage. Morphological composition was expressed as a percentage of whole plant dry matter. The stalk diameter of four to six stalks from each plant density subplot was measured at harvest in 1987 and 1988 midway between the first and second nodes across the flattened side. In 1989 measurement was made across the flattened side midway between the fourth and fifth nodes.

Whole plant, leaf blade and stalk samples were ground sequentially through a 0.08 inch screen in a shear mill and through a 0.04 inch screen of an impact mill and stored at room temperature in plastic vials until analysis. Near infrared reflectance spectroscopy (Model 6250, NIRSystems, Silver Springs, MD) was used to analyze samples for crude protein (CP, whole plants only), IVTD, ADF, cellulose and ADL (whole plants and stalks only). Samples for calibrating the NIRS were selected

Table 1. Temperature, rainfall and irrigation water applied during the growing season in 1987, 1988 and 1989.

	Mean daily temperature†					Monthly rainfall (R) and irrigation (I)						
	1987	1988	1989	Long-term‡ average		1987 R	1987 I	1988 R	1988 I	1989 R	1989 I	Long-term‡ average
	°F					inches						
Mar	52.2	55.2	55.6	54.9		1.7		0.6		3.1		1.6
Apr	62.2	64.2	65.7	64.8		0.6		1.8		1.6		3.4
May	72.7	71.8	73.2	71.4		9.1		5.7	3.4	7.0		4.6
Jun	77.2	76.8	75.4	79.0		3.9		2.4	3.4	7.9	4.0	2.5
Jul	81.3	81.7	81.3	82.8		0.5	5.4	2.6	4.0	1.3	3.0	2.4
Aug	83.7	84.4	79.7	82.2		1.7	7.0	0.9	4.6	2.9		1.9
Sep	74.0	75.6	71.2	75.2		1.3	1.2	3.0		3.6		3.0
					Total	18.8	13.6	17.0	15.4	27.4	7.0	19.4

†(maximum temperature + minimum temperature)/2.
‡Long-term average temperature and rainfall based on data from 1942 to 1975.

based on spectral characteristics via the program SUBSET (Infrasoft International, Port Matilda, PA).

Calibration samples were analyzed for CP, (Kjeldahl N x 6.25; Bremner, 1965), ADF, cellulose, ADL and IVTD (Goering and Van Soest, 1970). Decalin and sodium sulfite were omitted from the ADF procedure. Calibrations for ADF, cellulose and ADL were done individually for whole plants, leaf blades and stalks, whereas IVTD was calibrated for combined components. A stepwise multiple regression procedure (Infrasoft International, Port Matilda, PA) was used to develop calibration equations.

Because the number of plant density treatments and the range in plant densities were different among years, a separate analysis of variance was computed for each year. Sums of squares for N rate main effects and interactions were partitioned into linear and lack-of-fit effects. Sums of squares for plant density main effects and interactions were partitioned into linear, quadratic or lack-of-fit effects (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Dry Matter Yield

Yield of forage sorghum responded differently to N rate under irrigated and dryland treatments (N rate by irrigation interaction) in 1987 and 1988 but not in 1989 (Fig. 1). In 1987, irrigated sorghum yielded less than dryland sorghum when no N was applied. Both dryland and irrigated sorghum increased in yield with the addition of 160 lb N acre^{-1}; however, the yield response for irrigated sorghum was greater (4.7 tons dry matter acre^{-1}) than for dryland sorghum (2.5 tons). Yield of irrigated sorghum increased by 1 ton acre^{-1} when N was increased from 160 to 320 lb acre^{-1}, whereas dryland sorghum did not respond to the additional N. In 1988, dryland and irrigated sorghum yielded the same with no N fertilizer; however, irrigated sorghum yield increased by 5.2 tons dry matter acre^{-1} with 160 lb N acre^{-1}, whereas dryland sorghum yield increased by 3.2 tons acre^{-1}. There was a slight increase in yield when the N rate was increased from 160 to 320 lb N acre^{-1} for irrigated sorghum, whereas dryland sorghum decreased slightly in yield at the high N rate. In 1989, there was no interaction between N rate and dryland or irrigated treatments but there was a significant response to N. Yield increased by 3.5 tons acre^{-1} with the addition of 160 lb N acre^{-1} and there was no further yield response as N rate was increased to 320 lb N acre^{-1}. Jensen and Sletten (1965) reported a similar interaction of N rate with irrigation level for grain sorghum where they found that irrigated sorghum yielded more grain with increased N than did dryland sorghum. Current recommendations by the Texas Agricultural Extension Service (TAEX, 1989) are 180 to 220 lb of N acre^{-1} (soil N plus fertilizer N) to achieve yields of 7 to 9 tons of sorghum dry matter acre^{-1} (20 to 25 tons of 35% dry matter silage acre^{-1}). Our data suggest that a slightly lower rate (160 lb N acre^{-1}) would be adequate for forage sorghum in this area.

The differences among years in yield response to irrigation probably were due to differences in the amount, frequency and distribution of rainfall each year (rainfall amounts are in Table 1).

In 1988, when the yield response to irrigation was greatest, the yield increase due

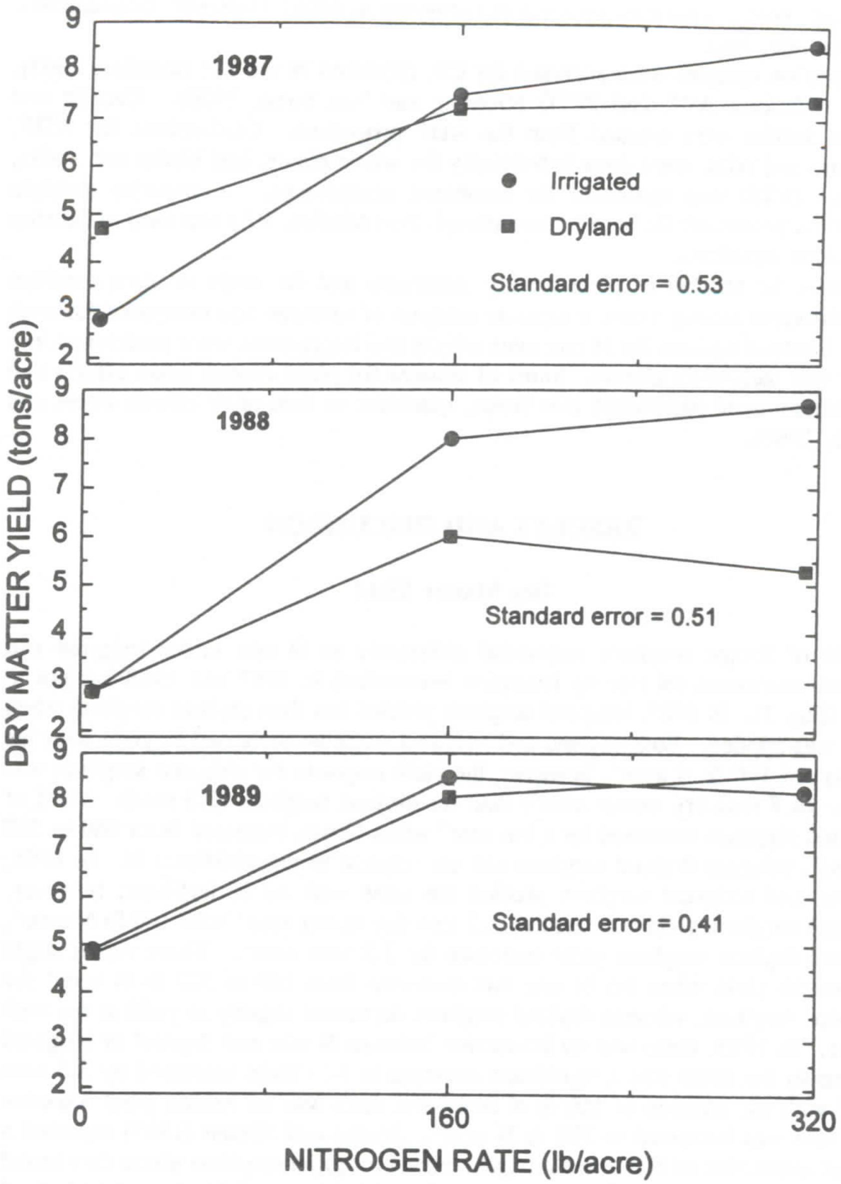

Figure 1. Yield response of dryland and irrigated forage sorghum to rate of N fertilizer. Standard errors in 1987 (n = 12) and 1988 (n = 16) are for the interaction of water treatment and N rate. There was no interaction in 1989, therefore the standard error is for the average response to N rate (n = 32). Partitioning of the sums of squares for the N main effect into linear and lack-of-fit components indicated that the lack-of-fit effect was significant ($P < 0.05$) for each treatment in each year.

to irrigation was 2 tons of dry matter acre^{-1} (5.7 tons of 35% dry matter silage) with 160 lb of N acre^{-1} and 3.4 tons of dry matter (9.7 tons of 35% dry matter silage) at 320 lb N acre.$^{-1}$ Sorghum silage sells for about $16 per wet ton (35% dry matter) in northcentral Texas and the minimum cost for pumping irrigation water is $7 per acre-inch. Custom harvest costs are $6.50 per wet ton and N (ammonium nitrate) sells for $0.29 lb^{-1}. Total irrigation water applied in 1988 was 15.4 in. (Table 1). Thus, the increased gross return would have been $91 acre^{-1} (5.7 tons x $16 ton^{-1}) and $155 acre^{-1} (9.7 tons x $16 ton^{-1}) higher for the irrigated 160 lb and 320 lb N acre^{-1} treatments, respectively, compared to similar N rates under dryland conditions. Net returns would have been -$54 acre^{-1} [$91 minus the $108 pumping cost and $37 harvest cost (5.7 tons x $6.50 ton^{-1})] for the irrigated 160 lb N treatment and -$16 acre^{-1} [$155 minus the $108 pumping cost and $63 harvest cost (9.7 x $6.50 ton^{-1})] for the irrigated 320 lb N treatment. Thus, irrigation of forage sorghum in this study was not profitable.

Dry matter yield increased with increasing plant density in each year (Fig. 2), however, the size and pattern of the response differed. In 1987, yield did not increase at densities above 50 000, whereas in 1988 and 1989, yield increased linearly ($P < 0.05$) with increasing plant density. The response to plant density was probably much greater in 1989 because of the above-normal rainfall. Although yield increased linearly with increasing plant density in 1988, the yield increase at the highest plant density was only 0.2 ton acre^{-1}. There was no interaction of plant density with irrigation treatment during any year. In 1988, there was a plant density by N rate interaction in which nonfertilized sorghum did not respond to increased plant density, whereas when N was applied, yield increased as plant density increased (data not shown). No lodging, which may occur at high plant populations, was observed in our experiment.

Our data suggest that plant populations of 80 000 to 100 000 plants acre^{-1} would be appropriate for silage production. The number of seeds per lb of the hybrid we used was determined to be 14 500. Thus, assuming 70% emergence, plant densities of 80 000 to 100 000 would require a seeding rate of 8 to 10 lb acre^{-1}. The seeding rate recommended for FS-25e by the seed company is 5 to 8 lb acre^{-1} for limited irrigation or favorable dryland conditions and 8 to 12 lb acre^{-1} under full irrigation.

Proportions of Panicle, Leaf Blade and Stalk

Irrigated and dryland sorghum differed in panicle proportion at different N levels in 1987 and 1988 (Fig. 3). Dryland sorghum maintained a higher panicle proportion than irrigated sorghum at N fertilizer rates of 160 and 320 lb acre^{-1} (Fig. 3). In 1989, dryland and irrigated sorghum had similar panicle proportions and both increased with increasing N rate.

Stalk and leaf blade proportions of sorghum responded similarly under dryland and irrigated treatments. The average response to N rate is presented in Fig 4. Stalk proportion did not change in response to N in 1987, increased with 160 lb N in 1988, and decreased with increased N rate in 1989. Leaf blade proportion was highest under 0 N, then declined at 160 lb N acre^{-1}. There was no difference in leaf blade proportion between the 160 and 320 lb acre^{-1} N rates.

Plant density generally did not have a large effect on the proportion of leaf blade, stalk or panicle. However, increased plant density reduced stalk diameter by 22, 40 and 33% in 1987, 1988 and 1989, respectively (data not shown). Leighton et al.

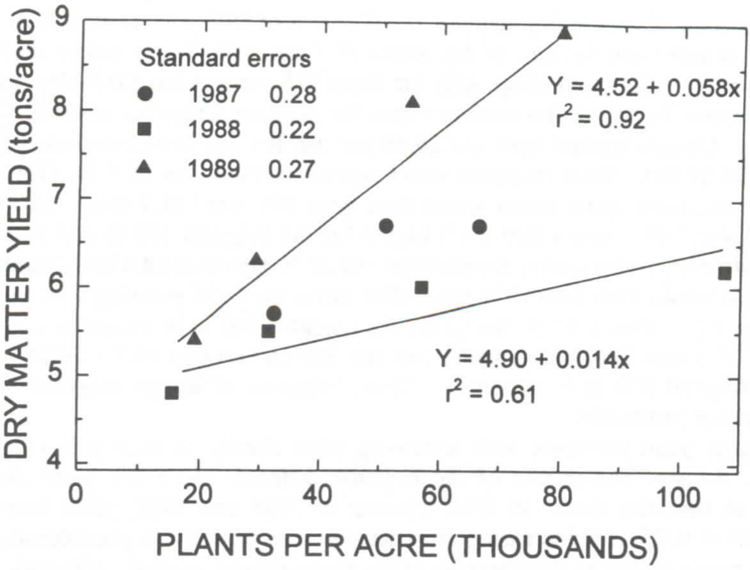

Figure 2. Yield response of forage sorghum to plant density during 3 years. Partitioning of the sums of squares for the plant density main effect into linear, quadratic and lack-of-fit components indicated that the linear component was significant in 1988 and 1989, whereas the lack-of-fit effect was significant in 1987. Standard errors are based on N = 24.

(1976) also reported no changes in stover or panicle proportions of forage sorghum when seeding rates were increased from 4 to 12 lb acre^{-1}. Carravetta et al. (1990a) reported that the leaf to stem ratio of three sorghum genotypes decreased as plant density increased primarily because of an increased plant height at the higher densities, which implied that the stalk proportion increased at higher densities.

Forage Quality Responses

Leaf Blades

Digestibility and fiber concentration of sorghum leaf blades were affected by N rate in 1987 and 1988 and by plant density in 1988 and 1989 (Table 2). Although the effect of N application was significant, the changes in IVTD, ADF and cellulose with N fertilizer were slight. Increased plant density in 1988 increased ADF and cellulose concentration and reduced IVTD in 1988 and 1989. Irrigated sorghum leaf blades were more ($P < 0.05$) digestible (76.8 vs. 75.6%) than dryland sorghum leaf blades.

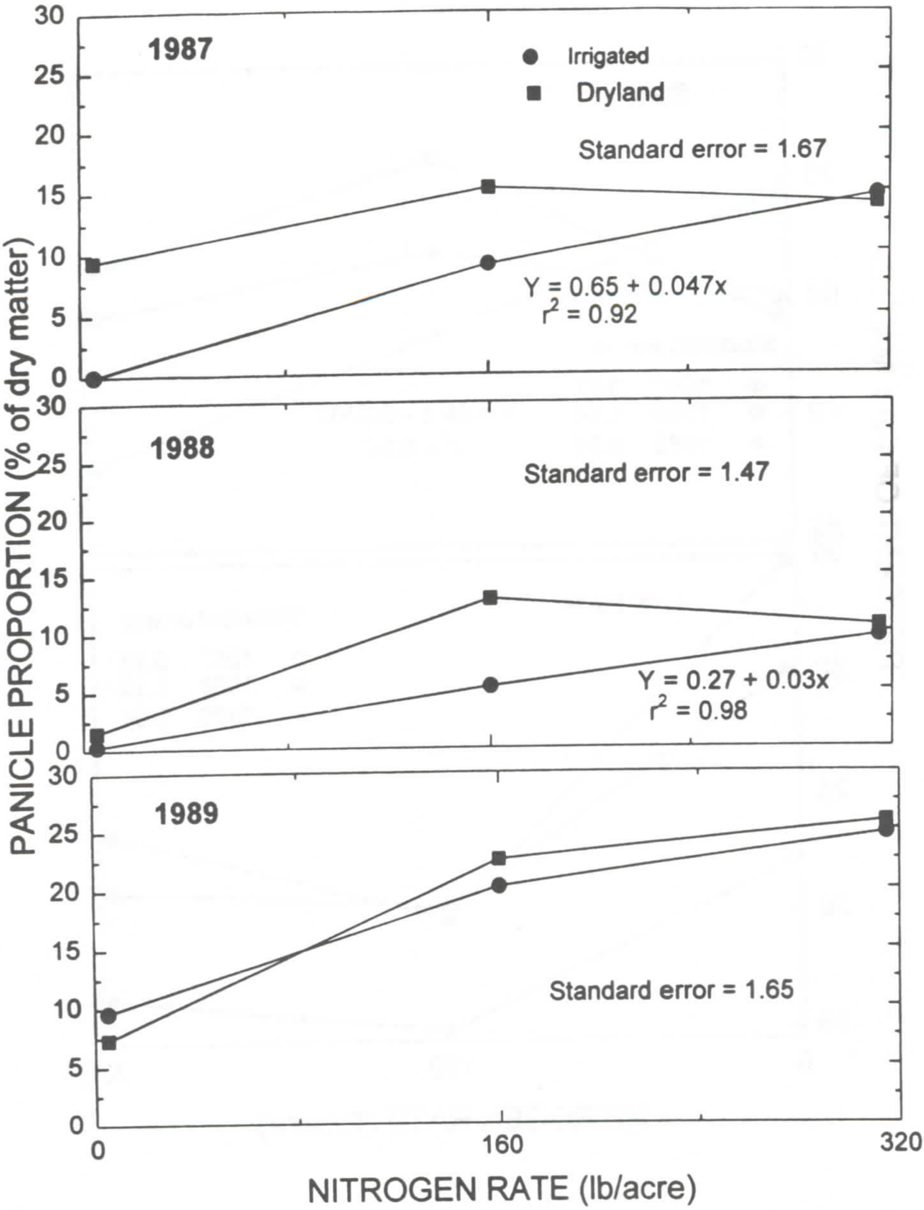

Figure 3. Changes in the proportions of panicle with N rate in irrigated and dryland forage sorghum during 3 years. Standard errors in 1987 (n = 12) and 1988 (n = 16) are for the interaction of water treatment and N rate. There was no interaction in 1989, therefore the standard error is for the average response to N rate (n = 32). Partitioning of the sums of squares for the N main effect into linear and lack-of-fit components indicated that the lack-of-fit effect was significant ($P < 0.05$) for the dryland treatment in each year, whereas the linear component was significant for the irrigated treatment in 1987 and 1988.

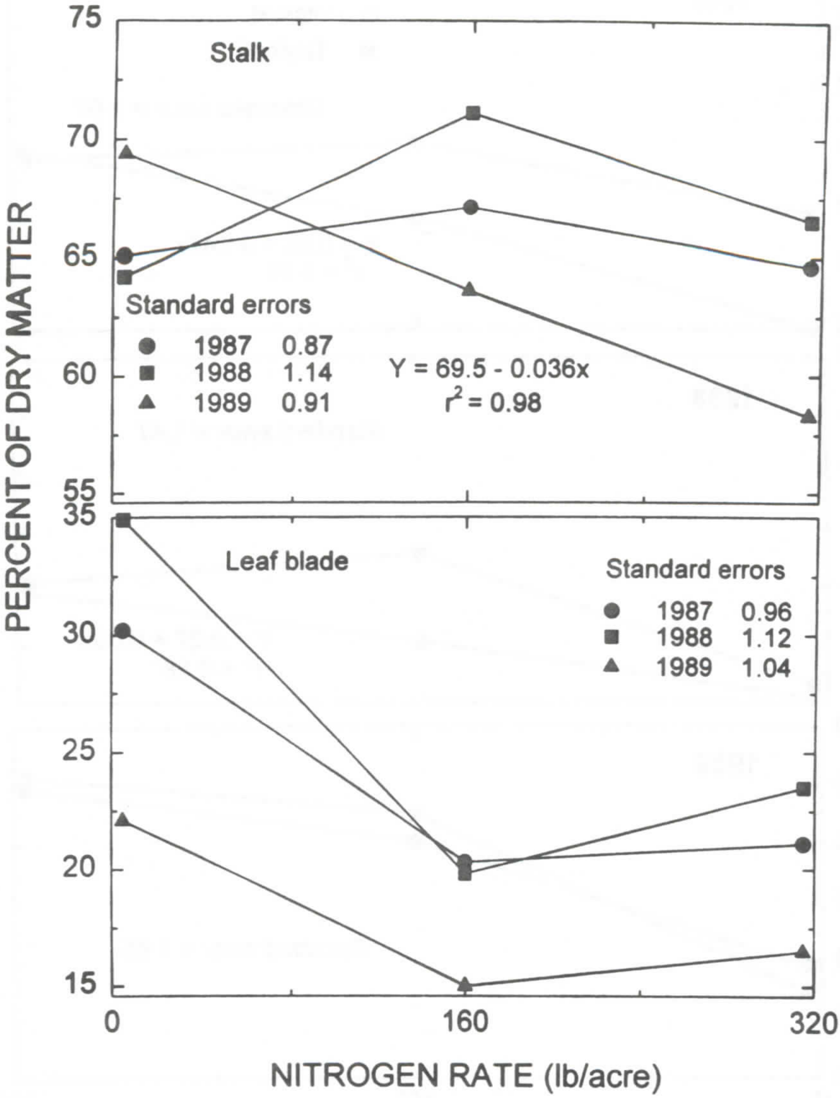

Figure 4. Changes in the proportion of leaf blade and stalk in forage sorghum with N rate during 3 years. Partitioning of the sums of squares for the N main effect into linear and lack-of-fit components indicated that there was no ($P > 0.05$) effect of N on stalk proportions in 1987, a lack-of-fit effect in 1988 and a linear response in 1989. For leaf blade, the lack-of-fit component was significant in each year. Stand errors are based on n = 24 (1987) or 32 (1988 and 1989).

Stalks

There was a significant interaction among water treatment, N rate and plant density for IVTD of sorghum stalks in 1987 and 1988. In 1987, stalk IVTD decreased with increasing plant density except for irrigated 0 N and dryland 160 lb N treatments, which decreased then increased in IVTD with plant density (data not shown). Similarly in 1988, IVTD of all treatments except dryland 0 N and 320 lb N treatments declined with increasing plant density (data not shown). In 1989, there were no significant treatment effects. The changes in IVTD with plant density may be related to morphological changes in the stalk. At higher plant densities, sorghum stalks are smaller in diameter and the proportion of pith tissue, which is relatively highly digestible (Akin et al., 1993), is reduced relative to the amount of rind tissue, which is more lignified and less digestible than pith (Akin et al., 1993). Carravetta et al. (1990b) reported that sorghum stalks increased in neutral detergent fiber (NDF) and permanganate lignin (as a proportion of NDF) as plant density increased, whereas in vitro digestibility decreased. Fuller and Reagan (1989) also noted an increase in fiber concentrations of 'Wray' sweet sorghum with increased plant density.

There was a significant N by water treatment interaction for fiber components in 1987 and 1988 (Tables 3 and 4). In 1987, ADF concentrations were similar at the 0 and 160 N rates and highest at the 320 N rate in irrigated sorghum stalks, whereas dryland sorghum ADF was lowest at 0 N and similar at 160 and 320 N. In 1988, ADF concentrations decreased at 160 lb N acre^{-1} under irrigation, but remained constant under dryland conditions. Cellulose and ADF concentrations were greater in irrigated than dryland sorghum stalks in both years. Acid detergent lignin concentrations were greater in irrigated than dryland sorghum stalks and increased with N applied except for dryland sorghum in 1988 when ADL concentration was highest at 160 lb N acre^{-1}.

In our study, under 0 N, there were no correlations ($P > 0.05$) of lignocellulose components or IVTD with stalk diameter; however, under medium to high N fertilization, IVTD was positively correlated ($P < 0.05$; $r = 0.34$ and 0.52 for 1988 and 1989) with stalk diameter.

Whole Plants

Water treatment and N rate affected most forage quality indicators in 1987 and 1988 (Table 5). Dryland sorghum was more digestible than irrigated sorghum and higher in CP. This was also reflected in lower ADF and ADL concentrations of dryland sorghum than irrigated sorghum. Kipnis et al. (1994) also noted that in vitro digestibility of forage sorghum was increased by drought stress and reported that the higher digestibility of stressed sorghum was associated with an accumulation of sucrose in the stalk.

Sorghum IVTD decreased by 3.4% with applied N fertilizer in 1988. Although ADF and cellulose concentrations decreased with applied N, lignin concentrations increased by 23% in 1987 and 30% in 1988 which probably reduced IVTD. Atkins and Boucher (1992) also reported lower ADF concentrations with high N fertility in forage sorghum. In our study, the higher N rate coupled with irrigation may have

Table 2. Digestibility and fiber components of sorghum leaf blades as affected by N rate in 1987 and 1988 and plant density in 1988 and 1989.

Treatment		IVTD†	ADF	CELL
		--------------------% of dry matter--------------------		
N rate, lb acre^{-1}			1987	
0		76.5	38.1	32.8
160		74.4	38.4	32.9
320		75.0	37.3	31.3
	Effect‡	LOF*	LOF*	LOF**
	S.E.	0.16	0.31	0.27
			1988	
0		76.4	35.2	31.4
160		76.6	35.0	30.4
320		75.6	34.7	30.1
	Effect	LOF**	NS	L***
	S.E.	0.23	0.23	0.17
1000 Plants acre^{-1}			1988	
15.5		76.6	34.3	29.9
31.4		76.3	34.8	30.5
56.9		76.0	35.3	31.0
107.3		75.8	35.4	31.2
	Effect	L*	L**	L***
	S.E.	0.18	0.21	0.17
			1989	
19.0		72.4	34.6	29.0
29.2		71.8	35.7	29.8
54.8		71.2	36.1	30.2
79.7		70.5	37.7	31.5
	Effect	L**	L**	L**
	S.E.	0.54	0.44	0.56

*, **, *** = Significant differences at $P \leq 0.05$, 0.01 and 0.001.
NS = not significant.
†IVTD = in vitro true digestibility, ADF = acid detergent fiber, CELL = cellulose.
‡L = linear, LOF = lack-of-fit.

Table 3. Digestibility and fiber components of sorghum stalks as affected by N rate and water treatment in 1987.

Treatment	N rate, lb acre^{-1} 0	160	320	Avg.	Effect†	Standard errors Water treatment	N rate	Interaction
	---------% of dry matter---------							
	In Vitro True Digestibility							
Irrigated	76.4	73.1	71.6	73.3		0.14NS	0.39*	0.47NS
Dryland	74.9	72.6	73.5	73.6				
Avg.	75.6	72.8	72.6		LOF			
	Acid Detergent Fiber							
Irrigated	33.4	33.2	34.8	33.8	L	0.20*	0.28**	0.38*
Dryland	31.2	32.5	32.8	32.2	L			
Avg.	32.3	32.9	33.8					
	Cellulose							
Irrigated	28.2	28.5	28.8	28.5		0.08*	0.20*	0.25NS
Dryland	27.6	28.3	28.4	28.1				
Avg.	27.9	28.4	28.6		L			
	Acid Detergent Lignin							
Irrigated	3.54	4.28	4.92	4.24	L	0.06**	0.09***	0.12*
Dryland	3.27	3.72	3.37	3.65	L			
Avg.	3.40	4.00	4.44					

*, **, *** = Significant differences at P≤ 0.05, 0.01 and 0.001.

NS = not significant.

†L = linear, LOF = lack-of-fit.

Table 4. Digestibility and fiber components of sorghum stalks as affected by N rate and water treatment in 1988.

Treatment	N rate, lb acre^{-1}				Effect†	Standard errors		
	0	160	320	Avg.		Water treatment	N rate	Interaction
	---------% of dry matter----------							
	In Vitro True Digestibility							
Irrigated	75.6	74.0	71.7	73.8		0.23**	0.29**	0.41NS
Dryland	78.4	75.1	74.0	75.8				
Avg.	77.0	74.6	72.8		L			
	Acid Detergent Fiber							
Irrigated	35.0	32.4	34.2	33.9	LOF	0.20**	0.29NS	0.39**
Dryland	29.7	30.6	30.2	30.2	NS			
Avg.	32.3	31.6	32.2					
	Cellulose							
Irrigated	29.1	27.9	29.4	28.8	LOF	0.13**	0.13***	0.20***
Dryland	25.6	26.8	27.7	26.7	L			
Avg.	27.3	27.4	28.6					
	Acid Detergent Lignin							
Irrigated	4.19	4.38	4.81	4.46	L	0.03***	0.10*	0.12**
Dryland	3.31	3.97	3.30	3.53	LOF			
Avg.	3.75	4.18	4.06					

*, **, *** = Significant differences at $P \leq 0.05$, 0.01 and 0.001.

NS = not significant.

†L = linear, LOF = lack-of-fit.

resulted in less accumulation of soluble carbohydrates in the plant because of their use for synthesis of structural material which subsequently resulted in higher fiber concentrations and reduced digestibility.

Crude protein increased with increased N fertility in 1987 and 1988. In 1989, the only significant effects were plant density for CP and an interaction of water treatment by plant density for ADF (data not shown).

Correlations among proportions of plant components and fiber or digestibility of the sorghum whole plant were inconsistent. Acid detergent fiber in the whole plant was negatively correlated with panicle proportion and IVTD was positively correlated with leaf proportion in 1987 and 1988 (Table 6). Acid detergent fiber was positively correlated with leaf proportion in 1987 and 1989. The positive correlation of ADF with leaf proportion and negative correlation with panicle proportion is consistent with the negative correlation between leaf and panicle proportion. There was no correlation of whole-plant IVTD with panicle proportion in 1987 and 1989 and the correlation coefficient in 1988 was low. White et al. (1991) reported that grain proportion had a large and positive effect on forage sorghum silage digestibility; however, the grain proportions they reported (28 to 41% of whole plant DM) were higher than the panicle proportions we observed (5 to 25%).

CONCLUSIONS

Our data show that irrigating forage sorghum to produce silage was not profitable in this region. Nitrogen at a rate of 160 lb acre^{-1} and a plant density between 80 000 and 100 000 plants acre^{-1} were adequate for silage yields. Varying N rate and plant density changed the proportions of panicle, leaf blade and stalk but these changes did not adversely affect yield.

Our results suggest that digestibility and fiber components should not have a bearing on plant population recommendations for forage sorghum grown for silage. Nitrogen fertilizer did reduce digestibility and increase fiber; however, the reductions were minor compared with the dry matter yield increase and increase in crude protein with applied N. Supplemental irrigation reduced stalk and whole plant forage quality and, taken with the inconsistent yield responses, may not be an economical recommendation for sorghum silage production in this area.

Table 5. Digestibility, fiber and crude protein concentration of sorghum whole plants in 1987 and 1988.

Treatment	IVTD†	ADF	CELL	ADL	CP
	---------------------------% of dry matter---------------------------				
			1987		
Water treatment					
Irrigated	74.9	34.4	29.1	4.25	3.4
Dryland	75.8	32.7	28.0	3.82	4.4
S.E.	0.14*	0.26*	0.21NS	0.014***	0.08*
N rate, lb acre^{-1}					
0	75.8	35.2	31.2	3.58	3.40
160	75.1	32.9	27.8	4.12	3.40
360	75.2	32.5	26.6	4.40	3.70
Effect†	NS	LOF	LOF*	L***	LOF**
S.E.	0.38	0.26	0.36	0.059	0.12
			1988		
Water treatment					
Irrigated	74.7	33.6	28.0	4.23	3.20
Dryland	76.4	31.6	27.2	3.65	4.90
S.E.	0.09**	0.56NS	0.41NS	0.083*	0.10*
N rate, lb acre^{-1}					
0	76.7	27.1	24.9	2.03	3.20
160	75.9	26.9	23.7	2.67	5.50
320	74.1	25.5	22.5	2.64	6.40
Effect	L**	LOF**	LOF*	L**	LOF**
S.E.	0.28	0.50	0.38	0.054	0.016

*,**,*** = Significant at P< 0.05, 0.01 and 0.001.

NS = not significant.

†IVTD = in vitro true digestibility, ADF = acid detergent fiber, CELL = cellulose, ADL = acid detergent lignin, CP = crude protein.

‡L = linear, LOF = lack-of-fit.

Table 6. Correlations ($P < 0.05$) of whole plant acid detergent fiber (ADF) and in vitro true digestibility (IVTD) with stalk diameter and morphological composition of sorghum.

Item	Stalk diameter	Proportion of whole plant			n
		Stalk	Leaf	Panicle	
			1987		
ADF	-0.49	NS†	0.64	-0.79	68
IVTD	NS	NS	0.33	NS	69
			1988		
ADF	NS	NS	NS	-0.49	96
IVTD	NS	-0.43	0.49	-0.19	96
			1989		
ADF	NS	NS	0.37	NS	31
IVTD	0.36	NS	NS	NS	32

† NS = not significant

REFERENCES

Akin, D.E., L.L. Rigsby, W.W. Hanna, and C.E. Lyon. 1993. In vitro digestion and textural strength of rind and pith of normal and brown midrib stems. Anim. Feed Sci. Tech. 43:303-314.

Atkins, C.J., and B.D. Boucher. 1992. The economics of a high rate of nitrogen fertilization on forage sorghum for dairy production. p. 221-230. In M.A. Foale et al. (ed.) Proc. Second Australian Sorghum Conf. Gatton, Australia, 4-6 Feb., 1992. Australian Inst. Agric. Sci. Occ. Publ. no. 68. Melbourne.

Bremner, J.M. 1965. Inorganic forms of nitrogen. p. 1179-1237. In C.A. Black et al. (ed.) Methods of soil analysis. Part 2. Agron. Monogr. 9. ASA, Madison, WI.

Ball, D.M., C.S. Hoveland, and G.D. Lacefield. 1991. Silage production and feeding. p. 147-153. In Southern forages. Potash and Phosphate Institute and Foundation for Agronomic Research, Atlanta, GA.

Carravetta, G.J., J.H. Cherney, and K.D. Johnson. 1990a. Within-row spacing influences on diverse sorghum genotypes: I. Morphology. Agron. J. 82:206-210.

Carravetta, G.J., J.H. Cherney, and K.D. Johnson. 1990b. Within-row spacing influences on diverse sorghum genotypes: II. Dry matter yield and forage quality. Agron. J. 82:210-215.

Fuller, B.W., and T.E. Reagan. 1989. The relationship of sweet sorghum plant fiber and survival of the sugarcane borer, Diatraea saccharalis (F.) (Lepidoptera:Pyralidae). J. Agric. Entomol. 6:113-118.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analysis (Apparatus, reagents, procedures, and some applications). USDA-ARS Agric. Handb. no. 379. U.S. Gov. Print. Off. Washington, DC.

Goodrich, R.D., and J.C. Meiske. 1985. Corn and sorghum silages. p. 527-536. In M.E. Heath et al. (ed.) Forages: The science of grassland agriculture. Iowa State University Press, Ames.

Gourley, L.M., and J.W. Lusk. 1978. Genetic parameters related to sorghum silage quality. J. Dairy Sci. 61:1821-1827.

Jensen, M.E., and W.H. Sletten. 1965. Evaporation and soil moisture-fertilizer interrelationships with irrigated grain sorghum in the southern Great Plains. USDA-ARS Cons. Res. Rpt. No. 5. U.S. Gov. Print. Office, Washington, DC.

Kipnis, T., M. Sagi, L. Dvash, G. Krivat, and A. Sadeh. 1994. Drought and salinity stress improve the quality of forage sorghum. p. 69. In Abstracts of the Natl. Conf. on Forage Quality, Evaluation, and Utilization. Lincoln, NE, Apr. 13-15. Univ. of Nebraska, Lincoln.

Leighton, R.E., J.K. Riggs, J.W. Sorenson, and E.C. Holt. 1976. Silage and haylages. p. 290-324. In Grasses and legumes in Texas. Development, production, and utilization. Texas Agric. Exp. Stn. Res. Monogr. 6c.

Martin, J.H., and J.C. Stephens. 1955. The culture and use of sorghums for forage. USDA Farmers Bull. 1844. U.S. Gov. Print. Office, Washington, DC.

Martin, J.H., W.H. Leonard, and D.L. Stamp. 1976. Sorghum. p. 383-414. In Principles of field crop production. 3rd Ed. Macmillan, New York.

Miller, F.R. 1976. Sorghum hybrids. p. 237-243. In Grasses and legumes in Texas: Development, production, and utilization. Texas Agric. Exp. Stn. Res. Monogr. 6c.

Musick, J.T., and D.A. Dusek. 1969. Grain sorghum row spacing and planting rates under limited irrigation in the Texas high plains. Texas Agric. Exp. Stn. Bull. MP-932.

Schaller, F.W. 1980. Crops for silage. Iowa State Univ. Coop. Ext. Serv. Pamphlet 417d.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw Hill, New York.

Texas Agricultural Extension Service (TAEX). 1989. Soil, plant, and water testing laboratory suggested fertilization for silage production. Publ. AGR 11-3.

Wagner, B.J., J.R. Thomas, E.R. Harris, E. Deleon, C.G. Ford, and J.D. Kelley. 1973. Soil survey of Erath County, Texas. p. 61. USDA-SCS. U.S. Gov. Print. Office, Washington, DC.

White, J.S., K.K. Bolsen, G. Posler, and J.W. Neill. 1991. Forage sorghum silage dry matter disappearance as influenced by plant part portion. Anim. Feed Sci. Technol. 33:313-322.