Reprinted from *Agronomy Journal*
Vol. 83, No. 6

Nutrient and Carbohydrate Partitioning in Sorghum Stover

J. M. Powell, F. M. Hons,* and G. G. McBee

ABSTRACT

Although petroleum fuels have been abundant during the past decade, alternative energy sources are needed for the long term. Sorghum [*Sorghum bicolor* (L.) Moench] stover has been demonstrated to be a potential biomass energy source. Complete aboveground crop removal, however, can result in soil degradation. Differential dry matter, nutrient, and carbohydrate partitioning by sorghum cultivars may allow management strategies that return certain stover parts to the field while removing other portions for alternative uses, such as energy production. A field study was conducted to determine N, P, K, nonstructural carbohydrate, cellulose, hemicellulose, and lignin distributions in stover of three diverse sorghum cultivars of differing harvest indices. Determinations were based on total vegetative biomass; total blades; total stalks; and upper, middle, and lower blades and stalks. Concentrations of N and P were higher in blades than stalks and generally declined from upper to lower stover parts. Large carbohydrate and lignin concentration differences were observed on the basis of cultivar and stover part. Greater nutrient partitioning to the upper third of the intermediate- and forage-type sorghum stovers was observed as compared to the conventional grain cultivar. Stover carbohydrates for all cultivars were mainly contained in the lower two-thirds of the stalk fraction. A system was proposed for returning upper stover portions to soil, while removing remaining portions for alternative uses.

SORGHUM has been identified as a good biomass crop for fermentation to methane or ethanol (Miller and Creelman, 1980; Creelman et al., 1981; Lacewell et al., 1986). Removal of all aboveground dry matter over time, however, can result in declining soil productivity. Differential partitioning of nutrients and carbohydrates in sorghum stovers may allow the removal of components high in carbohydrates for energy production and the return of other components to the field.

Plant parts can vary in mineral content and carbohydrate composition, which directly impact decomposition rates by soil microorganisms, palatability to ruminant livestock, and usefulness as alternate energy sources. Structural carbohydrate and lignin concentrations in cell walls may vary widely in stover parts, directly affecting their value as a livestock feed or biomass energy source (Van Soest, 1982; Reed et al., 1988). Significant cultivar differences in structural and nonstructural carbohydrate concentrations and relative proportions of cellulose, hemicellulose, and lignin may also exist in sorghum stovers (Ferraris and Charles-Edwards, 1986; Smith et al., 1987; McBee and Miller, 1990).

The objective of this study was to determine sorghum cultivar effects on dry matter, nutrient, total nonstructural carbohydrate, cellulose, hemicellulose, and lignin distributions in various stover components.

Soil and Crop Sciences Dep., Texas A&M Univ., College Station, TX 77843-2474. Contribution of Texas Agricultural Experiment Station. Research partially supported by the Gas Research Institute, Chicago, IL. Received 27 July 1990. *Corresponding author.

Published in Agron. J. 83:933–937 (1991).

MATERIALS AND METHODS

Field experiments were conducted at the Texas Agricultural Experiment Station Research Farm in Burleson County near College Station on a Ships clay soil (very fine, mixed, thermic Udic Chromustert) during 1986 and 1987. Average annual precipitation at the site (50-yr period) is 980 mm, 45% of which occurs between the April to August cropping period. Three sorghum cultivars were used in the study: ATx623 × RTx430, a conventional grain type; ATx623 × Hegari, an intermediate-type sorghum producing a relatively high yield of both grain and stover; and Grassl, a forage-type sorghum. The experimental design was a randomized complete block with each cultivar being replicated four times in plots consisting of six rows, 7.6 m long and 0.68 m apart.

Plots received 112 kg N ha^{-1} as NH_4NO_3, with half the N broadcast preplant and worked into prepared beds by using a rolling cultivator. The remaining fertilizer N was subsurface banded approximately 30 d after planting. Planting occurred in late March each year, with harvest normally occurring in early to mid-August. Grain and stover yields and plant samples were obtained from the middle two rows of each six-row plot when the kernels were approximately 10 d post-black layer. Panicles for grain yield determination were hand-harvested from the middle 3 m of the two rows sampled in each plot and threshed in a stationary plot thresher. Grain moisture was determined by electrical resistance and yields were corrected to 140 g kg^{-1} moisture. Stover was removed 2 cm above the soil surface in the area harvested for grain and immediately weighed. Subsamples were taken for dry matter determination and calculation of total stover dry matter yield. Two additional plants per plot were sampled for chemical analysis of total stover, three plants per plot were sampled for analysis of total blades and stalks, and three additional plants were used for analysis of upper, middle, and lower blades and stalks. Plants for these stover analyses were also cut 2 cm above soil level. Panicles were removed at the peduncle and leaf sheaths were included with stalk fractions. Plants used for analysis of upper, middle, and lower blades and stalks were measured and divided equally into the above portions. The conventional grain and forage-type sorghums were sampled for dry matter, nutrient, carbohydrate, and lignin partitioning in 1986 and 1987, whereas the intermediate-type sorghum was sampled for these parameters in 1987 only. The cultivar ATx623 × Rio was originally used as the intermediate cultivar in 1986. Because of severe lodging of this cultivar, however, no data were collected for the intermediate cultivar in 1986 and ATx623 × Hegari was substituted as the intermediate cultivar in 1987.

After oven-drying (60 °C, 4 d), samples were initially ground through a hammer mill to pass a 10-mm screen and subsequently ground in a high-speed mill to <1 mm. Subsamples were acid digested (Nelson and Sommers, 1980) and analyzed for N and P by autoanalyzer (Technicon, 1977), while K was determined by inductively coupled plasma spectroscopy. A phenolsulfuric acid procedure (Guiragossin et al., 1979) was used to determine total nonstructural carbohydrate contents as hexose equivalents in stover material. Samples were extracted by placing 1 g of ground tissue in 50-mL centrifuge tubes and boiling in 20 mL of distilled water for 30 min. After cooling, 10 mL of 0.25% amylase plus 10 mL of 0.5% amyloglucosidase were added to each sample and allowed to incubate for 24 h at 60 °C. Samples were subsequently filtered and brought to 50 mL volume for analysis. The procedure of Goering and Van Soest (1970) was used to determine hemicellulose, lignin, and cellulose. During neutral detergent fiber extraction, approximately 2 mL of 2% amylase was added to each sample to digest excessive starch and facilitate sample filtering (Robertson and Van Soest, 1977).

Dry matter weights were multiplied by respective nutrient and carbohydrate concentrations to yield nutrient and carbohydrate contents on a plant part basis. Yields for upper, middle, and lower stover fractions were determined by summing respective blade and stalk yields.

Analysis of variance using the general linear models procedure (SAS Institute, 1982) was used to determine yearly cultivar and stover plant part differences in dry matter, N, P, K, and structural and nonstructural carbohydrate concentrations and yields. Tukey's Honestly Significant Difference Test (Montgomery, 1984) was used to delineate differences in treatment means where appropriate.

RESULTS AND DISCUSSION

Total Stover Dry Matter, Nitrogen, Phosphorus, Potassium, and Carbohydrate Yields

Total aboveground dry matter yield (grain + stover) and nutrient and carbohydrate assimilation and partitioning varied considerably among the three sorghum cultivars. Total aboveground dry matter yield averaged 11.3 Mg ha^{-1} for ATx623 × RTx430 (conventional grain-type sorghum), 21.2 Mg ha^{-1} for ATx623 × Hegari (intermediate-type sorghum) and 23.2 Mg ha^{-1} for Grassl (forage-type sorghum). Harvest indices for these three sorghums were 53.8, 20.1, and 2.5%, respectively. Total aboveground N, P, and K contents of ATx623 × RTx430 were 103, 24, and 129 kg ha^{-1} with approximately 71, 65, and 13% of these totals being contained in grain. ATx623 × Hegari contained 96, 26, and 301 kg ha^{-1} of total aboveground N, P, and K with 59, 47, and 5% of the totals in grain, respectively. Except for the 1 yr of limited (1.1 Mg ha^{-1}) grain production by Grassl (1986), all N (108), P (30), and K (287 kg ha^{-1}) remained in vegetative material. Grassl is highly sensitive to the interaction of photoperiod and temperature and normally will not flower at our location.

Large cultivar differences in stover dry matter and stover, N, P, and K yields were observed (Fig. 1). Grassl stover dry matter, N, and P yields were significantly greater than those of the other cultivars. Although Grassl stover dry matter production was only 33% greater than that of ATx623 × Hegari, Grassl stover N and P contents were more than twice as large. Grain of ATx623 × Hegari (4.2 Mg ha^{-1}) was a strong sink for N and P and was primarily responsible for observed stover N and P differences between the intermediate and forage cultivars.

Significant cultivar differences in total stover carbohydrate and lignin yields and partitioning were also observed (Fig. 2). Approximately 81% of total plant aboveground nonstructural carbohydrates [assuming sorghum grain contains approximately 75% starch (Doggett, 1970)] produced by the conventional grain sorghum was contained in grain as compared to 44% of total nonstructural carbohydrates contained in grain for the intermediate-type sorghum. Since the forage sorghum produced a small amount of grain in only 1 yr, most nonstructural carbohydrates were contained in the vegetative material.

Each cultivar also differed as to relative proportions of the various carbohydrates and lignin contained in stover (Fig. 2). Grassl and ATx623 × Hegari stovers would be more suitable for potential fermentation to methane or ethanol than ATx623 × RTx430 stover since nonstructural carbohydrates are most rapidly converted, followed by structural carbohydrates (McBee and Miller, 1990).

Dry Matter, Nutrient, Carbohydrate, and Lignin Concentrations in Stover Parts

The conventional grain cultivar had a smaller blade:stalk ratio (1:2.5; Table 1) than the intermediate-type (1:6.2; Table 2) or the forage sorghum (1:4.6; Table 3). Middle blades comprised the greatest percent-

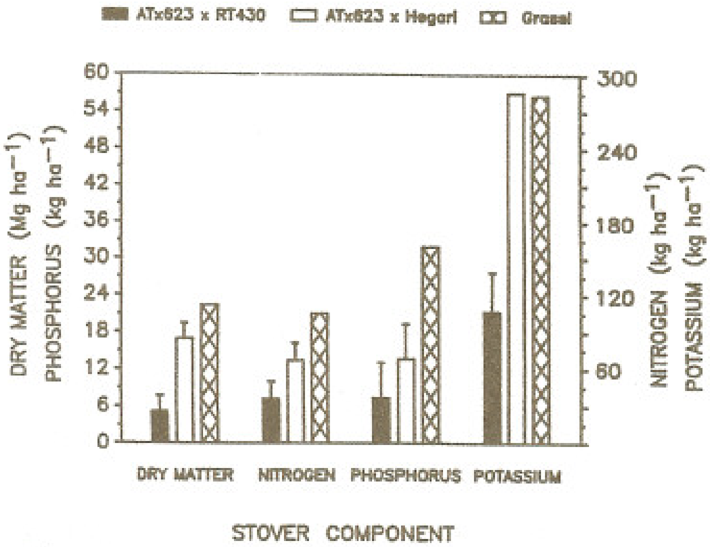

Fig. 1. Cultivar differences for sorghum stover dry matter and nutrient yields [vertical bars (I) represent $HSD_{0.05}$ for between cultivar comparisons within stover component].

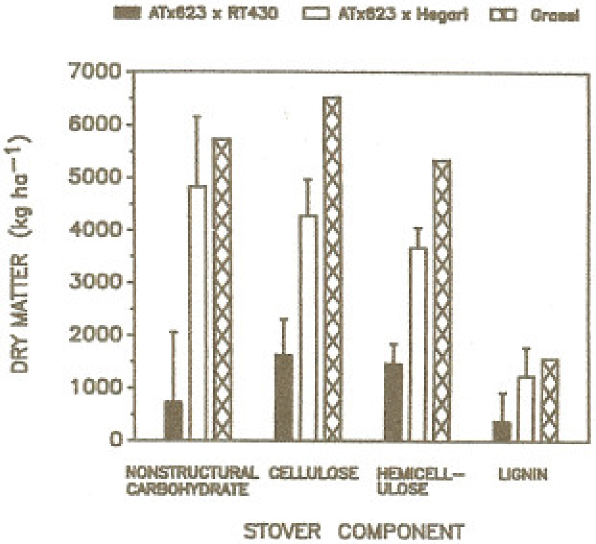

Fig. 2. Cultivar differences for sorghum stover carbohydrate and lignin yields [vertical bars (I) represent $HSD_{0.05}$ for between cultivar comparisons within stover component].

age of the total blade dry matter of ATx623 × RTx430 and ATx623 × Hegari, whereas upper and middle blades comprised similar proportions of Grassl blade dry matter. The greatest portion of stover dry matter for all cultivars came from lower stalks, which constituted from 27 to 33% of total stover dry matter. Sums of upper, middle, and lower blades and upper, middle, and lower stalks were not identical to total blade and stalk values in tables because different plants were sampled for the respective determinations as described in Materials and Methods.

Concentrations of N and P were greater in blades than stalks and generally declined from upper to lower stover parts (Tables 1, 2, and 3). Potassium concentrations were somewhat similar in Grassl blade and stalk fractions, but were much higher in ATx623 ×

Table 1. Dry matter (DM), N, P, K, nonstructural carbohydrate (NSC), cellulose (CL), hemicellulose (HC), and lignin (LG) concentrations in AT×623 × RT×430 stover parts (combined means of 1986 and 1987).

Stover Part	DM	N	P	K	NSC	CL	HC	LG
	% of total stover	g kg⁻¹						
Total Stover	100	6.0	1.4	20.7	142	313	282	71
Blades, total	28.4	13.8	2.4	12.3	100	249	329	54
Upper	8.3	14.8	2.5	12.3	141	254	325	57
Middle	13.2	11.4	2.0	13.2	83	261	320	49
Lower	5.8	8.5	1.5	6.6	108	292	293	65
Stalks, total	71.6	4.6	1.6	24.4	212	316	255	71
Upper	10.5	5.0	1.3	25.7	75	334	328	75
Middle	25.0	4.6	1.4	23.1	148	337	276	77
Lower	37.2	3.1	1.3	21.8	245	337	234	72
HSD ALL†	–	3.2	0.8	5.3	41	61	47	24
HSD Blades	–	2.8	1.2	4.3	35	NS	NS	NS
HSD Stalk	–	1.4	NS‡	NS	33	NS	29	NS

† All indicates Honestly Significant Difference (HSD) ($p < 0.05$) for all column pairwise comparisons; HSD Blades and HSD Stalks for comparing respective upper, middle and lower components.
‡ NS indicates no significant difference.

Table 2. Dry matter (DM), N, P, K, nonstructural carbohydrate (NSC), cellulose (CL), hemicellulose (HC), and lignin (LG) concentrations in AT×623 × Hegari stover parts (1987).

Stover part	DM	N	P	K	NSC	CL	HC	LG
	% of total Stover	g kg⁻¹						
Total Stover	100	2.3	0.8	16.9	285	253	217	73
Blades, total	13.8	7.4	1.2	12.9	89	269	338	55
Upper	5.1	9.6	1.7	9.1	ND‡	ND	ND	ND
Middle	7.1	5.8	1.0	14.7	ND	ND	ND	ND
Lower	3.6	4.7	0.7	12.4	ND	ND	ND	ND
Stalks, total	86.2	1.9	0.8	16.8	389	234	207	76
Upper	21.2	2.5	0.8	15.0	ND	ND	ND	ND
Middle	26.1	1.4	0.7	16.5	ND	ND	ND	ND
Lower	36.9	1.5	0.7	20.6	ND	ND	ND	ND
HSD All†	–	1.9	0.5	4.0	51	23	17	7
HSD Blades	–	2.3	0.9	NS	–	–	–	–
HSD Stalks	–	0.8	NS	1.6	–	–	–	–

† All indicates Honestly Significant Difference (HSD) ($p < 0.05$) for all column pairwise comparisons; HSD Blades and HSD Stalks for comparing respective upper, middle and lower components.
‡ ND signifies not determined; NS indicates no significant difference.

Table 3. Dry matter (DM), N, P, K, nonstructural carbohydrate (NSC), cellulose (CL), hemicellulose (HC), and lignin (LG) concentrations in Grassl stover parts (combined means of 1986 and 1987).

Stover	DM	N	P	K	NSC	CL	HC	LG
	% of total stover	g kg⁻¹						
Total Stover	100	4.5	1.4	13.2	271	291	239	70
Blades, total	18.0	12.2	2.0	15.0	112	298	387	54
Upper	6.9	16.0	2.3	12.5	160	264	421	51
Middle	6.3	8.9	1.4	16.6	87	331	355	60
Lower	2.7	7.1	1.1	13.6	67	336	311	66
Stalks, total	82.0	3.7	1.2	12.9	316	275	213	65
Upper	15.9	4.6	1.4	12.2	305	267	290	52
Middle	28.1	2.3	1.0	10.7	308	276	204	68
Lower	40.0	2.3	1.0	12.9	297	301	205	85
HSD All†	–	2.7	0.5	4.0	32	38	47	15
HSD Blades	–	2.8	0.4	2.8	36	64	17	5
HSD Stalks	–	0.9	NS‡	NS	NS	14	59	13

† All indicates Honestly Significant Difference (HSD) ($p < 0.05$) for all column pairwise comparisons; HSD Blades and HSD Stalks for comparing respective upper, middle and lower components.
‡ NS indicates no significant difference.

Table 4. Quantities of dry matter, nutrients, and carbohydrates contained in the upper one-third and lower two-thirds of sorghum stovers.

	Cultivars					
	ATX623 × RTX430		ATX623 × Hegari		Grassl	
Stover Component	Upper third	Lower two-thirds	Upper third	Lower two-thirds	Upper third	Lower two-thirds
Dry matter (Mg ha^{-1})	1.0(19)†	4.2	4.4(26)	12.5	5.1(23)	17.3
Nitrogen (kg ha^{-1})	8.3(25)	25.4	17.0(40)	25.1	55.6(52)	52.0
Phosphorus (kg ha^{-1})	2.0(26)	5.7	4.3(31)	9.5	11.9(39)	18.4
Potassium (kg ha^{-1})	15.2(15)	87.8	61.4(17)	226.9	71.3(25)	215.9
Nonstructural carbohydrates (Mg ha^{-1})	0.10(12)	0.75	ND‡	ND	1.08(18)	5.05
Cellulose (Mg ha^{-1})	0.30(18)	1.35	ND	ND	1.37(21)	5.17
Hemicellulose (Mg ha^{-1})	0.32(22)	1.12	ND	ND	1.70(31)	3.82
Lignin (Mg ha^{-1})	0.06(17)	0.29	ND	ND	0.26(17)	1.26

† Numbers in parentheses indicate the percentage of the parameter contained in the upper third of stover.
‡ No fractionation of carbohydrates for this cultivar corresponding to upper, middle and lower stover components.

RTx430 stalks than blades. Nutrient accumulation in upper plant parts in sorghums and other cereals is normally indicative of nutrient remobilization during grain development (Vanderlip, 1972; Marschner, 1986). Shoot apexes remain photosynthetically active during grain fill and have greater nutrient requirements (Pate and Layzell, 1981).

Although values were averaged over 2 yr, one difference due to year was noted for total N concentration in ATx623 × RTx430. Total stover and total blade N concentrations were significantly greater ($p < 0.01$) in 1987 than 1986. Grain yields for this cultivar in 1986 and 1987 were 6.7 and 5.4 Mg ha^{-1}, respectively. Greater stover N concentration in 1987 may have been due to reduced sink demand associated with lower grain yields.

The two-fold increase in ATx623 × Hegari stover dry matter yields as compared to ATx623 × RTx430 resulted in dilution of nutrient concentrations in all stover components (Tables 1 and 2). Nitrogen and P concentrations in Grassl stover tended to be higher than in ATx623 × Hegari stover (Tables 2 and 3), probably because Grassl produced no or only a very small grain sink while the intermediate-type sorghum exhibited a moderate grain yield.

Carbohydrate and lignin concentrations varied considerably between stover parts (Tables 1, 2, and 3). Concentrations of hemicellulose were generally higher in blades than stalks, whereas the reverse was true for lignin. Stalks contained higher concentrations of nonstructural carbohydrates, most structural carbohydrates, and lignin than did blades. The higher concentrations of lignin in stalks was possibly due to its role in cell-wall strength and plant support. Stalks contained higher concentrations of nonstructural carbohydrates and may have served as a storage organ for these carbohydrates. Nonstructural carbohydrate concentrations were higher in upper than in middle or lower blade fractions and may be associated with reported carbohydrate accumulations in upper plant parts after grain fill, especially in axillary branches (Vietor et al., 1990). The two-fold increase in Grassl nonstructural-carbohydrate concentrations in upper as compared with middle and lower blade fractions was probably due to continued photosynthesis by upper leaves and lack of a significant reproductive sink for remobilization.

Stover Management Based on Nutrients and Carbohydrates in Stover Parts

Nutrient, lignin, and carbohydrate partitioning in sorghum stover suggested that the upper third of Grassl stover might be returned to the field, while the remaining middle and lower portions, high in nonstructural and structural carbohydrates, could be used for alternative purposes, such as methane production (Table 4). The upper one-third of Grassl stover contained approximately 1.6, 1.5, and 0.7 times the total N, P, and K contained in the total aboveground stover of the conventional grain cultivar. Although only 23% of Grassl's total vegetative dry weight was contained in the upper third of the stover, this portion contained 52 and 39% of the total stover N and P, respectively. These values contrasted with 40 and 31% and 25 and 26% of total stover N and P in the upper stover thirds of ATx623 × Hegari and ATx623 × RTx430. The quantities of N, P, and K in ATx623 × Hegari upper stover components were only about half of that contained in the total aboveground stover of the conventional grain cultivar.

Dry matter, nutrients, and carbohydrates in the lower two-thirds of stover were greatest for Grassl (Table 4). If nonstructural carbohydrates, cellulose, and hemicellulose are assumed digestible or fermentable (McBee et al., 1987), then Grassl produced 18.2 Mg ha^{-1} of potentially digestible stover carbohydrates, 77.2% of which were located in the lower two-thirds of stover. ATx623 × RTx430 yielded only 3.94 Mg ha^{-1} of potentially digestible stover carbohydrates, with 81.7% being found in the lower two-thirds of stover.

Digestibility of the cell wall components in cereal stovers largely depends on the extent of lignification (Van Soest, 1982; 1988). Cell walls of ATx623 × RTx430 and Grassl on a total stover basis had similar cellulose:hemicellulose:lignin ratios of 1:0.87:0.21 and 1:0.84:0.23, respectively, indicating that these stovers might be more easily converted to methane or ethanol than ATx623 × Hegari stover with a cell wall ratio of 1:0.90:0.31.

CONCLUSIONS

Cultivar differences were observed for dry matter, nutrient, nonstructural and structural carbohydrate, and lignin yields and partitioning. The cultivar Grassl appeared the most suitable as a biomass energy source based on stover carbohydrate yields and partitioning.

REFERENCES

Creelman, R.A., L.W. Rooney, and F.R. Miller. 1981. Sorghum. p. 395–426. *In* Y. Pomeran and L. Munck (ed.) Cereals: A renewable resource. American Association of Cereal Chemists, St. Paul, MN.

Doggett, H. 1970. Sorghum. Longmans, Green and Co., London.

Ferraris, R., and D.A. Charles-Edwards. 1986. A comparative analysis of the growth of sweet and forage sorghum crops. II. Accumulation of soluble carbohydrates and nitrogen. Aust. J. Agric. Res. 37:495–512.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analysis (Apparatus, reagents, procedures, and some applications). Agric. Handbook no. 379. U.S. Gov. Print. Office, Washington, D.C.

Guiragossin, V.Y., S.W. Van Scoyoc, and J.D. Axtell. 1979. Chemical and biological methods for grain and forage sorghum. Dep. of Agron., Purdue Univ., West Lafayette, IN.

Lacewell, R.D., P.W. Teague, and S.M. Masud. 1986. Economics and financial feasibility of high energy sorghum. p. 7.1–7.25. *In* E.A. Hiler (ed.) Sorghum for methane production: Annual report. Gas Research Inst., Chicago, IL.

Marschner, Horst. 1986. The mineral nutrition of higher plants. Academic Press, New York.

McBee, G.G., and F.R. Miller. 1990. Carbohydrate and lignin partitioning in sorghum stems and blades. Agron. J. 82:687–690.

McBee, G.G., F.R. Miller, R.E. Dominy, and R.L. Monk. 1987. Quality of sorghum biomass for methanogenesis. p. 251–260. *In* D.L. Klass (ed.) Energy from biomass and wastes, X. Elsevier Applied Sci. Publ., London.

Miller, F.R., and R.A. Creelman. 1980. Sorghum - a new fuel. p. 219–232. *In* H.D. Loden and D. Wilkinson (ed.) Proc. 35th Annual Corn Sorghum Res. Conf., Chicago, IL. 9–11 Dec. 1980. American Seed Trade Assoc., Chicago, IL.

Montgomery, D.C. 1984. Design and analyses of experiments, 2nd ed. John Wiley and Sons, New York.

Nelson, D.W., and L.E. Sommers. 1980. Total nitrogen analysis of soil and plant tissue. J. Assoc. Off. Anal. Chem. 63:770–778.

Pate, J.S., and D.B. Layzell. 1981. Carbon and nitrogen partitioning in the whole plant - a thesis based on empirical modeling. p. 94–134. *In* J.D. Bewley (ed.) Nitrogen and carbon metabolism. Martinus Nijhoff/Dr. W. Junk Publ., The Hague, Netherlands.

Reed, J., Y. Kebede, and L. Fussell. 1988. Factors affecting the nutritive value of sorghum and millet crop residues. p. 233–252. *In* J. Reed, B. Capper and P. Neate (ed.) Plant breeding and the nutritive value of crop residues. Proc. Workshop, Addis Ababa, Ethiopia. 7–10 Dec. 1987. International Livestock Center for Africa, (ILCA), Addis Ababa, Ethiopia.

Robertson, J.B., and P.J. Van Soest. 1977. Dietary fiber estimation in concentrate feedstuffs. 69th meeting of the Am. Soc. of Animal Sci., Madison, WI. 23–24 July 1977. U.W. Press, Madison, WI.

SAS Institute. 1982. SAS user's guide: Statistics. SAS Institute, Inc., Cary, NC.

Smith, G.A., M.O. Bagby, R.T. Lewellan, D.L. Doney, P.H. Moore, F.J. Hills, L.G. Campbell, G.J. Hogaboam, G.E. Coe, and K. Freeman. 1987. Evaluation of sweet sorghum for fermentable sugar production potential. Crop Sci. 27:788–793.

Technicon, 1977. Determination of nitrogen in BS digests. Technicon Industrial Method 334-74 W/B. Technicon Industrial Systems, Tarrytown, NY.

Vanderlip, R.L. 1972. How a sorghum plant develops. Coop. Ext. Serv. Circ. 1203. Kansas Agric. Exp. Stn., Manhattan, KS.

Van Soest, P.J. 1982. Nutritional ecology of the ruminant. Cornell University Press, Ithaca, NY.

Van Soest, P.J. 1988. Effect of environment and quality of fibre on the nutritive value of crop residues. p. 71–96. *In* J. Reed, B. Capper and P. Neate (ed.) Plant breeding and the nutritive value of crop residues. Proc. Workshop, Addis Ababa, Ethiopia, 7–10 Dec. 1987. International Livestock Center for Africa, (ILCA), Addis Ababa, Ethiopia.

Vietor, D.M., F.R. Miller, and H.T. Cralle. 1990. Nonstructural carbohydrates in axillary branches and main stem of senescent and nonsenescent sorghum types. Crop Sci. 30:97–100.