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DEVELOPMENT OF SWEET SORGHUM AS AN ENERGY CROP

Volume 1: Agricultural Task

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RESEARCH REPORT

on

DEVELOPMENT OF SWEET SORGHUM AS AN ENERGY CROP

VOLUME I: AGRICULTURAL TASK

to

U.S. DEPARTMENT OF ENERGY

May 31, 1980

by

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and

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in cooperation with

Kansas State University, Louisiana State University,
North Dakota State University, Texas A & M University,
U.S. Department of Agriculture, University of Florida,
and University of Nebraska

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EXECUTIVE SUMMARY

An interregional experimental agricultural task was undertaken to evaluate biomass and sugar yields of sweet sorghum using similar cultural practices. Climatic conditions varied from North Dakota to southern Texas and Florida having respective frost-free days of 121 and 300 (Table 1). Maximum yields obtained in 1978 and 1979 at the various experimental locations ranged from 12.0 to 40.5 t/ha for dry biomass and from 2.9 to 13.2 t/ha for total sugars (Table 2). Assuming 582 l of ethanol can be produced per metric ton of sugars, equivalent ethanol yields range from 1688 to 7682 l/ha.

In addition to sweet sorghum, new sorghum hybrids, male-sterile corn, and sugarcane were investigated as potential sugar-stalk crops for producing ethanol from fermentation.

Major conclusions emerging from the 1979 program are:

- Sweet sorghum can be successfully grown in all major agricultural regions in the Eastern U.S. evaluated in this study (Figure 1).
- Sweet sorghum yields were primarily correlated with Total Growing Degree Days (TGDD) accumulated from March 1 to October 7, 1979 (Figures 1-2).
- In most cases potential ethanol yields produced from sweet sorghum will be higher with lower input costs than can be produced from conventional grain crops such as corn, grain sorghum, and wheat.
- Advantageous cultural practices which have wide application for producing maximum sweet sorghum yields include:
  1. Row Spacing: 50-75 cm
  2. Plant Population: 100-150 thous./ha
  3. Nitrogen Fertilizer: 50-150 kg/ha
  4. Cultivars: MN 1500, a long-season cultivar, is desirable for regions with 5000-6000 TGDD.

     Wray, grown at all locations, is high-yielding and widely adapted for regions having more than 2000 TGDD (Table 1).

TABLE 1. ENVIRONMENTAL FACTORS AT EIGHT SITES INVOLVED IN 1979 EVALUATION OF SWEET SORGHUM

Site	Latitude/Longitude (a)	Number of Frost-Free Days (a)	Growing Season Months (b)	Temperature C (b)	Rainfall (cm) (c)	Primary Soil Orders (a)
Belle Glade, Florida	26° 41' 2" N/80° 40' 1" W	300	May-October	26.2 (d)	100.08 (d)	Histosols
Manhattan, Kansas	39° 11' 0" N/96° 34' 5" W	180	May-October	21 (d)	54.40 (d)	Hapludolls
Baton Rouge and Houma, Louisiana	30° 27' 0" N/91° 11' 1" W 29° 35' 8" N/90° 43' 0" W	300	May-October	25.3 (e)	102.24 (e)	Haplaquepts
Meridian, Mississippi	32° 22' 8" N/88° 42' 0" W	240	June-October	24.0 (f)	57.2 (d)	Paleudults
Lincoln, Nebraska	40° 49' 4" N/96° 41' 1" W	150	May-September	19.7 (g)	42.1 (g)	Argiudolls
Fargo, North Dakota	46° 52' 5" N/96° 47' 8" W	120	April-October	13.6 (f)	50.98 (f)	Haplaquolls
Columbus, Ohio	39° 59' 7" W/83° 00' 1" W	150	April-November	16.4 (h)	96.82 (h)	Hapludolfs
Weslaco, Texas	26° 09' 5" S/97° 59' 5" W	300	May-October	NA (i)	36.42 (i)	Haplustolls

a) Source: U.S. Dept. of the Interior, Geological Survey, 1970.

b) Average over 1979 growing season for sweet sorghum.

c) Total over 1979 growing season for sweet sorghum.

d) From local daily metereorological data, (NOAA).

e) From Houma, LA, daily metereological data, (NOAA).

f) From local daily climatological data, National Climatic Center, National Oceanic and Atmospheric Administration, Asheville, North Carolina.

g) From Figures 4 and 5, supplied by J. Maranville, Lincoln, Nebraska.

h) From Ohio Weekly Crop - Weather Summaries, Ohio Crop Reporting Service, Columbus, Ohio.

i) S. Reeves, 1980 (Personal Communication, rainfall data, and temperature data was not available) Texas A & M University, Westlaco, Texas.

TABLE 2. MAXIMUM SWEET SORGHUM YIELDS PRODUCED AT 8 SITES IN 1978 AND 1979.

Location	Maximum Yields, 1978-1979				Wray Cultivar Yields, 1979	
	Biomass		Total Sugars		Biomass	Total Sugars
	t/ha					
	1978	1979	1978	1979		
Baton Rouge, LA	28.8	31.7	8.5	11.9	16.2	8.8
Belle Glade, FL	40.5[a]	12.0	13.2[a]	5.5	34.8[b]	13.2[b]
Columbus, OH	22.2	18.5	6.5	3.1	17.5	3.1
Fargo, ND[c]	--	12.5	--	2.9	12.5	2.7
Lincoln, NE[c]	--	19.3	--	6.3	16.0	6.3
Manhattan, KS[c]	--	24.7	--	4.0	19.2	3.9
Meridian, MS	22.4	28.8	7.7	8.6	28.8	8.6
Weslaco, TX	30.5	30.0	9.0	6.5	18.0	5.7

a This value is the sum of two crops of sweet sorghum produced during the 1978 growing season.

b This value is from 1978 results since Wray was not grown in Florida during 1979. Wray was double-cropped in Florida in 1978.

c This site was not included in sweet sorghum experiments in 1978.

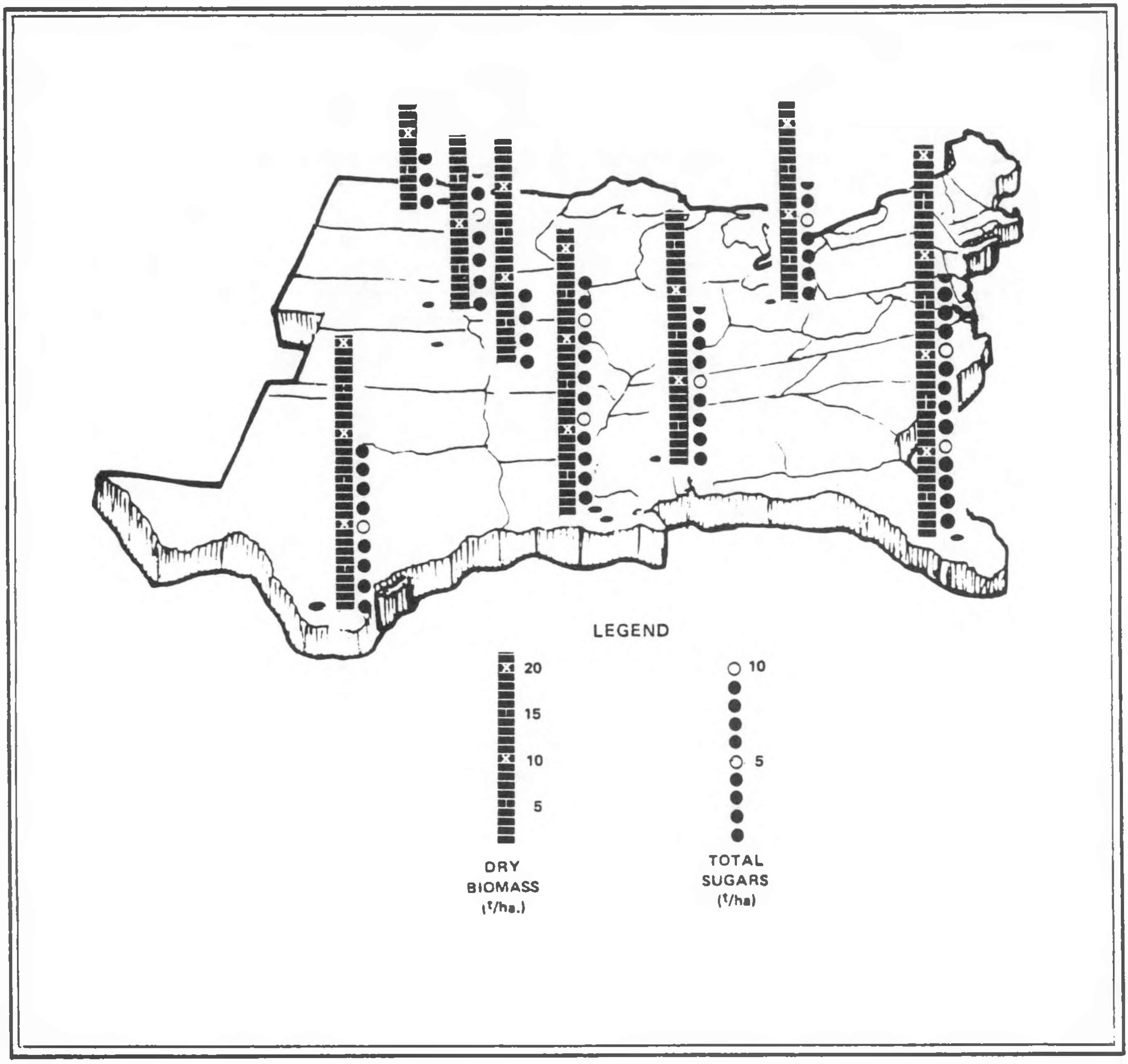

FIGURE 1. MAXIMUM BIOMASS AND TOTAL SUGAR YIELDS FOR EIGHT EXPERIMENTAL SITES IN 1978-79

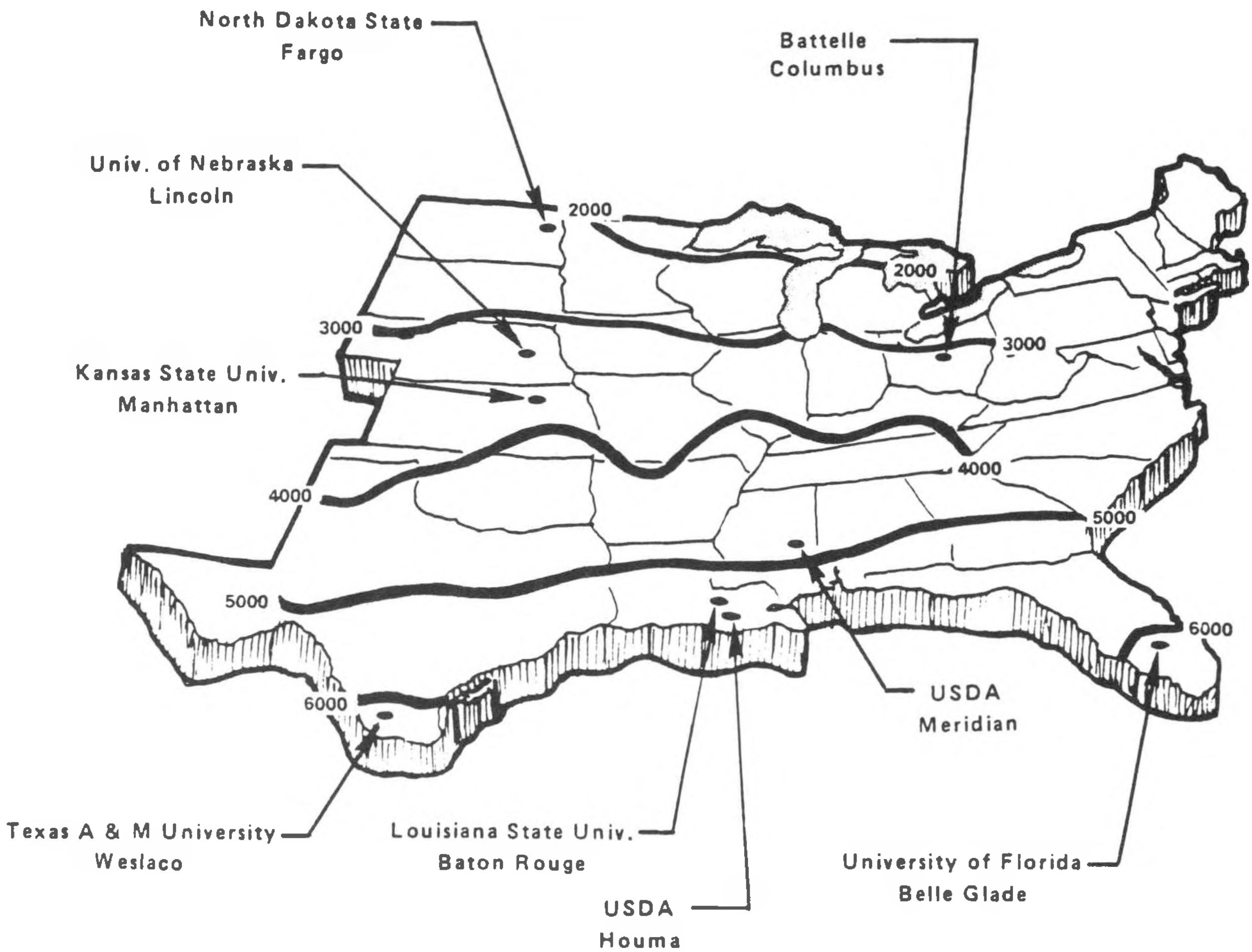

FIGURE 2. TOTAL GROWING DEGREE DAYS ACCUMULATED IN 1979 IN THE EASTERN U.S.

- Hybrid sweet-stemmed grain sorghum may have potential for producing alcohol from both sugar and grain. Use of these hybrids may overcome the juice preservation problem associated with using sweet sorghum alone.
- In the northern regions, climatically adapted male-sterile corn hybrids exhibited potential for high yields of stalk sugars.
- Although limited in potential acreages, sugarcane continued to offer the highest biomass and sugar yields for the southern tips of the continental U.S. However, to further increase sugar production, sweet sorghum may be grown during the fallow season.

Although much progress has been made in the development of sugar-stalk crops for liquid fuels production, the following issues are as yet unresolved:

- Harvesting and Processing - Compatible harvesting and processing equipment for sugar-stalk crops has not been developed for areas where an in-place sugarcane industry is not present. In the Great Plains and Midwest modified forage choppers may be used if a compatible juice extraction process can be developed.
- Juice Preservation - Innovative methods for preserving sugar-enriched juice must be developed to gain plant-operating efficiency by extending the length of processing time for the harvested crop.
- By products - Stillage from sugar-stalk crops fermentation is high in dissolved organic compounds and inorganic salts. If not treated properly, this material can present environmental problems. Thus, appropriate treatment methods must be developed which are compatible with regional environments where the crops are grown.
- Biomass Removal - Removal of all biomass from the originating field results in excessive erosion in the Great Plains and Midwestern regions. Thus, harvesting methods should be developed to leave plant components which are not sugar-enriched in the field, i.e., tops and leaves.

Conclusions from this program strongly support the continued investigation and development of sorghums, sugarcane, and other sugar-stalk crops for conversion to liquid fuels. New concepts in plant breeding and cultural practices must be developed in the coming 5 years to insure continued growth in liquid fuels production beyond what can be supplied by grain conversion alone. Failure to develop new cropping systems for liquid fuels may eventually dislocate grain prices and destabilize food markets. Thus, efficient utilization of existing crop resources and development of new crops is necessary for successful U.S. development of large-scale liquid fuels production.

PRINCIPAL FINDINGS

Faced with depressed grain prices resulting from a grain export embargo, the current administration in attempting a rapid expansion of the fuel alcohol industry in all major agricultural regions. Hopefully, this effort will provide more strength to a faltering agricultural economy by providing a new market outlet for carryover grain stocks. In addition, many agricultural waste products such as whey and cull potatoes can be fermented to ethanol. However, in order to contribute significantly to the liquid fuel consumption in the U.S. projected for the coming decades, other widely-adapted high-yielding alcohol crops must be developed (U.S. DOE, 1979).

Sweet sorghum is one of several agricultural crops from which fuel-grade ethanol can be derived. The premise of this integrated research program is that rapid exploitation of existing sweet sorghum lines and development of new sorghum hybrids could substantially reduce land requirements necessary to meet projected alcohol production for the next 20 years.

For the past 3 years, Battelle's Columbus Division and several co-investigators have conducted interregional investigations with the objective of evaluating sweet sorghum and sugarcane as major alcohol-producing crops in the continental United States. These crops were selected primarily on the basis of high alcohol yield per unit land area and a favorable energy balance in the conversion to alcohol.

The following section is a comprehensive summary of the principal findings compiled in the 1979 program. This section is intended to serve as a supplement to the full report and may be used to gain an overview of the program.

Approach

The primary goal of the 1979 research program was to determine the the agronomic feasibility of developing sweet sorghum, sweet sorghum hybrids, and sugarcane as energy-producing crops in 4 major agricultural regions in the U.S. The following objectives were proposed to fulfill this goal.

1. Determine response of sweet sorghum to major latitudinal and longitudinal gradients in the U.S. in terms of biomass and sugar production and plant composition.
2. Determine optimal cultural practices and select outstanding cultivars of sweet sorghum and sweet-grain sorghum hybrids.
3. Evaluate sweet sorghum as a rotational crop and the potential for commercialization in the midwest through crop trials performed by interested farmers.
4. Estimate production costs of sweet sorghum and determine competitive prices and yields in each region.
5. Formulate an analytical approach to estimate the impact of growing sweet sorghum on the agricultural economy of the U.S.
6. Continue experiments evaluating the potential of sugarcane for energy production in portions of Louisiana and Florida.

Various cultivars of sweet sorghum were evaluated under rigorous climatological conditions to better define the geographic range of the crop. Field-testing in the northern and midwestern U.S. is especially crucial in view of the fact that sweet sorghum is best adapted to the more temperate climate of the southern states.

The outcome of this program will provide information needed in making a go/no-go decision relative to sweet sorghum as a major energy crop in the U.S.

Summary

Climatological Summary

A climatological summary from each of the experimental sites indicates the diversity of weather patterns encountered in the program (Table 1). In the southern extremes of southern Texas, Louisiana, and Florida sugarcane can be grown as well as sweet sorghum. In these areas the frost-free period and the mean annual temperature are in excess of 300 days and 20 C, respectively. The northern extreme location was Fargo, North Dakota, where the frost-free period and mean annual temperature was 120 days and 13.6 C respectively.

Growing a warm-season sugar crop such as sweet sorghum in this region is considered marginal. The specific locations of the experimental sites also provide an east-west gradient where the primary variable is the amount of rainfall (Table 1). In addition, differing soil types reflect the historical climate pattern, parent material, and native vegetation at each site.

Uniform Experimental Design

A Uniform Experimental Design (UED) was established at five locations (Manhattan, Kansas; Baton Rouge, Louisiana; Lincoln, Nebraska; Fargo, North Dakota; and Weslaco, Texas). The field experimental design was a split plot arrangement with 4 blocks of each treatment. Main plot treatments consisted of three row spacings (50, 75, and 100 cm) while split plots consisted of 3 sweet sorghum cultivars. The Wray cultivar was grown at all locations for uniform comparisons; the two alternate cultivars at each site were selected on the basis of climatic adaptation.

Parameters to be measured at various stages of plant development were specified prior to experimentation and listed in Table 3. In addition, areas to be sampled within each plot were specified for each of the three harvests. All collected data were satistically analyzed to indicate those treatments which were significantly different from others in the same classification. The results were computerized for further processing and reported in graphic form.

TABLE 3. PARAMETERS MEASURED AT VARIOUS STAGES OF PLANT GROWTH FOR THE UNIFORM EXPERIMENTAL DESIGN.

Parameter	Stage of Plant Growth
Plant Population	Mature
Plant Height	Mature
Biomass	Boot, Anthesis, Mature
Stalk Sugars	Anthesis, Mature
Stalk Fiber	Mature
Plant Nutrients	Mature

Plant Population and Plant Height. Greater tillering was a general response to increased northerly latitude. This response was most likely due to a longer photoperiod during the growing season. Overall, plant populations varied from 80-180 thousand plants per hectare on 50 cm row widths to 40-60 thousand plants per hectare on 100 cm rows. Ironically, the North Dakota site, which produced lowest yields, had the highest plant populations. Thus, increased tillering at the northern latitudes is considered disadvantageous to sweet sorghum development and should be reduced through a plant breeding program.

Differences among sites with respect to plant height were not as dramatic as differences in plant populations. Overall, plant height ranged from 250-380 cm among the 5 locations.

Dry Biomass. An important factor to recognize in the biomass data is that the plants were harvested at various stages of physiological maturity. Thus, the harvests were not completed at the same time during the growing season. The advantage ofthis method is that the yield data are directly comparable among locations since the plants are at the same level of maturity at the three prescribed harvests.

Overall, the sweet sorghum cultivars achieved 35-80 percent of their mature biomass yield at the boot stage of growth. Final biomass yields ranged from a low of 10 t/ha at Fargo to a high of 48 t/ha at Baton Rouge. In most cases the 50 and 75 cm row spacings were significantly greater in biomass yield that the 100 cm spacing. However, the most dramatic yield increases were achieved by the use of a long-season variety (MN 1500) in Louisiana and Texas. Yield differences between the other varieties grown at the 5 locations were not as great.

Total Sugars Yield. Overall, 50 to 100 percent of the total sugars yield was attained at the anthesis growth stage among the 5 locations. Several variables, including cultivar, growing degree days, and photoperiod may account for differences in sugar accumulation after anthesis. Sugar yields largely reflected biomass yields with respect to row spacing, cultivars, and location. Sugar yields were lowest in Fargo (1.5-3.0 t/ha) and greatest at Baton Rouge (6.1-11.9 t/ha). Comparable sugar yields were attained at Manhattan, Lincoln, and Weslaco, with yields ranging from 1.8 to 6.5 t/ha. Sugar yield increases associated with MN 1500 were not as dramatic as increases in biomass yield due to its lower percent sugar content relative to other cultivars.

Acid Detergent Fiber. Acid detergent fiber (ADF) generally reflected biomass differences between locations, cultivars, and row spacings. Yields ranged from a low of approximately 2 t/ha in Fargo to a high of 14 t/ha in Baton Rouge. Consistent with biomass yields, the MN 1500 cultivar grown at Baton Rouge and Weslaco attained the highest ADF yields.

Plant Nutrients. Plant uptake of nitrogen varied from approximatily 100 to 200 kg/ha among the locations. More importantly, the amount of nitrogen taken up per unit of biomass yield ranged from approximately 6 to 12 kg N/t of biomass. This wide variation indicates that more research emphasis should be placed on efficient N utilization in sweet sorghum. The optimal level of N fertilization for sweet sorghum will be different in each major agricultural region depending on residual soil N, soil type, climatic conditions, and cultural practices. In general, sweet sorghum will require less nitrogen per unit alcohol production compared to grain crops because sweet sorghum does not convert as much photosynthate into nitrogen rich proteins.

Phosphorus (P) uptake by sweet sorghum ranged from 10 to 50 kg/ha among the locations. Greatest variations in P uptake occurred among sites compared to the other within site variables of cultivar and row spacing. Phosphorus uptake (kg) per ton of biomass yield ranged from 0.5 to 2.0. These results reflect differences in available soil P among the various locations.

Potassium uptake exceeded 300 kg/ha at 3 locations (Texas, Kansas, and Nebraska) where available soil levels of K are a relatively large proportion of the potassium taken up by the plants accumulated in the stalks most of which would be extracted with the sweet sorghum juice for the fermentation process. This soluble salt could potentially be a problem in disposing the liquid residues (stillage) of fermentation which are produced with ethanol in a 10:1 ratio. Thus, safe disposal practices or alternate uses for stillage must be developed for fermentation facilities to conform to existing water quality standards.

Sweet Sorghum Studies at Columbus, Ohio

Field studies at Battelle-Columbus Divisions' Bioenvironmental Laboratory included three separate experiments designed to accomplish the following objectives:

- Identify sweet sorghum cultivars for producing maximum biomass and sugar yields in the midwest.
- Identify appropriate cultural practices for cultivating sweet sorghum in the corn-belt region.
- Determine the response of sweet sorghum to fertilizer nitrogen in the Midwest.

As is well documented in many agronomic production studies, the weather during the growing season greatly affects crop growth and in most instances is the factor which limits final yield. In 1979, weather adversely affected crop growth, particularly the percent sugars in the stalk and the stalk yield per unit land area.

Each of the three field experiments; (1) Cultivar Selection, (2) Plant Configuration, and (3) Nitrogen Fertility, was implimented using a split-plot design with 4 blocks for each treatment. Biomass and sugar yield data were collected from each experiment in addition to nutrient analyses in the Nitrogen Fertility Studies. Summarized results of these studies are as follows.

Cultivar Selection Studies. A total of eight cultivars were included in the cultivar selection studies at Columbus. The three commercially-released cultivars, Dale, Wray, and Sugar Drip, outyielded the five unreleased cultivars in all facets of production (dry biomass, sugars, and fiber). The highest dry biomass yield was 17.8 t/ha by the cultivar Dale. However, Wray produced the highest level of sugar and fiber at 2.98 and 4.58 t/ha, respectively.

The main conclusion from this trial is that none of the tested cultivars are completely satisfactory for growing in the more northern climate, with approximately 3200 growing degree days. This conclusion is supported by the fact that the percent sugars in the tested varieties at Columbus ranged from 4 to 6, while the same cultivars at Meridian will average 10 to 15. These results also indicate the need for developing new germplasm in order to raise sugar yields in the midwest to comparable values in the southern U.S.

Plant Configuration Studies. In this experiment three cultivars were grown in four spatial configurations: (1) 76 cm interrow, 15 cm intrarow; (2) 46 cm interrow, 16 cm intrarow; (3) 46 cm interrow, 7.5 intrarow; and (4) 15 cm interrow and 15 cm intrarow with 92 cm between groups of 4 rows. Due to adverse weather conditions, biomass yields for the various cultivars grown at the different row spacings/plant populations were approximately 25 percent lower than those reported for 1978. The highest biomass yield recorded was 17.5 t/ha for Wray and the overall treatment mean being approximately 15 t/ha.

In general, total sugar yield was affected more by poor growing conditions than was the total biomass production with yields 40-50 percent lower than in 1978. The range of total sugars yields was from 2.16 t/ha with Sugar Drip at the 15 cm interrow - 15 cm interplant spacing to 3.05 with Wray at the 46 cm interrow - 15 cm interplant spacing. Results of this experiment imply that there is no advantage in growing sweet sorghum in more intensive plant configurations than the 76/7.5 cm inter-/intra-row spacing. These results are consistent with row spacing experiments within the Uniform Experimental Design conducted at other sites.

Nitrogen Fertility Studies. In this experiment three cultivars, Dale, Wray, and Sugar Drip, were grown with four different levels of nitrogen fertilizer (0, 112, 224, and 336 kg N/ha). Biomass and sugar yields did not respond to N applications greater than 112 kg/ha. Also, there were no differences among the varieties with respect to N fertility level. The overall mean (across cultivars and N-levels) of dry biomass yield was 15.1 t/ha, while that of the control (no N) was 9.9 t/ha. Sugar yields followed the same trend as the dry biomass yields.

Overall, approximately 7 kg of nitrogen were required to produce each ton of dry, above-ground biomass in the N-fertilized plots. In plots receiving no nitrogen, 5.2 kg were required to produce each ton of dry biomass. These results were comparable to other sites, leading to the general conclusion that sweet sorghum requires 5 to 10 kg N/t biomass produced. Thus, N fertility should be sufficient to meet a preconceived yield goal. For example, if a yield of 25 t/ha of biomass is anticipated than 125-250 kg N/ha will be required for the crop.

In consideration of the negative weather factors during the 1979 growing season, additional N fertilizer studies should be conducted in the midwest to more completely define N requirements for sweet sorghum.

Sweet Sorghum Studies at Belle Glade, Florida

Sweet sorghum studies conducted at Belle Glade included a row spacing study using double and single 71 cm rows. Maximum yields were produced on the single 71 cm rows. Maximum biomass and sugar yields were 11 and 5 t/ha, respectively. Results of the study indicate that sweet sorghum is highly adaptable to the south Florida climate, although plant pests and diseases may be a problem.

Sweet Sorghum Studies at Manhattan, Kansas

Observations were made for 18 cultivars of sweet sorghum grown primarily to determine general adaptation to Kansas.

There was considerable variation in flowering date among the eighteen cultivars. All varieties except Sart reached the soft dough stage and all except Sart and Brandes reached the ripe stage. Sugar content, determined by a hand held refractometer, ranged from 10 to 20 percent. Unreplicated biomass yields from a single row ranged from 10 to 162 kg/row. These observations indicate that most of these cultivars of sweet sorghum could be grown successfully in Kansas.

Sweet Sorghum Row Spacing Trial at Meridian, Mississippi

Rows spaced 46, 61 cm and two lines of plants centered on 107-cm produced more dry stalks than those spaced 107 cm (Figure 1). Rows spaced 76, 91, and 107 cm were similar in yield of dry stalks. The row spacing x cultivar interaction was highly significant. Row width affected dry stalk production more with Wray than Rio.

Sweet Sorghum Studies ar Fargo, North Dakota

Cultivar Selection. Sweet sorghum is a warm-up season crop adapted to the temperate climates of the world. Most sweet sorghum genotypes available in the United States were developed and grown in the humid South with little information available on genotypic response under northern climatic conditions. Therefore, the objective of this study was to evaluate sweet sorghum's genotypic response to the very short growing season, long daylength climate typical of Fargo.

The plant density and maturing rating was evaluated for 17 sweet sorghum genotypes grown at Fargo in 1979. Stands were quite excellent for all genotypes except Ramada Sart, Wray, and MER 63-7. The plant density may be a reflection of seed availability rather than stand establishment since all seed supplied was planted and stands thinned to approximately 4.4 plants/m. MER 61-1 and MER 63-7 were the earliest maturing sweet sorghums with 30-70 percent anthesis on September 11, but even those varieties were only approaching the soft dough growth stage when a killing frost occurred October 4, about 1 week later than normal. Six genotypes, Wray, MER 69-7, Keller, Dale, Rex, and Collier, were in the late jointing to boot stage and five genotypes, Brandes, Sugar Drip, Brawley, Rio, and Rex, were in the late boot to heading growth stage when harvested. A late planting date and a cool August were experienced in 1979 which might influence the sweet sorghum's maturity. Conversely, September was 2.3 C above normal. These data suggest that an earlier maturing sweet sorghum variety may be necessary to grow sweet sorghums effectively under Fargo conditions.

Nitrogen Fertilization Experiment

One major requirement to facilitate sweet sorghum as a viable energy crop is a favorable releationship between the BTU's necessary to grow and convert the crop to fuel and the BTU's produced by the crop. The amount of commercial N applied to sweet sorghum fields will affect this relationship since commercial N production requires large quantities of natural gas. However, N is an essential element necessary for economical production of sweet sorghum. Therefore, the objective was to preliminarily evaluate the effect of N fertilization rate on biomass, sugar production, and nutrient removal by sweet sorghum.

Increasing the nitrogen rate increased the wet and dry sweet sorghum biomass. Applying 50 kg N/ha increased the dry biomass 1.32 t/ha above the unfertilized treatment. The next N increment increased the yield only 0.54 t/ha, the next two increments increased the yield only p.33 t/ha. Stalk yields increased lineraly for the first two N increments which increased the stalk yield from 4.56 t/ha for the unfertilized treatment to 5.64 t/ha for the 100 kg N/ha treatment. Leaf yields increased about 15 percent with the first N increment but increased only slightly at higher rates. Tops yield appeared to increase slightly for the first N increment but the increase was not statistically significant. The percentage stalk, leaf, or top fraction of the total biomass was unaffected by the N fertilization rate.

Deferred Processing Experiment

Sweet sorghum harvest under Fargo conditions would normally begin after a killing frost. It is not uncommon for temperatures to remain cool following a killing frost. Thus, the effect of delayed harvest on the sugar level of stored stalks was determined.

Total sugars in stalks of sweet sorghums was influenced by the time of processing. Standing samples of Wray had sugar levels on November 5 similar to the level of October 4. Delayed harvest to November 5 by letting the sweet sorghum stand in the field probably would be impractical since severe lodging occurred October 17 which could hinder harvesting. Delayed harvest to December 6 decreased total sugars and resulted in an apparent conversion of some sucrose to similar sugars.

Stacked samples of MER 63-7 sweet sorghum decreased slightly in total sugar primarily due to a decrease in glucose levels with storage from October 4 to November 5. Dry matter samples were nearly similar with the November 5 sampling about 1.5 percent above the 19 percent average at the October 4 harvest. Storage until December 6 resulted in a loss of 20 percent of the total sugars with an apparent conversion of some sucrose to glucose and fructose.

High-Energy and Sweet Sorghum Field Trials at Weslaco, Texas

A high-yielding grain (H.-E.) sorghum having a sweet stalk was suggested as a potential candidate as a source of food and energy, allowing for the production of alcohol from carbohydrates contained in both stalks and grain. In addition, production of fuel H.-E. sorghum could be used as a food and fiber source.

A breeder's nursery was planted at Weslaco as a means of observing a large selection of hybrids for their potential as a H.-E. sorghum. These sorghums had grain yield ranging from 5,605 to 7,847 kg/ha. Mean daily carbohydrate accumulation, including starch and sugars, ranged from 52.59 to 64.23 kg/ha resulting in a total carbohydrate yield of 5,469.46 to 6,680.15 kg/ha. Carbohydrate yields per day can be compared with 62.93 kg/ha for Rio, a conventional sweet sorghum cultivar.

Preliminary screening for H.-E. sorghum indicates there is adequate genetic material to increase stalk carbohydrate concentrations while maintaining high grain yield. Results indicate that not only can high stalk carbohydrate levels be maintained, but the ratio of glucose/ fructose to sucrose can be altered to meet the needs of industry.

H.-E. sorghum will be capable of producing fermentable carbohydrates at a rate equal to or higher than sweet sorghums, thus providing good energy crop in areas with short growing seasons. An added advantage of H.-E. sorghum is the production of stable carbohydrates in the grain (starch) which can be stored and used when needed.

Sugarcane Field Trials

Houma, Louisiana. A preliminary study indicated that early generation hybrids of *Saccharum spontaneum* X commercial sugarcane cultivars produced higher yields of cane and total solids per acre than commercial sugarcane cultivars. These early generation hybrids are vigorous; by having better stubbling ability; cold, insect, and disease resistance; making them superior to commercial hybrids. It may be possible to grow them for more ratoon crops, on the worst lands, with less energy input. Their ratoon vigor should do much to compensate for the rigors and damage of cultivation and mechanical harvesting at narrow row spacings. This experiment was conducted to measure the variation in production of total solids per hectar of early generation *S. spontaneum* hybrids in the line breeding collection at the USDA Sugarcane Laboratory, Houma, Louisiana.

The results agree with those of the previous study in that the highest yielding clones occurred in the early backcross generations. This suggests that further progress is possible by intercrossing F_1 or BC_1 hybrids and selection for total solids per acre in their progenies. The results also suggest that a level of Brix or fermentable solids equal to that of late maturing commercial clones, like CP 61-37, could be combined with high yield and stubbling vigor, in a breeding program. A limited breeding and selection program is in progress at Houma to accomplish this.

Bell Glade, Florida. High biomass, sugar and fiber were produced from sugarcane on sand and muck soils in south Florida. Yields were as in previous years, higher for the narrow row spacing where solar radiation utilization was more efficient than in plant cane. Likewise it is greater for a second ratoon than for a first ratoon.

Evaluation of Tilby Machine. A unique laboratory-scale Tilby stalk splitter and depithing unit was tested and routinely used at Weslaco and Columbus. The advantage of this machine is that it allows for separation of the stalk rind material from the sugar-rich pith contained within the rind. Thus, sugar extractions can be made from a more refined sample of pith. Once commercially developed, the Tilby machine will facilitate the extraction of clean rind material which can possibly be used for making pressed-fiber board.

INTRODUCTION

Background

Development of renewable sources of liquid fuels in the U.S. is necessary to reduce dependence on imported oil. The constant rise in OPEC oil prices coupled with an oil import tax and price deregulation of new domestic oil provides the necessary economic incentives to produce ethanol fuel from agricultural raw materials. Legislative action in the next 12 months may also provide guaranteed loans and grants through a "Synfuels Bill" for the great amounts of venture capital necessary for a rapidly expanding biomass fuels industry.

After imposing a U.S. grain embargo on the U.S.S.R., President Carter stated that resulting excess domestic grain supply could be converted to fuel-grade ethanol through a government-backed expansion of the alcohol industry (Carter, 1980). Thus, for the next 3-5 years, if surpluses continue to remain high, conventional grain crops will most likely keep industry saturated with carbohydrate feedstock without adversely affecting domestic food prices.

In the long-term (10-20 years), as world-wide petroleum supplies dwindle and as food demand increases, new energy crops through innovative conversion technologies must replace grains as the primary feedstock for biomass fuel production. Sorghum cultivars may offer the most promise as a large-scale energy crop based on the following advantageous characteristics:

- Genetic diversity - Over 17,000 lines of sorghum exist in the world collection.
- Climatic adaptation - Sorghum can be grown in any of the agricultural regions of the continental U.S.
- Biomass - Sorghum, if climatically adapted, can compete in photosynthate production with any conventional crop currently grown in the U.S.
- Production economics - Most sorghum is drought tolerant and efficient in nutrient use which lowers production input costs without sacrifices in yield.

Sweet sorghum and its hybrids are among the least exploited agronomic crops but are highly promising for fuels production provided that seasonality problems can be overcome. Battelle's premise is that rapid exploitation of existing sweet sorghum lines and the development of new hybrids could substantially reduce the land requirements necessary to meet biomass fuel goals for the next 20 years.

For the past 3 years, Battelle's Columbus Division and several co-investigators have conducted interregional investigations related to biomass and sugar production for conversion to alcohol and other fuels. These investigations have primarily emphasized the production of sweet sorghum and sugarcane due to their ability to produce high biomass and readily fermentable sugars which yield a highly favorable energy balance when convereted to ethanol.

Description of Sweet Sorghum

Sweet sorghum is a member of the grass family and is closely related to grain sorghum, broomcorn, Johnsongrass, and Sudan grass. Sweet sorghum plants are slow to develop after germination, especially in soil having temperatures below 15.6 C. This characteristic makes sweet sorghum develop slower than other crops in the more northerly regions of the U.S. However, after the plant is established, it will grow very quickly with sufficient moisture. As with other sorghums, sweet sorghum is drought tolerant and is adaptable to most major agricultural regions of the United States.

Sweet sorghum grows to a height of 305 to 427 cm with a maximum stem diameter of 2.5 to 5.1 cm at maturity. Sweet sorghum produces a seed head at the top of the plant which ripens 100 to 150 days after planting. Sugar begins to accumulate in the pithy stalk when the seed is in the soft dough stage. Stalks can be harvested after maximum sugar accumulation usually occurring from the hard dough to ripe stage. Stalks are very fibrous and may be used for the manufacture of press board if the pith is cleanly separated.

Although sweet sorghum hybrids have not been developed, several high-producing cultivars have been released for commercial use from the U.S. Sugar Crops Field Station at Meridian, Mississippi. Among these, Wray, Rio, and Dale appear to be most widely adapted to the Midwestern and Great Plains regions. Biomass and sugar yields for Wray ranged from 14.0 to 29.0 and from 6.0 to 11.0 t/ha, respectively, from a single crop in 1979 (Lipinsky, et. al.). Accordingly, Wray was selected to be grown at all sites in 1979.

Objectives and Scope

The primary goal of the 1979 research program was to determine the agronomic feasibility of developing sweet sorghum, sweet sorghum hybrids, and sugarcane as energy-producing crops in 4 major agricultural regions of the U.S. The following objectives were proposed to fulfill this goal.

1. Determine response of sweet sorghum to major latitudinal and longitudinal gradients in the U.S. in terms of biomass and sugar production and plant composition.
2. Determine optimal cultural practices and select outstanding cultivars of sweet sorghum and sweet-grain sorghum hybrids.
3. Continue experiments evaluating the potential of sugarcane for energy production in portions of Louisiana and Florida
4. Evaluate sweet sorghum as a rotational crop and the potential for commercialization in the Midwest through crop trials.
5. Estimate production costs of sweet sorghum and determine competitive prices and yields in each region.
6. Formulate an analytical approach to estimate the impact of growing sweet sorghum on the agricultural economy of the U.S.

The results of objectives 1-3 are reported in Volume I, "Agricultural Task" (this volume), while the results of objectives 4-6 are included in Volume II, "Commercialization Studies".

The outcome of this program will provide information to help DOE make a go/no-go decision relative to sweet sorghum as a major energy crop in the U.S.

Technical Approach

The approach of the agricultural task was to employ a multi-faceted study involving researchers and commercial growers in 10 states. Agronomic research included experiments designed to expand on existing knowledge for the optimization of sweet sorghum production. These studies included plant configuration, variety and fertility trials, and were conducted in Ohio, Louisiana, Texas, and Mississippi. Researchers at these locations have been associated with this program for 2-3 years.

New research sites were added to the program in 1979 at Manhattan, Kansas; Lincoln, Nebraska; and Fargo, North Dakota. In order to provide comparable data for the program a Uniform Experimental Design was used by researchers at the new sites in addition to sites at Weslaco, Texas and Baton Rouge, Louisiana. The purpose of this design was to evaluate sweet sorghum yields as a function of various cultivars and row spacings.

On-farm studies (reported in Volume II) were established for the first time in Ohio, Illinois, and Iowa. These studies, coordinated by the Farm Bureau in each state, were designed as an initial step in the transfer of developing technology to the public sector for commercialization. The purpose was to identify issues, time frames, and costs associated with implementation to research findings.

Sugarcane investigations continued to evaluate promising high-fiber cultivars in Houma, Louisiana and ratoon cropping on two soil types at Belle Glade, Florida.

Information gained from the 1979 research program will ultimately be used to determine the feasibility of raising sweet sorghum, sweet-grain sorghum hybrids, and sugarcane as major crops for fuel production in regions where each can be grown successfully.

Organization and Management Plan

Battelle, in conjunction with collaborative scientists from the USDA and various universities, has maintained a tight structural organization, while simultaneously allowing for the introduction of research innovations and new ideas. In addition, the program has benefitted from a continuity in research staff from all of the participating institutions. Thus, lines of communication were well established to solve problems as they arose.

The program organizational structure is shown in Figure 3. Mr. Edward Lipinsky, Program Manager, was responsible for the overall management of the program. Dr. W. T. Lawhon provided advisory and administrative input to the program. Dr. D. R. Jackson was responsible for the agricultural development activities at all locations. Mr. M. F. Arthur and Mr. S. Kresovich were responsible for the direction of agronomic research at Battelle's Bio-Environmental Laboratory. Dr. T. A. McClure served as leader of the agricultural economics tasks. Dr. D. A. Scantland was the coordinator of the Farm Bureau studies in addition to assisting in the agricultural economics tasks.

Researchers at each of the participating Experiment Stations of universities are shown in Table 4.

SITE DESCRIPTIONS

Belle Glade, Florida

The average annual temperature is 21-24 C and the frost-free season ranges from 300 to 365 days (Figure 1). The average annual rainfall is 157 cm, occurring mostly between May and November.

The Lake Okeechobee area is mostly low, nearly level land. It is divided into two general areas: sand in the eastern parts and muck in the Everglades. A first ratoon crop of sugarcane was studied on Riviera sand, approximately 38.6 km east of Belle Glade. Riviera sand is nearly level, poorly drained soil that has a thick sandy subsurface layer that tongues into a loamy subsoil at a depth of 59 to 102 cm. This soil is in broad low areas. Under natural conditions, the water table is within 25.4 cm of the surface for 2 to 4 months in most years within 25.4 to 76.2 cm for most of the remaining year, except during extreme dry periods. A second ratoon sugarcane and a sweet sorghum experiment were conducted at the Agricultural Research

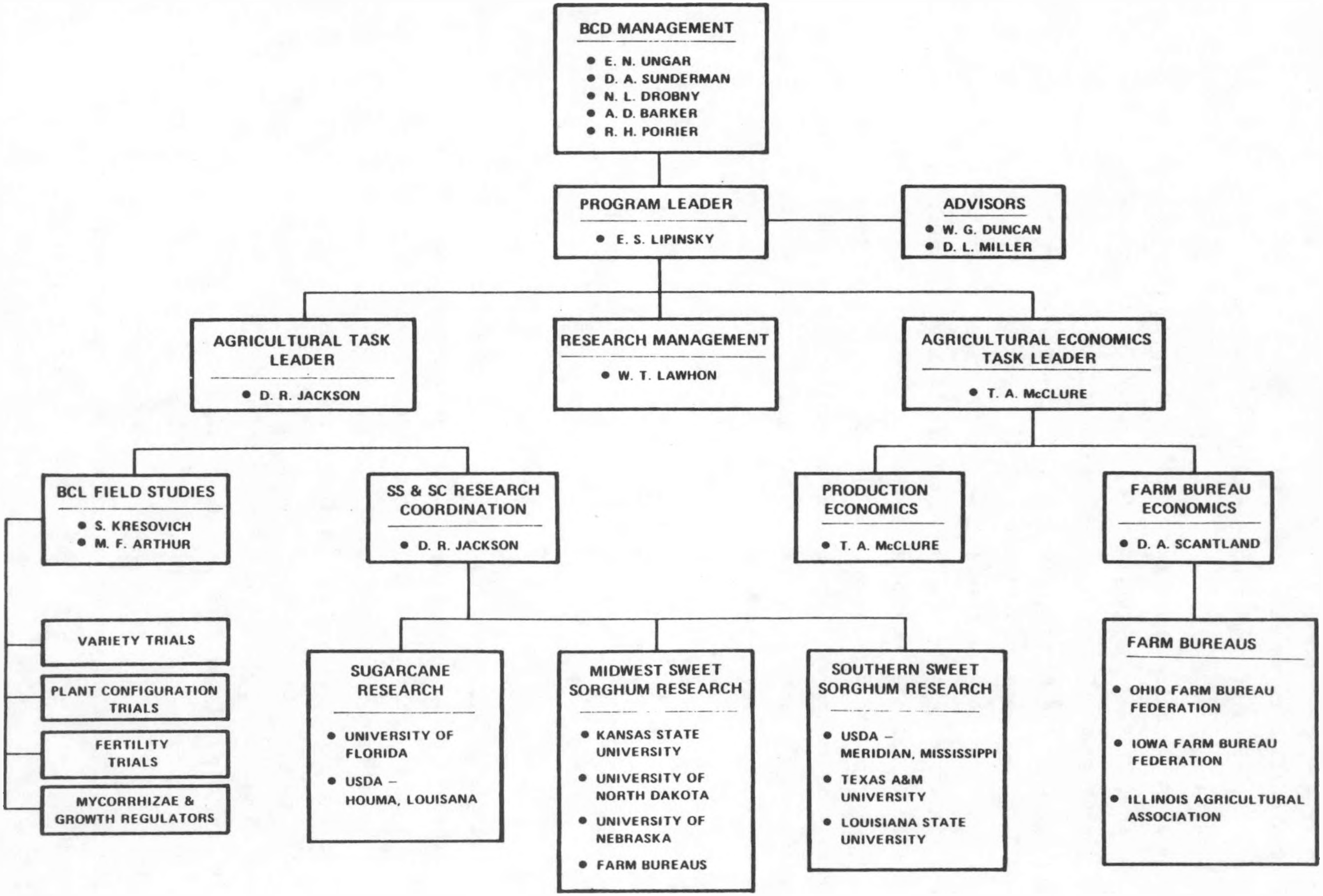

FIGURE 3. AGRICULTURAL TECHNOLOGY PROGRAM ORGANIZATION STRUCTURE

TABLE 4. USDA-SEA, UNIVERSITY, AND BATTELLE COLLABORATORS

Experimental Study Site	Project Personnel	Field
University of Florida Agricultural Research and Education Center Belle Glade, Florida 33430	Dr. Gary J. Gascho Dr. Gerald Kidder S. F. Shih	Plant Nutrition Sugar Cane Sugar Cane
Kansas State University Department of Agronomy Manhattan, Kansas 66502	Mr. Nicholas S. Hill Dr. Gerry L. Posler	Forage Crops Forage Crops
Louisiana State University Agronomy and Agricultural Engineering Department Baton Rouge, Louisiana 70803	Dr. Billy J. Cochran Dr. Ray Ricaud	Agricultural Engineer Agronomy, Sugar Crops
USDA-SEA U.S. Sugar Cane Field Laboratories P.O. Box 470 Houma, Louisiana 70360	R. D. Breaux Dr. James Irvine	Physiology Sugar Cane
USDA-SEA U.S. Sugar Crops Field Station Route 101, Box 152 Meridian, Mississippi 39301	Dr. Dempsey Broadhead Mr. Kelly Freeman Dr. Natale Zummo	Agronomy Agronomy Plant Pathology
University of Nebraska Department of Agronomy Lincoln, Nebraska 68583	Dr. Max D. Clegg Dr. Jerry W. Moranville	Crop Physiology Crop Physiology
North Dakota State University Agronomy Department Fargo, North Dakota 58102	J. D. Brosz Dr. Dwain W. Meyer	Forage Crops

(Continued)

Experimental Study Site	Project Personnel	Field
Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	Mr. Mickey F. Arthur Mrs. Melanie E. Davis Dr. Danny R. Jackson Mr. Stephen Kresovich Dr. Martin L. Price Mr. D. Alan Scantland	Microbiology Botany Soil Chemistry Agronomy Agrochemistry Agricultural Economy
Texas Agricultural Experiment Station Weslaco, Texas 785A6	Mr. J. W. Clark Dr. Chan Connolly Dr. R. A. Creelman Dr. T. W. Fuchs Dr. F. R. Miller Dr. Tim A. Reeves, Jr.	Plant Breeding Director Agronomy Entomology Plant Breeding Agronomy
USDA-SEA Food Crops Utilization Laboratory Weslaco, Texas 78546	Mr. B. A. Smith	Chemistry

and Education Center at Belle Glade on Pahokee muck, a nearly level, very poorly drained organic soil that rests on limestone at a depth of 91.4 to 130 cm. The soil is in broad, freshwater marshes. Under natural conditions, the soil is covered by water, or the water table is within 25.4 cm of the surface for 5 to 12 months during most years, except during extended dry periods.

Rapid urban expansion in this region is causing a rapid reduction in the acreage being farmed. Sugarcane has been increasing annually on the organic soils and it is the second most important crop in Florida after oranges. Production of winter vegetables, improved pasture grasses and clover and sod continue to be important crops in the regions.

Manhattan, Kansas

Kansas is located in the center of the Great Plains and has a dry continental climate. Average precipitation ranges from 101.5 cm in the southeast to 38.1 cm in the western part of the state. The 1979 growing season was excellent for crop production (Table 1). Rainfall was not above normal, but was received with excellent timeliness. Temperatures were generally below normal, with no days over 37.8 C at Manhattan.

The soils of the Agronomy North Farm in Manhattan are silt loam (Udic Argiustoll). A soil test of the experimental site indicated pH of 6.9, 91.01 kg/ha available phosphorus, 785.4 kg/ha available potassium, and 51.8 ppm available nitrogen.

Kansas ranks second to Texas in cropland acreage and the major harvested crops are wheat (4-4.8 million ha) and grain sorghum (2.2 million ha). Corn, soybeans, and alfalfa are other important crops (0.4-0.6 million ha each). About 8.09 million hectares of native range and cool-season pasture support the dominant livestock industry, beef cattle.

Baton Rouge and Houma, Louisiana

Louisiana has a freeze-free period of approximately 240 days annually in its sugarcane area. The average date of the first freeze ranges from November 20 to December 10. The average date of the last freeze ranges from February 18 to March 20. Annual average temperatures are 18-20 C over much of the region. The average annual rainfall is 146 cm without a definite dry or wet season (See Table 1).

The general soil areas in Louisiana are the Coastal Plain soils in the northeast, Loessial Terrace soils in the northwest and southwest, Coastal Prairies soil in the southwest and Recent Alluvium soils along the Mississippi and Red Rivers.

The estimated production of major crops in thousands of hectare in 1979 are: soybeans - 1,280, rice - 213, cotton - 186, hay - 150, sugarcane - 108, corn - 17, and sweet potatoes - 11. Soybeans are grown throughout the state, but mostly on the Alluvium and Terrace soils. Rice is grown on the Coastal Prairie soils. Cotton and corn are grown mostly on the Upper Alluvium soils. Hay crops are usually produced on Coastal Plain, Terrace and Flatwood soils. Sugarcane is grown on the Lower Alluvium and Terrace soils. Sweet potatoes are produced on Terrace soils.

Meridian, Mississippi

The average first killing frost date at Meridian, Mississippi is March 17 and the average last killing frost date is November 11. This gives a growing season of 238 days in length. The average temperature in January (the coldest month) is 9 C and the average temperature in July (the warmest month) is 26.8 C. The frost-free season is 200-280 days. The average annual rainfall is 133 cm, however the rainfall for 1979 was 182 cm.

The soil type of the test site is McLaurin loamy sand. Drained soils produce highly productive crops. Soils throughout much of this region are naturally poorly drained and consequently poorly suited to crop production. However, artificially drained soils are highly productive for such crops as cotton, soybeans, corn, and hay. The wettest areas that are not suitable for crop production remain in forests which are important for hardwood timber production.

Lincoln, Nebraska

The experimental cropping area is generally characterized by a yearly temperature average of 10.6 C and yearly precipitation total of 75.8 cm. The distribution of these variables (Figures 4 and 5) shows that the highest temperatures occur June, July and August while the highest percipitation is in May. During the growing season, July is usually the lowest month for precipitation and as can be seen in the figures, both temperature and precipitation vary widely. Average temperature and precipitation for the growing season (May - October) is 20 C and 56.2 cm, respectively.

Soils are generally Typic Argiudolls which are highly base saturated and slightly acid or neutral in the natural condition. This condition usually changes with intense fertilizing and liming practices. The exchange complex is highly saturated with calcium and magnesium. These soils contain ample potassium as a result of natural weathering of abundant feldspar minerals.

Crops generally grown include corn, grain sorghum, soybeans, wheat and small amounts of alfalfa. The cereals are almost always fertilized with N and P while the legumes require P only. Very little irrigation occurs in central eastern Nebraska although state-wide, irrigation plays a significant role in crop production.

Fargo, North Dakota

The North Dakota site was located in the heart of the Red River Valley of the North. Fargo was selected to represent an extreme northern latitude with very short growing season, but long day-lengths.

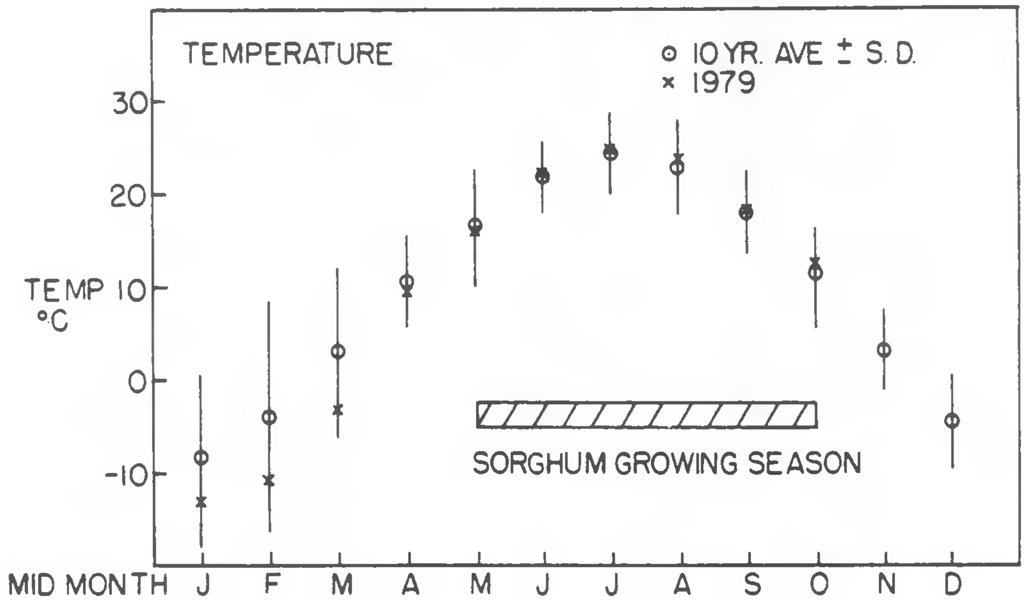

FIGURE 4. DISTRIBUTION OF TEMPERATURE DURING THE MONTHS OF 1979 IN LINCOLN, NEBRASKA

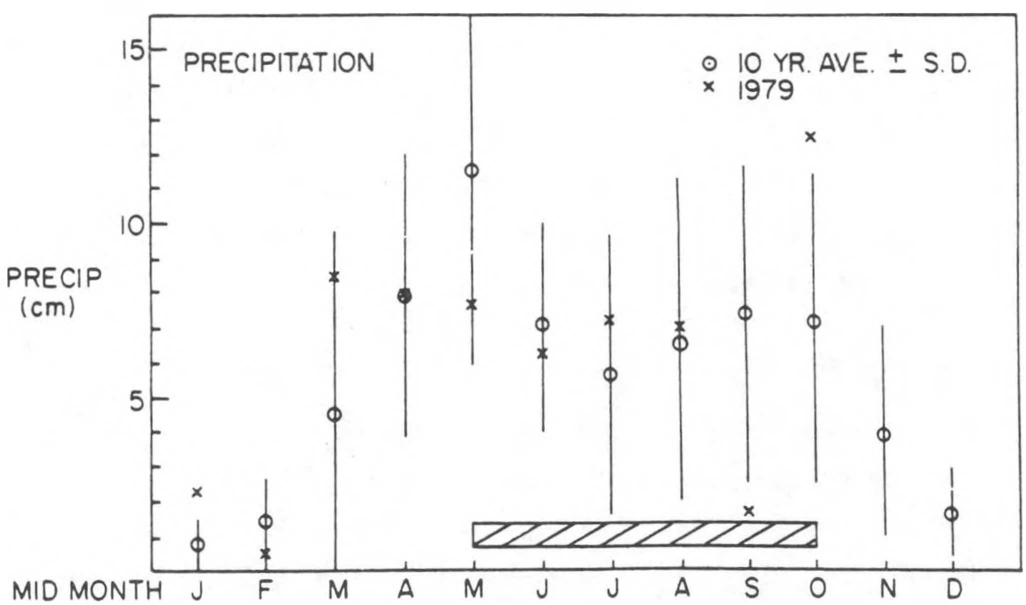

FIGURE 5. DISTRIBUTION OF PRECIPITATION DURING THE MONTHS OF 1979 IN LINCOLN, NEBRASKA

The outstanding feature of the Valley's climate is the very short growing season (137 days of 0 C or above) and the 16 to 18-hour daylength. The long-term mean temperatures during June, July, August, and September (the growing season of sweet sorghum at Fargo) are 18.6, 22.3, 19.6, and 16.7 C, respectively. Fargo averages less than 13 days annually of 32.2 C or greater. Obviously, the temperature is marginal for producing a long, warm-season crop like sweet sorghum. Precipitation averages 49.8 cm annually with approximately 80 percent occurring during the growing season. Precipitation is generally adequate for small grains, the predominant crop of the area.

The Red River Valley has predominantly fine-textured high-clay soils deposited by glacial Lake Agassiz. Tall grasses were the indigenous species, but these were plowed about a century ago. As a result the Valley soils are relatively high in productivity and neutral to calcareous in pH. The Fargo clay soil at the Fargo site tested 560 kg potassium (K) and 51 kg phosphorus (P)/ha in the upper 15 cm of soil and an average 92 kg nitrogen (N)/ha in the upper 61 cm of soil. The pH was 6.5, somewhat lower than normal for Fargo clay soils.

The major crops grown in the Valley in decreasing order of importance are hard red spring wheat, sunflowers, barley, summerfallow, corn, hay, durum, oats, soybeans, sugarbeets, potatoes, and flax. Although wheat predominates in the Valley, sunflower has increased dramatically in the last 3 years primarily at the expense of barley, oat, and flax acreage. Sugarbeets are an important crop throughout the Valley while potatoes are grown primarily in the northern half. Soybeans and corn are grown primarily in the southern portion of the Valley.

Columbus, Ohio

The annual precipitation is 62.5-87.5 cm over much of Ohio but ranges from 50 cm in the extreme northwest to 112.5 cm along the eastern and southeastern fringe (See Figure 1). Somewhat more than half of the annual precipitation falls during the growing season. Average annual temperatures are 7-13 C in much of the region but range from 4 C in the extreme northwest to 17 C in the extreme southwest. The frost-free season is 140-180 days in most of the region but is as short as 130 days along the northern fringe and as long as 235 days in the extreme southwest.

Gray-Brown Podzolic soils in the east and Brunizems in the west are dominant soils. Humic Grey soils and Bog soils on wet lowlands and Alluvial soils in bands along the major streams are also important.

Corn, soybeans, oats, and other feed grains are the most extensively grown crops. Hay, winter wheat, and many other crops are grown also. Much of the grain is fed to beef cattle and hogs on the farms where it is grown, but a large amount is shipped to other regions for livestock feed. Part of the grain is processed for food and for industrial uses.

Weslaco, Texas

The climate of the Lower Rio Grande Valley of Texas is subtropical and semi-arid, characterized by long, hot summers and short, mild winters. The growing season is approximately 300 days, and the average annual temperature is close to 23.3 C with the average annual daily maximum 30.6 C. January is the coldest month with an average daily minimum of 12.7 C. At Weslaco, a January-February freeze occurs about 2 out of every 3 years while a December freeze occurs about 1 out of every 2 years. The average rainfall is approximately 66 cm per year. Most of the precipitation falls in the form of thundershowers, resulting in geographically and seasonally, that amounts are uneven distribution. Large variations may occur over relatively small areas. The average number of days per year with 0.25 cm or more of precipitation is 36. The mean annual relative humidity averages about 75 to 80 percent. The winds flow across the Lower Rio Grande Valley from a southeast to south-southeasterly direction about 41 percent of the time. The Valley receives between 60 and 65 percent of the total possible sunshine annually.

The region's soil is one of its most valuable natural resources and supports a highly developed agricultural economy. Alluvial soils range from very silty river soils to heavy clay and sandy soils. Soil at the experimental site is classified as Willacy fine sandy loam (Order: Millisols, sub-group Udic Arguistolls). Willacy is the major soil type in the area.

The irrigation water supply for the Lower Rio Grande Valley is provided from two large impoundments on the Rio Grande River. There are approximately 283,000 hectares under irrigation and 405,000 hectares dry land in crop production.

IV. EXPERIMENTAL RESULTS

Uniform Experimental Design

Introduction

The UED was established at five locations (Manhattan, Kansas; Baton Rouge, Louisiana; Lincoln, Nebraska; Fargo, North Dakota; and Weslaco, Texas). The field experimental design was a split plot arrangement with 4 blocks of each treatment. Main plot treatments consisted of 3 cultivars. The Wray cultivar was grown at all locations for uniform comparisons; the two alternate cultivars at each site were selected on the basis of climatic adaptation.

Parameters to be measured at various stages of plant development were specified prior to experimentation and are listed in Table 3. In addition, areas to be sampled within each plot were specified for each of the three harvests. All collected data were analyzed statistically to indicate those treatments which were significantly different from others in the same classification. The results were computerized for further processing and reported in graphic form.

Implementation of the UED allows for clear evaluations of sweet sorghum yields in terms of widely different soil types and climatic conditions. Analysis of the results may lead to a better understanding of the most critical parameters needed to predict sweet sorghum yields across the continental U.S.

Experimental methods of the field and labor procedures are described in Appendix A.

Plant Population and Height

Manhattan, Kansas. Populations of all cultivars increased significantly with each narrowing of row width except Wray between 50 and 75 cm spacings (Figure 6). A significant cultivar row spacing interaction resulted from differences in the rate of decline in stalk number as row widths were widened. Rio and Dale tillered more than Wray, producing significantly more stalks in all row widths.

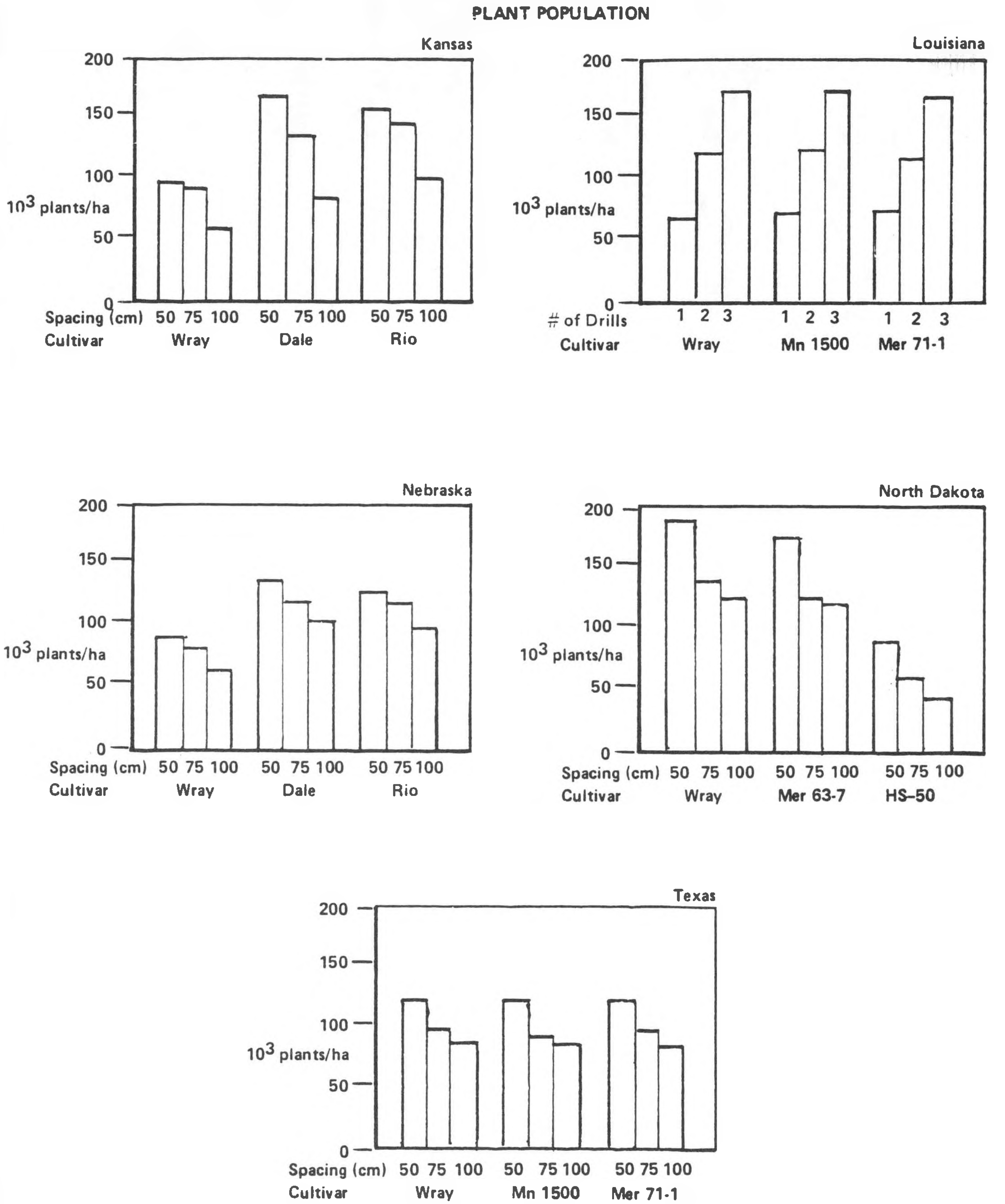

FIGURE 6. PLANT POPULATION OF SWEET SORGHUM AT MATURITY FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

Dale and Rio were similar in height and significantly taller ($P \leq .05$) than Wray at the mature stage (Figure 7). Plant heights for the 50 and 75 cm row spacings were similar and both were significantly taller than those at the 100 cm row spacing.

Baton Rouge, Louisiana. The plant populations and heights at maturity are shown in Figures 6 and 7. The number of plants per hectare, adjusted by thinning, averaged 7, 109, and 163 thousand for the one, two and three drills, respectively. The plants did not produce tillers and the population remained the same during the growing season. The average plant heights of each cultivar were similar at the boot stage. Wray was the shortest and MN 1500 was tallest at maturity. Generally, with some exceptions, the plants of each cultivar were taller and larger in stalk diameter with one drill than with the other drills.

Lincoln, Nebraska. The final harvested plant population (Figure 6) was significantly different among the cultivars. Dale and Rio were similar but significantly higher than Wray. The narrow row spacing (50 cm) was also significantly higher than either the intermediate or wide spacing. The 100 cm spacing was significantly lower than the other two spacings.

Plant height (Figure 7) was significantly greater for Dale (371 cm) than Rio (350 cm). Wray (324 cm) was the shortest in these experiments and significantly less than either of the other cultivars. No significant difference was detected for row spacing.

Fargo, North Dakota. The sweet sorghums produced more stalks/ unit area than the HS-50 male-sterile corn[1] (Figure 6). Wray and MER 63-7 averaged 2.77 and 2.47 stalks/established plant, respectively. Conversely, HS-50 produced very few tillers. The number of stalks/ha decreased as the row spacing increased. The 100-cm row spacing tended to produce more tillers (2.75 vs. 2.06 stalks/established plant) than narrower row spacings within the sweet sorghums; however, the cultivar by row spacing interaction was nonsignificant.

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(1) Note that this is the only site that included HS-50 male-sterile corn in the UED.

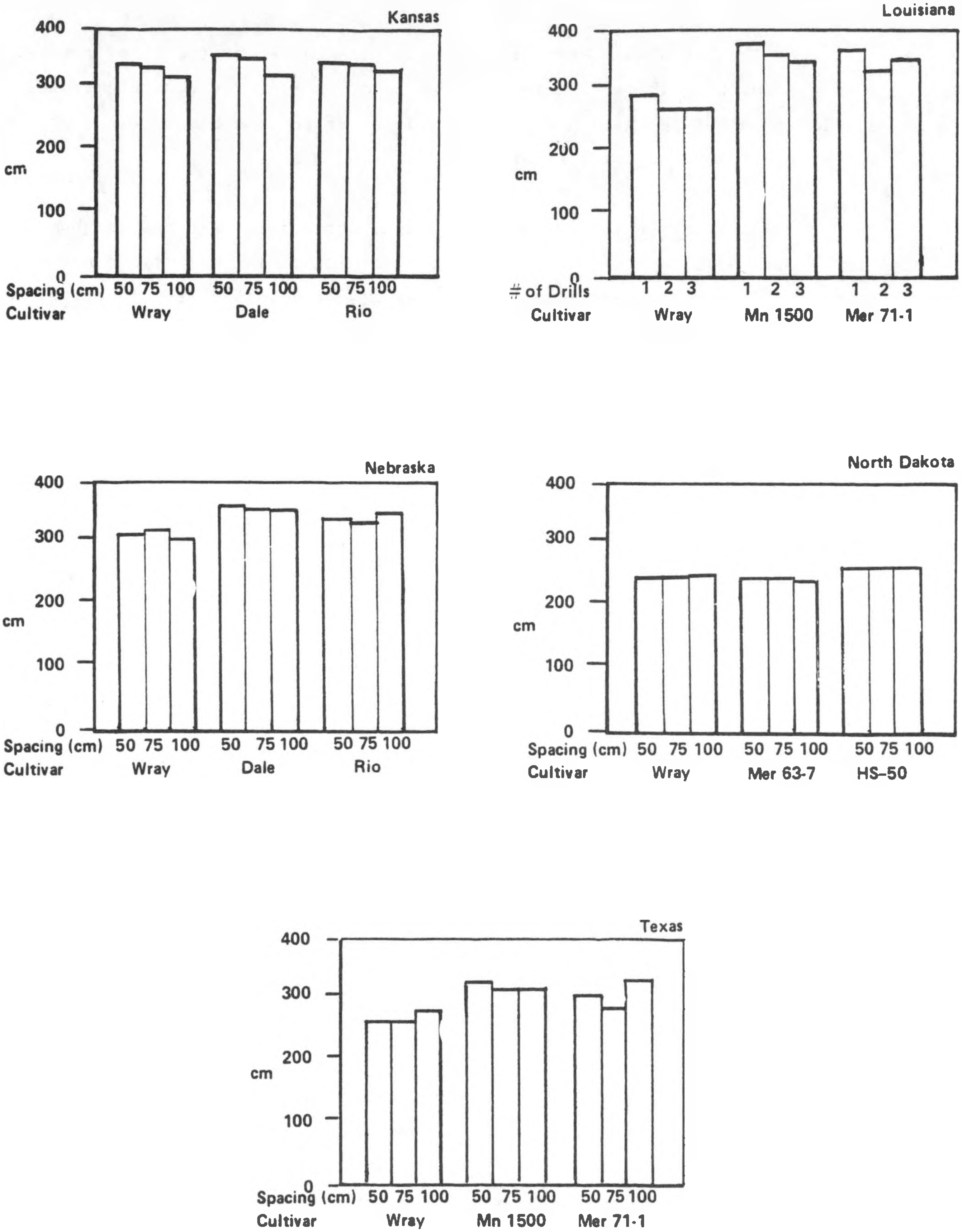

FIGURE 7. PLANT HEIGHT OF SWEET SORGHUM FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

The HS-50 male-sterile corn plant was taller at the final harvest than the sweet sorghums (Figure 7). Wray and MER 63-7 sweet sorghums were similar in plant height. Row spacing did not affect the plant height of the male-sterile corn or sweet sorghums.

Weslaco, Texas. Plant population, determined when the sorghum plants were eight centimeters high, showed a significant difference between each of the three row spacings. There was also a significant difference due to cultivar. Wray had the greatest population, followed by MER 71-1 and MN 1500. The initial planting was made such that there were more plants on the 50 cm row spacing followed by the 75 cm and the 100 cm row spacing. Plants were spaced 15 cm apart down the row and there were more rows per hectare in the 50 cm row tests.

The final population count was made at the last harvest from the same area that the initial count was made. The 50 cm rows had a decrease in population with MER 71-1 and MN 1500 and remained the same with Wray. The final plant count increased over the initial count with all cultivars at the 75 cm and 100 cm row spacing. The 100 cm row spacing had the greatest plant number increase, indicating that there was more room per plant in the 100 cm rows allowing for greater tillering. Figure 6 shows final plant population only.

The height of sorghum was measured at the final harvest of each cultivar. The height of sorghum plants was greater with MN 1500 followed by MER 71-1 and Wray. There was a significant difference between varieties. Row spacing also produced a significant increase in height. Plants in the 100 cm rows were significantly taller than plants in the 75 cm rows. The 50 cm row plants were intermediate in height (Figure 7).

Dry Biomass Production

Manhattan, Kansas. The 50 and 75 cm row spacings produced more ($P \leq 0.05$) dry biomass than the 100 cm row spacing at the anthesis and maturity stages (Figures 9 and 10). There did not appear to be any significant difference in the boot stage (Figure 8).

Rio produced 21.92 t/ha mean total dry biomass which was greater ($P \leq 0.05$) than Wray and Dale, with 18.2 and 18.1 t/ha, respectively (Figure 10). [illegible] mass differed significantly among cultivars,

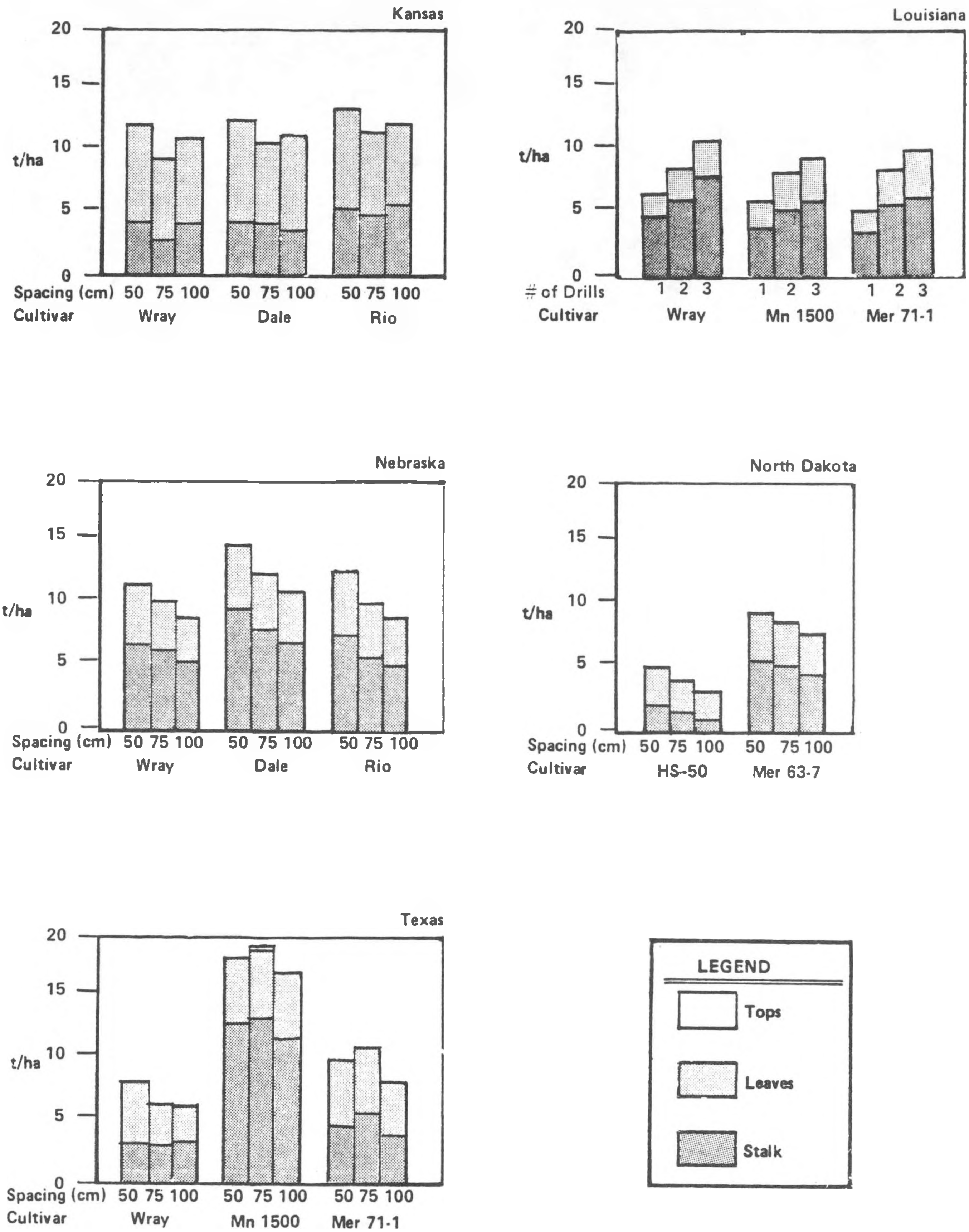

FIGURE 8. DRY BIOMASS OF SWEET SORGHUM AT ANTHESIS FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

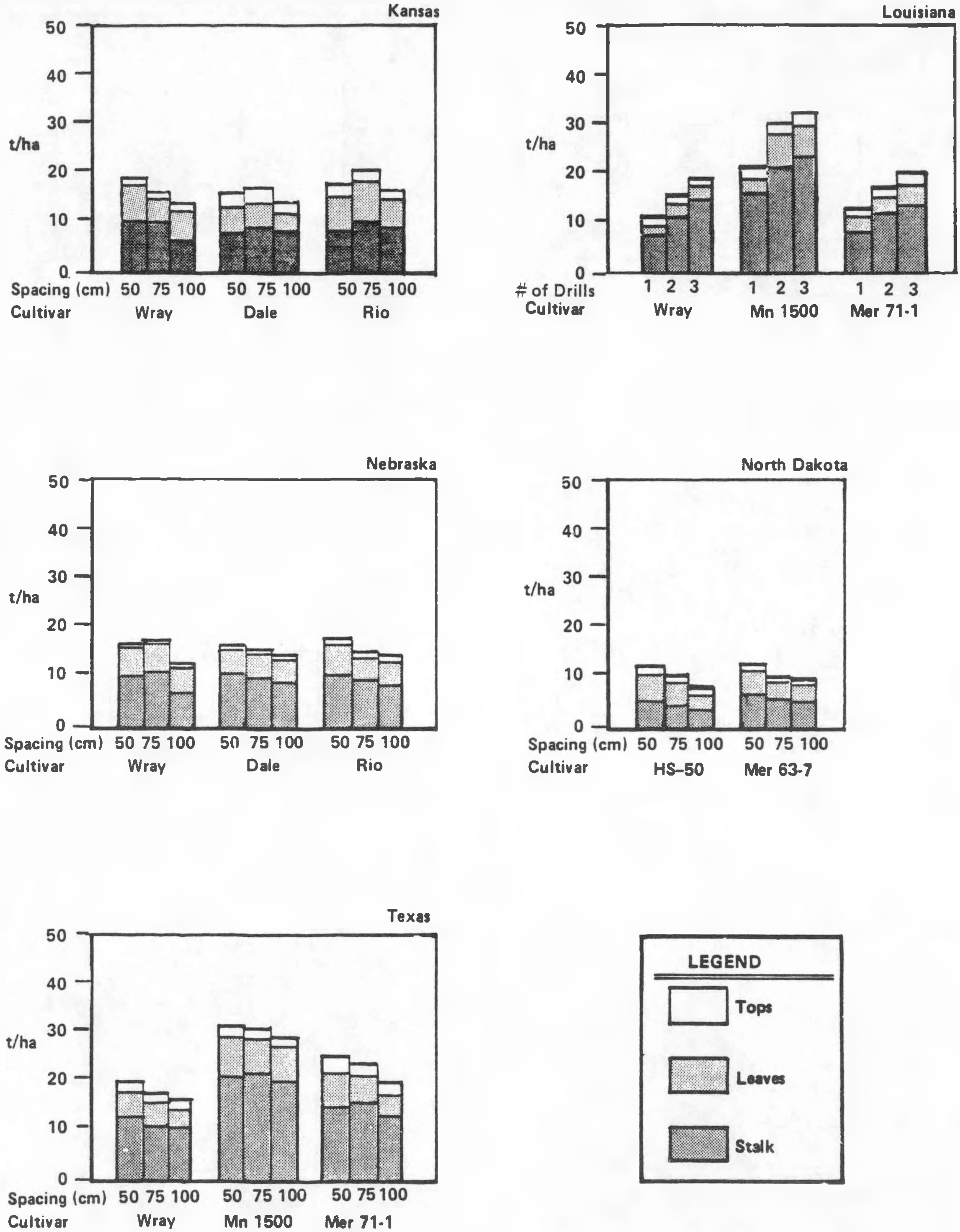

FIGURE 9. DRY BIOMASS OF SWEET SORGHUM AT ANTHESIS FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

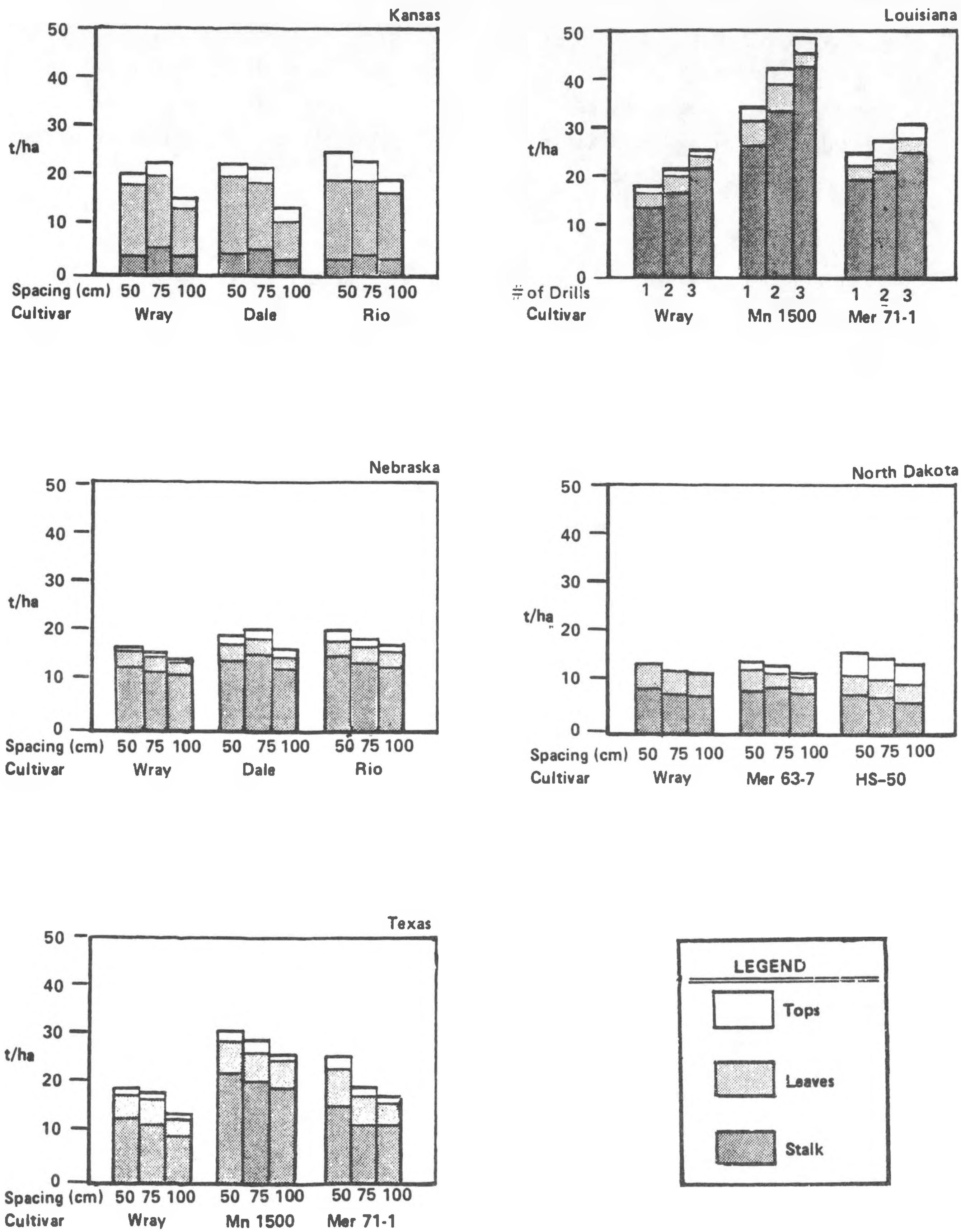

FIGURE 10. DRY BIOMASSS OF SWEET SORGHUM AT MATURITY FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

the leaf and stalk yields were not different. Rio produced greater ($P \leq 0.05$) top weight than Dale or Wray, and Dale produced significantly greater top weight than Wray. This difference probably largely reflects differences in seed production potential of these cultivars.

Baton Rouge, Louisiana. The biomass data at the boot stage of maturity are presented in Figure 8. The wet stalk yields ranged from 35.1 to 60.1 t/ha. MN 1500 was lower in wet stalk yield, but Wray was higher in dry stalk yield than the other cultivars. Wray was lower in wet and dry leaf yield than the other cultivars. MER 71-1 was lower in total wet yield but Wray was higher in total dry yield than the other cultivars. The yield of each cultivar increased significantly with each successive increase in number of drills, except between two and three drills within MN 1500.

The biomass data at the anthesis stage are presented in Figure 9. The wet stalk yields ranged from 41.3 to 79.1 t/ha and the dry stalk yield ranged from 12.5 to 28.0 t/ha. The Wray cultivar was the lowest and MN 1500 was the highest in the wet and dry yields of stalks, leaves, and tops. The yield of each variety increased with each successive increase in number of drills, except between two and three drills in wet stalks with MN 1500 and in wet leaves with Wray and in wet tops with MER 71-1.

The biomass data at maturity are shown in Figure 10. The wet stalk yields ranged from 40.3 to 84.5 t/ha and the dry stalk yield ranged from 14.5 to 35.0 t/ha. The Wray cultivar was the lowest and MN 1500 was the highest in the wet and dry yields of stalks, leaves, and tops in stalk fiber. The yield components of each cultivar increased with each successive increase in number of drills, except between two and three drills in wet leaves with Wray, and in wet leaves, wet and dry tops and total wet yield with MN 1500. The increases with MER 71-1 between one and two drills in dry stalks and fiber and between two and three drills in wet and dry tops were not significant.

Lincoln, Nebraska. Figure 8 shows the dry biomass at boot. The Dale cultivar yielded significantly more (13.4 t/ha) than either Wray (11.0 t/ha) or Rio (10.7 t/ha) which were similar. Also, the 50 cm spacing produced significantly higher yields (13.5 t/ha) than the 75 cm spacing (11.5 t/ha

The 100 cm spacing was significantly lower (10.2 t/ha) than the other two spacings. No interaction with varieties was detected indicating they reacted similarly. The cultivar differences for total yield at this stage were accounted for by the differences in stalk yields rather than leaf yields which were similar for all varieties. Stalks generally made up about 60 percent of the total yield. There were differences in both leaf and stalk yields for row spacing. Leaf and stalk yields at the 50 cm spacing were significantly greater than the 75 cm spacing. Again the 100 cm spacing produced significantly lower yields than the other two spacings for both plant parts.

Total biomass production at anthesis (Figure 9) was not significantly different among cultivars. Yields generally ranged from 14-15 t/ha. There were, however, significant differences detected among the three row spacings. Like the boot growth stage, the 50 cm spacing was the highest (16.1 t/ha), the 75 cm spacing intermediate (15.1 t/ha) and the 100 cm spacing the lowest (12.8 t/ha) in total biomass production. A significant cultivar-by-spacing interaction was detected. This was accounted for by Wray where the 50 and 75 cm spacings were similar, and Rio where the 75 and 100 cm spacings were similar. When plant parts were broken out and analyzed separately, there were significant differences for both stalks and tops, but not leaves among cultivars. The Wray cultivar was significantly lower than the other spacings for stalk and leaf biomass. The 50 cm and 75 cm spacings at anthesis, however, were similar for biomass production. Production of biomass by the tops was greatest at the 50 cm spacing followed by the 75 cm spacing and the 100 cm spacing. Spacing by cultivar interactions were detected for leaf and stalks biomass production but not for tops.

Dale (17.5 t/ha) and Rio (17.8 t/ha were similar in total yield and both significantly higher than Wray at maturity (15.1 t/ha) (Figure 10). A similar result was obtained for stalks among the three cultivars with this component generally making up about 77 percent of the total. Unlike either the boot or flowering stages, the 50 cm spacing (17.8 t/ha) was not significantly different from the 75 cm spacing (17.2 t/ha). The 100 cm spacing was significantly lower (15.5 t/ha) however than the other spacings. The tendency for the narrowest row spacing to yield more was offset in this case by cultivar Dale where the 75 cm spacing tended to yield the highest. However, the difference was not enough to produce a significant cultivar-by-spacing interaction. Stalks consistently made up 77 percent of the total weight for all cultivars.

Fargo, North Dakota. The dry biomass production of sweet sorghum and male-sterile corn during the boot and anthesis growth stage as affected by the row spacing at Fargo in 1979 is shown in Figures 8-9. The biomass production of MER 63-7 at the boot growth stage was close to double that of HS-50 at all row spacings. The stalk portion averaged 57 percent of the biomass for MER 63-7 but only 35 percent of the biomass for HS-50; yet, the leaf yield/ha was higher from MER 63-7 than HS-50. The biomass of MER 63-7 at the anthesis growth stage was higher than HS-50, but the HS-50 yield was only 1 to 2 t/ha less than MER 63-7. Stalks contributed 56 percent of the biomass in MER 63-7 and 45 percent in HS-50. HS-50 ears contributed 10 to 15 percent of the biomass, slightly higher than the 7 to 8 percent contributed by Mer 63-7 tops. The leaf, stalk, and total biomass decreased as the row spacing increased during the anthesis growth stage. The percent stalk biomass was unaffected by the row spacing. The biomass decreased significantly with an increase in row spacing for each species at both early sampling dates.

The biomass of sweet sorghums and male-sterile corn during the final harvest as influenced by the row spacing at Fargo in 1979 is shown in Figure 10. HS-50 male-sterile corn was higher-yielding than the sweet sorghum. MER 63-7 and Wray were similar in biomass yield even though Wray was still in the vegetative growth stage when the final harvest was taken. MER 63-7 produced the highest stalk yield averaging 7.1 t/ha, significantly higher than HS-50 at 5.7 t/ha. The sweet sorghums averaged 58 percent stalk biomass compared to only 43 percent for HS-50, but the HS-50 had 30 percent of the biomass yield in ears. Wray produced a higher leaf biomass (total and percent) than HS-50 or MER 63-7. Leaf, stalk, and total biomass decreased with an increase in the row spacing, but tops and ears were unaffected by the row spacing. Total biomass was increased 18.6, 12.9, and 20.4 percent for Wray, MER 63-7, and HS-50, respectively, by narrowing the row spacing from 100 to 50 cm.

Weslaco, Texas. MN 1500 cultivar yielded the greatest dry weight tonnage of stalks and leaves at all three harvest stages (Figures 8-10). The final harvest at all row spacings of MN 1500 had a significantly higher yield of both stalk and leaves while MER 71-1 produced a significantly higher yield than Wray. Row spacing showed a significant cultivar by row spacing interaction. Dry weight of leaves was greater at the 50 cm row spacing. Wray produced the greatest difference in dry leaf production. There was no difference in dry weight of leaves with the other two cultivars. MER 71-1 had a significantly greater tonnage of tops due to the larger seed heads. The 50 cm row plants produced tops significantly higher than the 100 cm spacing.

Row spacing had the greatest effect on total biomass with the early maturing cultivar Wray and the least effect with the late maturing cultivar MN 1500.

Sugar Yield

Manhattan, Kansas. Sucrose production did not differ between the 50 and 75 cm row spacings but was considerably more than the 100 cm row spacing (Figure 11). Wray produced the most sucrose per hectare and Rio produced significantly more Dale.

There were considerable variation in glucose production among cultivars and row spacings resulting in a significant cultivar by row spacing interaction. Glucose production of Wray was similar at all row spacings; Dale produced the most glucose at the 75 cm spacing; Rio had significantly less production in the 100 cm row spacing. Despite the presence of this interaction, Dale produced much more glucose than Wray and Rio in all row spacings.

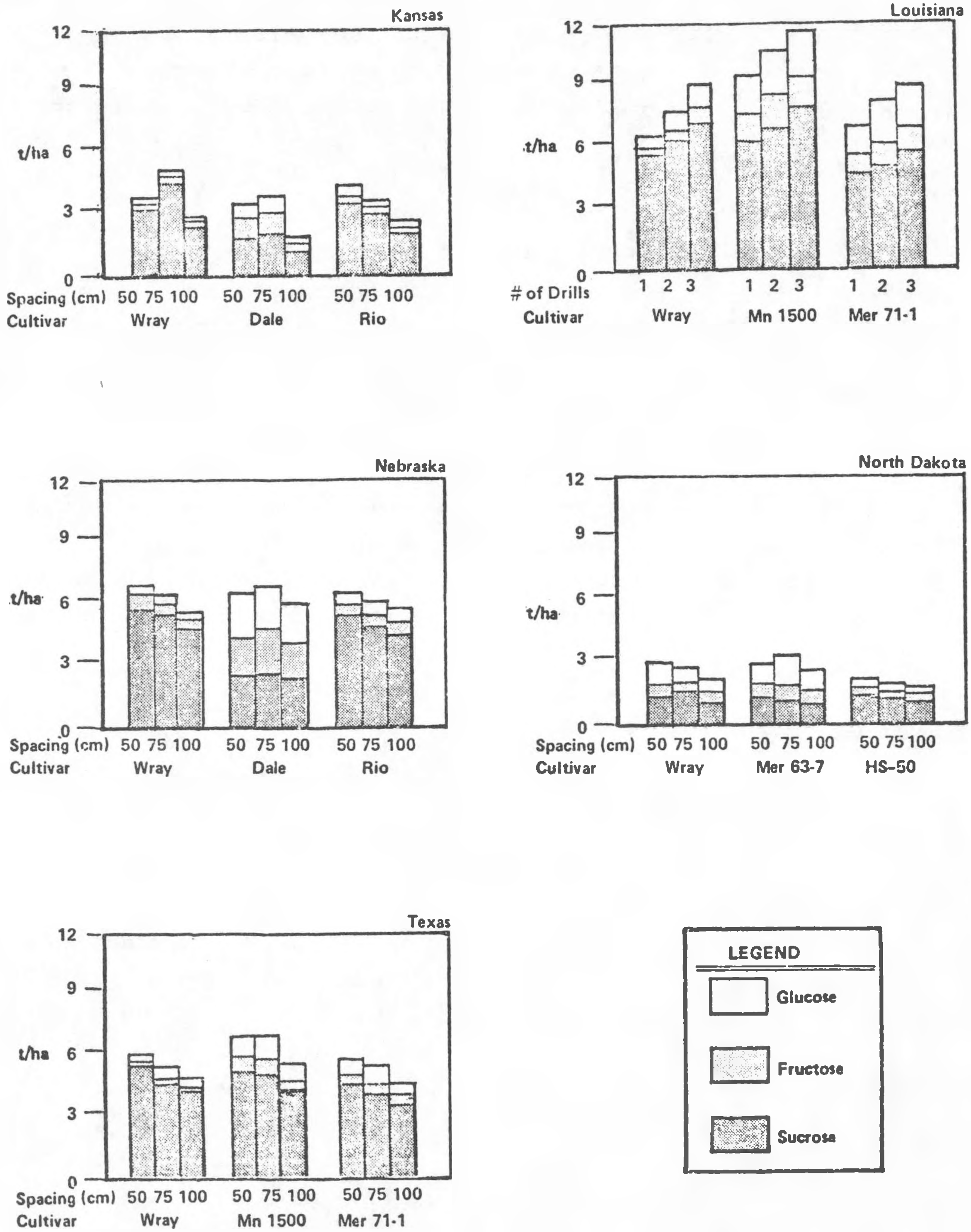

FIGURE 11. TOTAL SUGARS IN STALKS OF SWEET SORGHUM AT MATURITY FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

There was also a cultivar by row spacing interaction for fructose production. Wray was similar in fructose production at all row spacings; Dale produced less fructose in the 100 cm row spacing, and Rio had similar low fructose production at the 75 and 100 cm row spacings. As for glucose, Dale produced much more fructose than Rio and Wray at all row spacings. Rio produced more fructose than Wray in the 50 cm row spacing only.

There was no difference in total sugar production between the 50 and 75 cm row spacings and both were significantly greater than the 100 cm spacing.

Wray produced significantly more total sugar than Rio, and Rio produced more than Dale. Assuming 515 liters of ethanol per ton, these varieties would produce 1,578 to 1,903 liters of ethanol per hectare.

Baton Rouge, Louisiana. The stalk sugar yields at anthesis and maturity are shown in Figure 12. At anthesis, Wray was highest in sucrose yield and lowest in glucose and fructose yields, MN 1500 was the highest in total sugars, and MER 71-1 was the lowest in sucrose and total sugar yields. At maturity, MN 1500 was the highest in each of the sugars and MER 71-1 was the lowest in sucrose yield, but similar to Wray in total sugars. The sugar yields of each variety at each stage of maturity generally increased with each increase in number in drills, similar to the increases in stalk yields. MN 1500 with three drills produced the highest and Wray with one drill produced the lowest total sugar yields

Lincoln, Nebraska. The total sugar production of the stalk portion of the three cultivars tested at anthesis and the component makeup of total sugars is shown in Figure 12. Wray was significantly greater in stalk sugar production (4.2 t/ha) than either Dale (3.5 t/ha) or Rio (3.4 t/ha). Most of this was due to the much higher sucrose production by Wray. Dale was different in component makeup than either Wray or Rio, having significantly less sucrose. Sucrose was only 17 percent of the total in Dale while about 73 percent for the other varieties. Dale has been used as a syrup-producing cultivar because it has a higher percentage of simple sugars which do not readily crystallize.

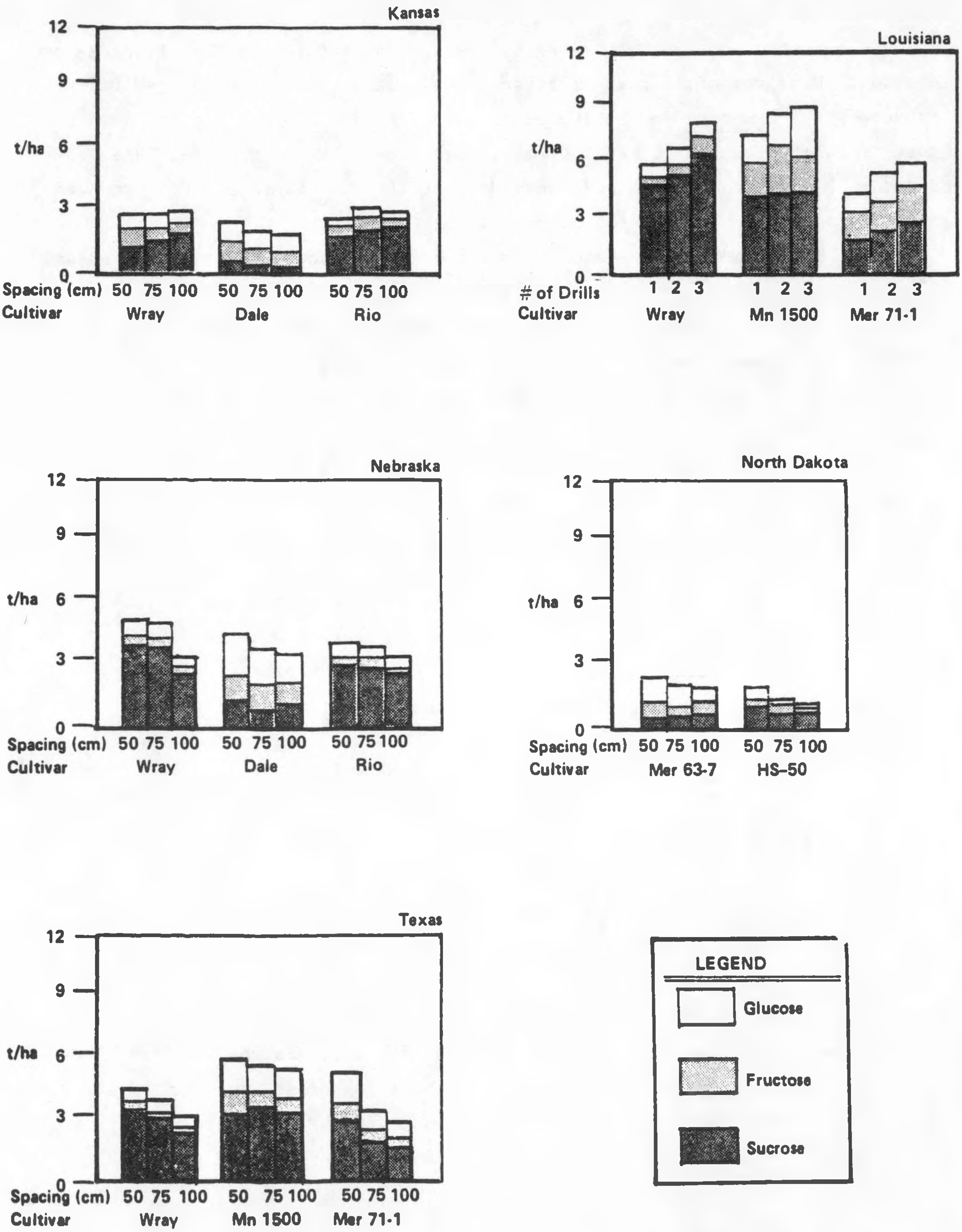

FIGURE 12. TOTAL SUGARS IN STALKS OF SWEET SORGHUM AT ANTHESIS FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

Spacing of 100 cm was found to produce much less total sugar than the other two spacings. This was most likely due to the effect of total biomass yield which was also much lower at the wider spacing (Figure 11) at anthesis.

Total sugars in stalks at maturity (Figure 11) were not significantly different among cultivars. The mean total sugar production was 5.5 t/ha. The pattern of component ratios of glucose, fructose, and sucrose was similar to that at anthesis Dale produced significantly less sucrose and more glucose and fructose than either Wray or Rio. Sucrose accounted for 34 percent of the total sugar for Dale, but up to 85 percent for Wray and Rio.

Row spacings of 50 cm or 75 cm resulted in significantly higher sugar production than the 100 cm spacing (Figure 11). Most likely this was due to the trends observed for total biomass yield where the 100 cm spacing was lower than the 50 and 75 cm spacings.

Fargo, North Dakota. Total sugars/ha were higher at the anthesis growth stage in MER 63-7 sweet sorghum than HS-50 male-sterile corn due to a higher glucose and fructose content (Figure 12). MER 63-7 averaged 4.5, 15.6, and 8.0 percent sucrose, glucose, and fructose, respectively. Narrowing the row spacing had little effect on the percent sucrose, glucose, or fructose, but the higher dry matter yields with narrow rows increased the glucose, fructose, and total sugar yields.

Total sugar yields were influenced by the cultivars and row spacing at the maturity (Figure 11). The two sweet sorghums produced significantly higher sugar yields than the male-sterile corn primarily due to the substantially higher percentage glucose and fructose in the stalks of the sweet sorghums. MER 63-7, Wray, and HS-50 averaged 16.4, 11.3, and 5.5 percent glucose and 7.3, 7.8, and 3.5 percent fructose, respectively. The 100-cm row spacings yielded only 80 percent of the sugar yield of 50 and 75-cm row spacings. MER 63-7 at the 75-cm row spacing produced the highest total sugar yield (2.97 t/ha) of all treatments due to a significantly higher glucose and fructose yield.

Weslaco, Texas. There was no significant effect due to row spacing in the concentration of sucrose, fructose, and glucose (Figure 11). There was a difference in concentration due to cultivars. Wray cultivar was higher in percent sucrose at both growth stages while MN 1500 and MER 71-1 were higher in concentrations of fructose and glucose. Sucrose concentrations were greater in all cultivars, followed by glucose and then fructose.

Sucrose yield (Figure 11) was significantly greater with Wray and MN 1500 while MN 1500 and MER 71-1 were significantly higher in tons of fructose and glucose, corresponding to the same trend as the percent sugars. Plants grown in 50 cm rows produced a greater yield of sucrose than plants grown in the 100 cm rows. The yield of fructose and glucose were not significantly different due to row spacing. MN 1500 produced the greatest sugar yield of 6.54 t/ha at maturity at the 50 cm row spacing (Figure 11).

Stalk Fiber[(1)]

Manhattan, Kansas. Total acid detergent fiber (ADF) production declined significantly with each increase in row width (Figure 13).

Wray and Dale did not differ ($P \leq 0.05$) in total stalk fiber production and both were significantly lower than Rio.

Baton Rouge, Louisiana. Total ADF production increased proportionally with number of drills. Fiber content paralleled dry biomass production; MN 1500 was the highest followed by MER 71-1 and Wray.

Lincoln, Nebraska. Acid detergent fiber in the stalks (Figure 13) was significantly greater for Rio (4.3 t/ha) than Dale (3.8 t/ha). Wray was significantly lower (3.0 t/ha) than the other two. The 100 cm spacing also was found to be significantly lower for ADF than the 50 cm or 75 cm spacing which were similar.

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(1) See later section, Analysis and Summary, p. , for definition and discussion of ADF, NDF, and TNC. Laboratory methods are given in Appendix A. P. A-30at.

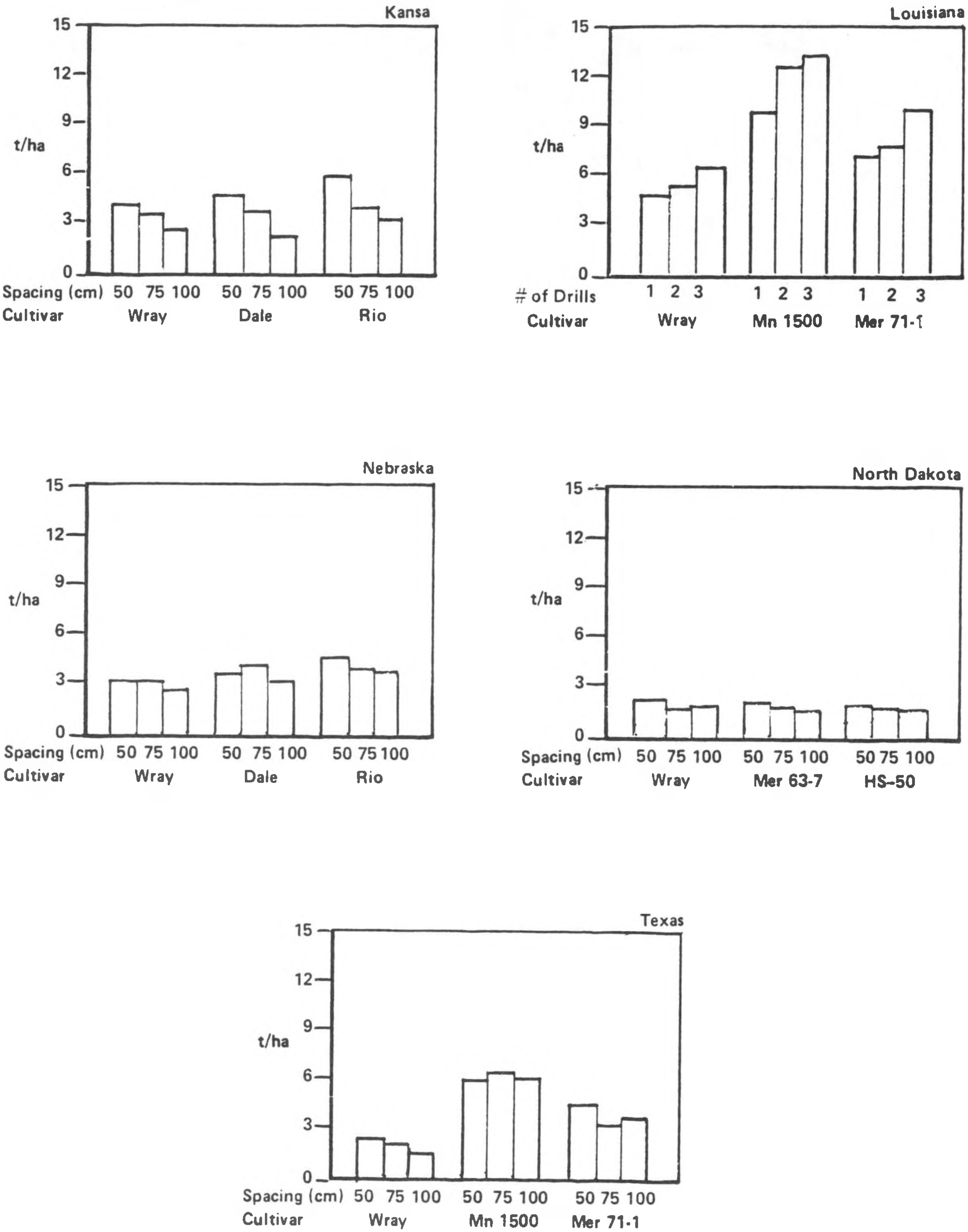

FIGURE 13. TOTAL ACID DETERGENT FIBER IN STALKS OF SWEET SORGHUM AT MATURITY FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

Neutral detergent fiber (NDF) followed the same varietal trend as ADF (Figure 14), but of increased magnitude in the values. Rio at 6.5 t/ha was significantly greater than Dale (5.8 t/ha) which in turn was greater than Wray (4.9 t/ha). In the case of NDF, however, no significant row spacing difference was found.

Total nonstructural carbohydrates (TNC) in stalks (Figure 15) were also different among cultivars but not similar to that for fiber. For TNC, variety Dale was the highest (5.4 t/ha) followed by Rio (4.8 t/ha) and Wray (4.3 t/ha). There was no significant difference in row spacing for TNC for these cultivars.

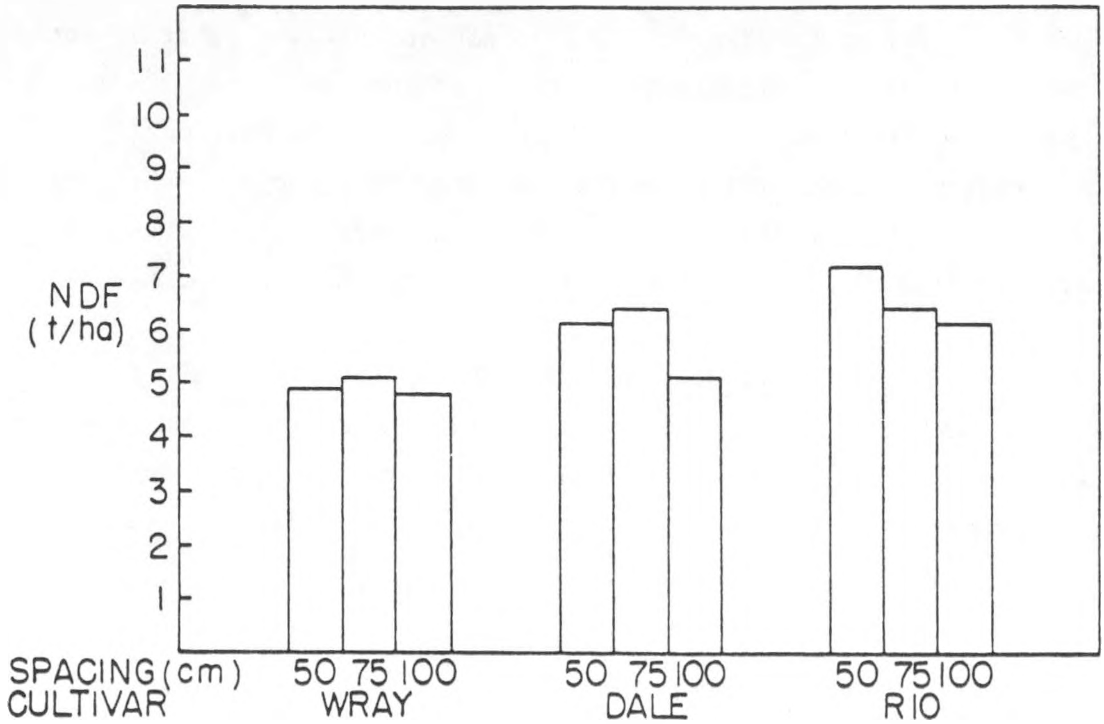

FIGURE 14. TOTAL NEUTRAL DETERGENT FIBER IN STALKS OF THREE SWEET SORGHUM CULTIVARS AT THREE ROW SPACINGS AT MATURITY IN NEBRASKA

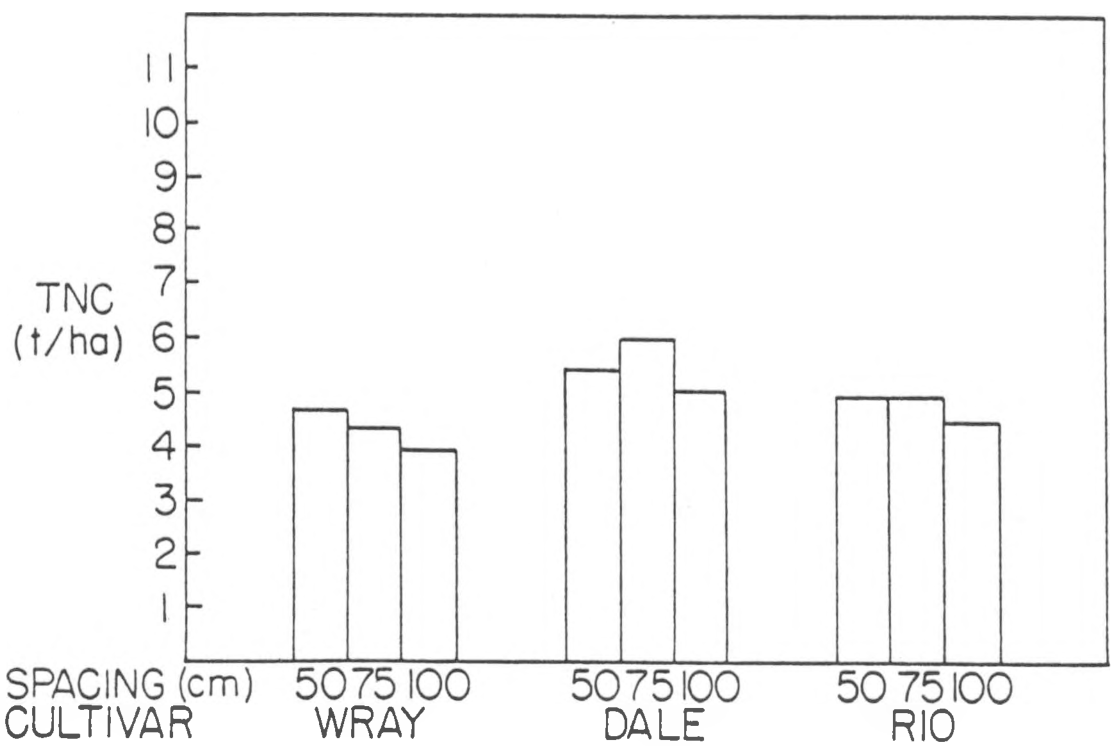

FIGURE 15. TOTAL NONSTRUCTURAL CARBOHYDRATES IN STALKS OF THREE SWEET SORGHUM CULTIVARS AT THREE ROW SPACINGS AT MATURITY IN NEBRASKA

Fargo, North Dakota. Fiber yield and percent fiber in stalks of sweet sorghum and male-sterile corn as influenced by row spacing are presented in Figure 13. Sweet sorghum produced significantly higher yields than did the male-sterile corn; Wray had a 2.9 percent higher fiber content than MER 63-7. Fiber yield increased with narrower row spacings, while percent fiber was unaffected by the row spacings.

Weslaco, Texas. The percent fiber in stalks is shown in Figure 13. The fiber percent was slightly lower in the stalks from 50 cm row spacing. The greatest percent difference was with the cultivar MN 1500. There was a 25 percent increase in fiber at the 100 cm row spacing. Wray cultivar contained the least fiber of the three cultivars.

Plant Uptake of N, P, and K

Manhattan, Kansas. Total nitrogen uptake by plants grown in the 50 and 75 cm row spacings did not differ significantly, but both were significantly greater ($P \leq 0.05$) than the uptake in the 100 cm row spacings (Figure 16). Nitrogen uptake in the leaf component was greatest at the 75 cm row spacing and least in 100 cm row spacing.

Total nitrogen uptake was similar for Wray and Rio, and both were significantly higher than Dale (Figure 16). There were no differences among cultivars in N uptake in the leaf component. Wray had significantly greater N in the stalks than Dale or Rio. Nitrogen utilization by stalks of Dale and Rio were not different. Rio contained a greater amount of N in the top fraction than Dale or Wray. This ranking was approximately similar to the ratio observed for dry biomass of the tops.

Total P uptake was greater in the 75 cm row spacing and significantly greater ($P \leq 0.05$) than the 100 cm row spacing (Figure 17). Uptake in the 50 cm row spacing was intermediate and not significantly different from either of the other spacings. Phosphorus in the leaves and stalks was greatest in the 75 cm row spacing and the 50 cm row spacing was significantly higher than the 100 cm spacing. There were no significant differences in P uptake in the tops among row spacings.

Rio utilized significantly more P than Wray or Dale (Figure 17). Wray and Dale were not significantly different. Although Rio utilized more total P, Wray utilized more P in the stalks than Rio and Rio utilized more

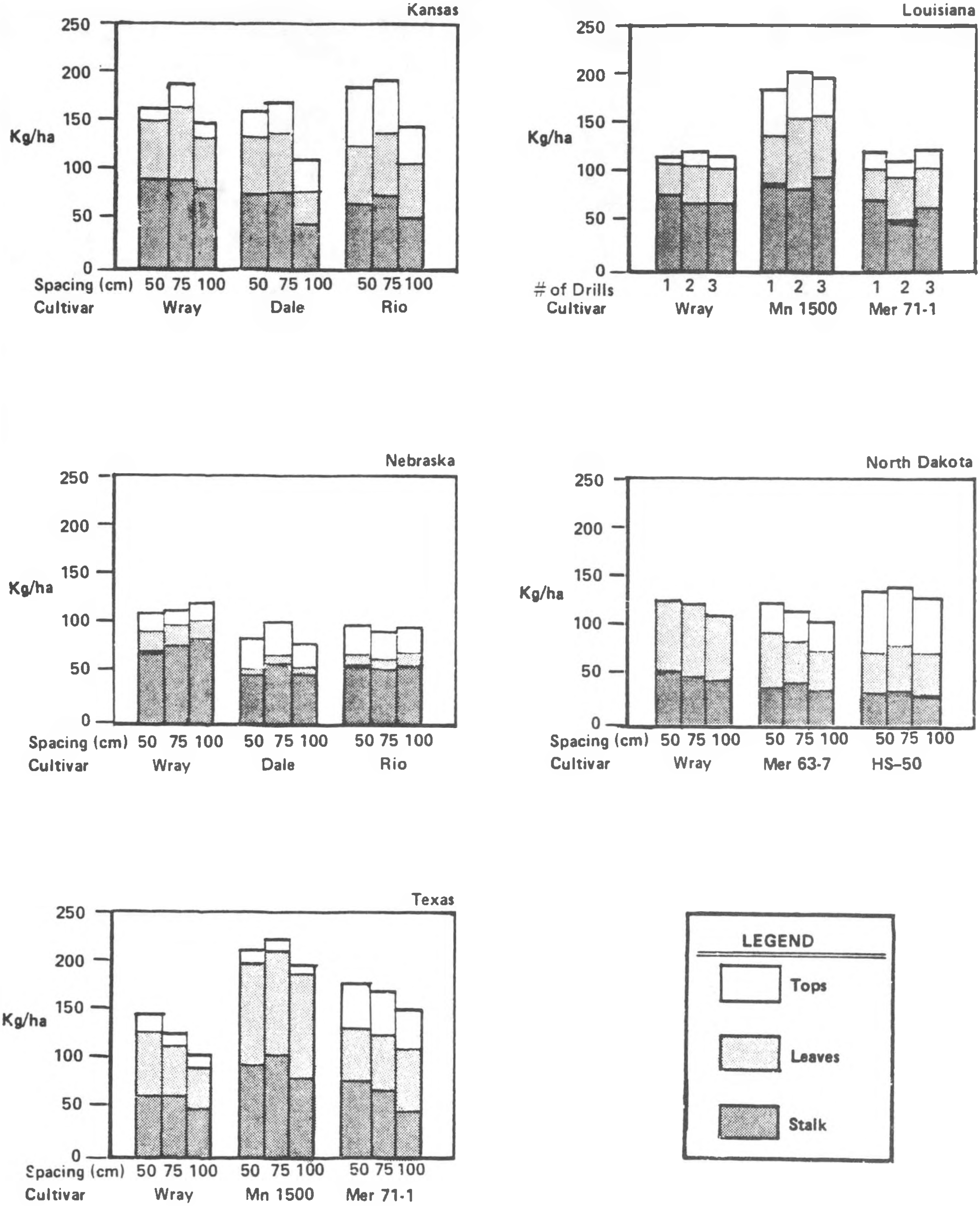

FIGURE 16. NITROGEN ACCUMULATION IN PLANT PARTS OF SWEET SORGHUM AT MATURITY FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

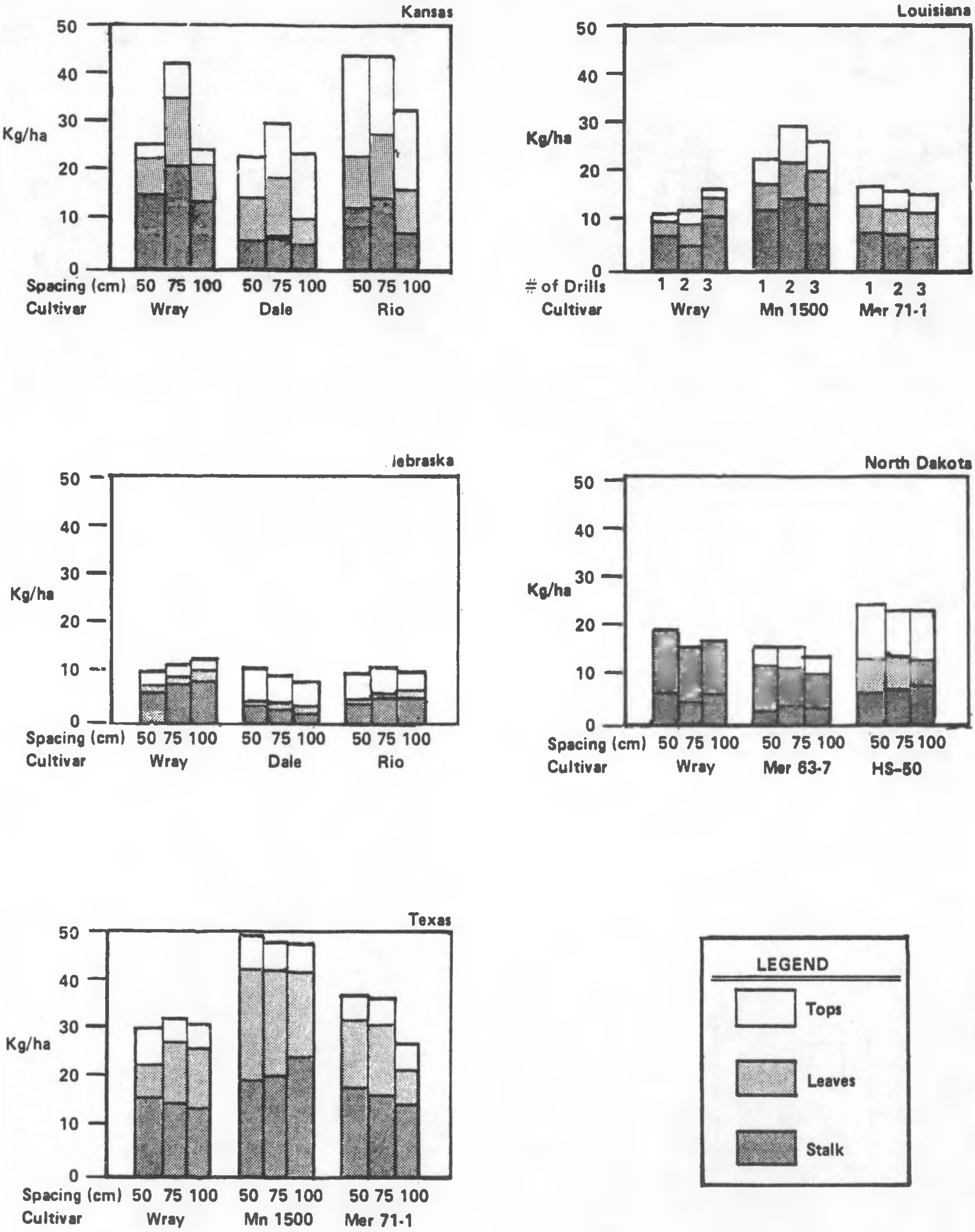

FIGURE 17. PHOSPHORUS ACCUMULATION IN PLATN PARTS OF SWEET SORGHUM AT MATURITY FORTHE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

than Dale. Phosphorus utilization in the top component again followed the pattern of dry biomass production. There were no significant differences among varieties for P utilization in the leaves.

Total K uptake was much greater in the 75 cm row spacing. Uptake in the 50 cm spacing was significantly greater than in the 100 cm spacing (Figure 18). The same relationship was noted for leaf and stalk components as for total K uptake. Uptake by the top component was similar for all row spacings.

Total K uptake was greatest ($P \leq 0.05$) for Rio, with Wray significantly greater than Dale (Figure 18). This greater uptake by Rio was due to the top component because Rio and Wray did not differ in K utilization in the leaf or stalk parts. Potassium uptake in the tops was again greater in Rio than in Dale or Wray. Approximately two-thirds of the total K uptake was in the stalks.

Baton Rouge, Louisiana. The N, P and K uptake in the stalks, leaves and tops at maturity is presented in Figures 16-18. Generally, the amounts of N, P, K uptake were largest in the stalks, intermediate in the leaves and smallest in the tops. The amounts of uptake in the stalks, leaves and tops were largest for N, intermediate for K and smallest for P. The total uptake of N, P and K was largest with MN 1500 and smallest with Wray.

Lincoln, Nebraska. Total uptakes of nutrients are shown in Figures 16-18. Nitrogen uptake was significantly greater in Wray (117.7 kg/ha) than either Dale (83.5 kg/ha) or Rio (92.2 kg/ha) which were similar. This was accounted for by uptake in the leaves and stalks of Wray which made up 15 percent and 71 percent of the total, respectively. Nitrogen uptake in the leaves and stalks of Wray were significantly higher than in the corresponding parts of either Dale or Rio which were similar. However, accumulation of N in the tops of Wray was significantly lower than the other two varieties. There was no difference in row spacing for N uptake and no cultivar by spacing interaction.

Uptake and accumulation of phosphorus showed that cultivar and spacings were similar. The cultivars generally accumulated 9.0-10.5 kg/ha P in tops, leaves, and stalks. There was a significant cultivar by spacing

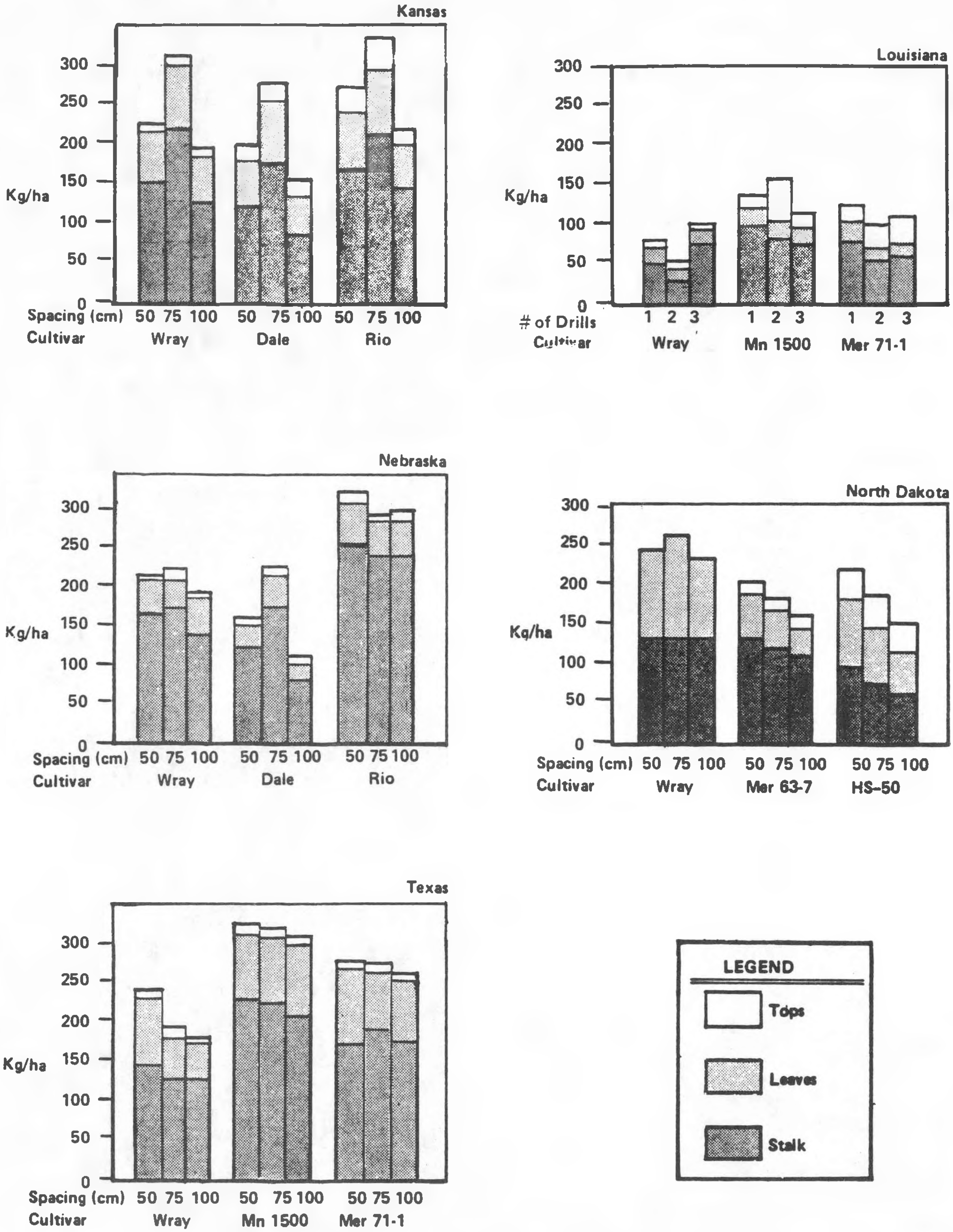

FIGURE 18. POTASSIUM ACCUMULATION IN PLANT PARTS OF SWEET SORGHUM AT MATURITY FOR THE UNIFORM EXPERIMENTAL DESIGN. LOCATIONS ARE: KANSAS, LOUISIANA, NEBRASKA, NORTH DAKOTA, AND TEXAS

interaction which indicated that they reacted differently when placed in different row spacings with respect to P uptake. Most of the element was found in the tops for Dale and Rio, while for Wray, the stalks appeared to accumulate P the most readily.

Cultivars differed significantly for K accumulation (Figure 18). Rio was significantly higher (293.6 kg/ha) than Wray (212.9 kg/ha) which, in turn, was significantly higher than Dale (175.4 kg/ha). Most of the K was accumulated in the stalk portion of these varieties (81-82 percent). Cultivars at a spacing of 75 cm accumulated significantly more K than those grown at either 50 cm or 100 cm. Total biomass production tended to follow a similar trend, although significance was not detected between the 50 cm and 75 cm spacing for biomass.

Fargo, North Dakota. Total N removed/ha for sweet sorghum and corn as influenced by row spacing is shown in Figure 16. HS-50 removed more total N than the sweet sorghum primarily due to the large amount of N in the ear component. Total N in the stalks of HS-50 was less than the sweet sorghum. Total N in the leaves of Wray was substantially higher than MER 63-7 and HS-50. Percent N was highest in the immature stems and leaves of Wray, percent N was similar in stems and leaves of MER 63-7 sweet sorghum and HS-50. Row spacing did not significantly affect the amount of total stalk, leaf, ear, or top N removed/ha. Narrow row spacing decreased the stalk and top N percentage, however.

Phosphorus removal from the soil was affected primarily by cultivar (Figure 17). Hs-50 removed 43 percent more P than the sweet sorghum primarily as a result of the substantial P in the ear component. MER 63-7 contained less total and percent P in the stalks than HS-50 or Wray. HS-50 had less total and percent P in the leaves than the sweet sorghum. MER 63-7 contained less leaf P than Wray. Row spacing had little effect on the total or percent P of sweet sorghum or corn. Percent stalk P increased slightly with wider row spacing, however.

Potassium removal from the soil was affected by cultivar and row spacing (Figure 18). Wray removed about 40 percent more K from the soil than MER 63-7 or HS-50. Both total and percent leaf and stalk K were highest in Wray. Total and percent leaf K were higher in HS-50 than MER 63-7.

but total and percent stalk K were higher in MER 63-7 than HS-50. Total K removed increased with narrower row spacing, but stalk, leaf, ear, or top K was unaffected by the row spacing. Percent K in all plant parts was unaffected by the row spacing.

Weslaco, Texas. The percent of N, P, and K in sweet sorghum are shown in Figures 16-18. The nitrogen concentration is greater in leaves and tops while the potassium level is generally higher in the stalks. The concentration of phosphorus is greater in the tops followed by the leaves and stalks. There was no significant effect on concentration of N, P, or K due to row spacing. The concentration in tops varied due to different quantities of seed produced.

The removal of N, P, and K reflected the biomass removed by the sweet sorghum cultivars. A greater level of N, P, and K was removed at the narrow row spacing, and the cultivar MN 1500 removed the greatest amount of N, P, and K.

Summary

Manhattan, Kansas. Plants were harvested at boot, anthesis, and maturity. Field data were collected for stalk number, stalk diameter, stalk height, and biomass. Laboratory analyses were conducted for sugar content (glucose, fructose, and sucrose) fiber content, and uptake of N, P, and K.

At the boot stage of growth, very few differences among row spacings or among cultivars were significant. Stalk diameter in the 100 cm rows was larger than in 50 or 75 cm rows and Rio produced more leaf dry biomass than did Wray or Dale. The few significant differences may have resulted in part from the uneveness in growth up to this time.

At anthesis, there again were only a few important differences among cultivars or among row spacings. Plants grew taller and had smaller stalk diameters in narrower rows. Total stalk biomass yields were generally greatest in the 75 cm spacing. Dale was lowest in biomass yield and in sugar production. Stalk yield and total sugar yield did not differ among row spacings.

The maturity stage is optimum for harvesting sweet sorghum because biomass and sugar yields increased greatly compared to anthesis harvest. Plants in the 100 cm row spacing were shorter, had larger diamter, and yielded less total biomass, total sugar, and total fiber. The intermediate row spacing was usually better than or not significantly different from the 50 cm spacing.

Wray produced fewer and larger stalks and the greatest sugar yield. Rio tillered more, had smaller stalks and a higher top (grain) yield. Based upon these data, Wray would be the preferred cultivar for Kansas and there appears to be no advantage to row spacings narrower than 75 cm. Assuming 582 liters of ethanol per metric ton of sugar, Wray in 75 cm spacing produced a potential of 2604 l/ha (307 gal/acre). While this value probably cannot be attained every year under dryland conditions in Kansas, it probably is also not the maximum possible. The mean sugar yield for all spacings and cultivars was equivalent to 1930 l/ha (206 gal/acre). Assuming 0.36 l of ethanol per kg of grain sorghum, these sugar yields are equivalent to 7.9 and 5.7 t/ha (122 and 91 bu/acre), respectively. It thus seems quite probable that more alcohol can be derived from sweet sorghum than from grain sorghum in Kansas.

Baton Rouge, Louisiana. The biomass produced at each stage of maturity was generally lowest with Wray, intermediate with MER 71-1 and highest with MN 1500. Yields progressively increased from the boot stage to maturity.

The optimum plant population of each variety was in the range of the population rested. Plant population did not change during the growing season. Plant height increased from the boot stage to maturity. The plant height was lowest with Wray, intermediate with MER 71-1 and highest with MN 1500.

The total fermentable sugar yields at anthesis were highest with MN 1500 and lowest with MER 71-1. The sugar yields at maturity with Wray were similar to MER 71-1 and lower than with MN 1500.

The biomass and sugar yields of each cultivar at each stage of maturity generally increased with each successive increased in the number of drills and plant populations. However, since the stalk diameter decreased with increasing plant populations, the relationship between yield and plant population was not linear. Also, the smaller diameter of stalks increased lodging and could be a problem with mechanical harvesters. The preliminary results indicated that the optimum planting method in the Louisiana sugarcane area is two drills on six-foot rows with a plant population of approximately 100 thousands plants per hectare. This method could produce satisfactory yields that can be harvested with sugarcane harvesters.

The amounts of nutrient uptake were closely related to the total biomass. The differences among cultivars in N, P, K uptake per ton of total biomass were small. As an average of cultivars, the N, P, and K uptakes were 1.79, 0.23, and 1.29 kg/t of total wet biomass, respectively.

Lincoln, Nebraska. Sweet sorghum producton in Nebraska during 1979 compared quite favorably with production reported in more southern areas (Lipinsky et al., 1979). Total dry biomass was usually around 15-18 mt/ha at maturity. Of this the stalks generally made up 77 percent of the weight. Of the three tested, Rio was the eariliest maturing and Wray the latest. The lower yield by Wray probably was due to a stand problem and less tillering capability to overcome this effect. The apparent high yields in Nebraska of the cultivars could not be explained by unusual variations in the environmental conditions of moisture and temperature. Precipitation, however, was usually timely and enough heat units apparently accumulated to allow them to reach maturity. The year appeared to be good in Nebraska for excellent forage production in general.

The higher biomass at the narrower row spacings was not surprising, and has been reported before (Lipinsky et al., 1979). This may have been due to the increase in plant population as a result of planting in narrow rows. The narrow row effect of better light-canopy interactions and higher yields have been reported for other crops, but these experiments were not designed to clarify these effects in sweet sorghum since confounding with population was a factor. The problem of getting Wray established was evident in the final harvest where it was lower in number of live shoots. Even though Wray was not as tall as the other two cultivars, this difference was probably not a factor in its lower yield.

The pattern of total sugar production in stalks at anthesis and maturity corresponded to the biomass production at these growth stages. This would generally indicate that percentages were not different among cultivars on row spacings, but that stalk yield influenced the patterns observed to a large extent. However, Dale was markedly different from the other two in the ratios of glucose to fructose to sucrose in the stalks. For Dale, sucrose generally made up 34 percent of the total whereas for Wray and Rio, it was 85 percent at maturity. Dale has much higher glucose and fructose levels than Wray or Rio resulting in a total sugar production which was very similar for all three. The yields of around 5.5 mg/ha compared very favorably with yields reported elsewhere (Lipinsky et al., 1979). The different component sugar makeup among the cultivars indicated that a different biochemistry is at work which is not well understood at this time. Dale has been developed as a syrup variety as is evident by its high fructose/glucose content.

Total N uptake ranged from 84-118 kg/ha indicating significant amoungs would be removed in sweet sorghum production. Although Wray produced less total biomass than the others, it took up significantly more N. This was due to its high concentration in the stalk tissue primarily, although the leaf tissue of Wray had high concentrations also. These observations are significant in that they show a different efficiency for N among sweet sorghums in producing essentially the same growth. Nitrogen is the element most often used to sustain crop production and its cost is an important economic consideration.

Phosphorus, on the other hand, was not accumulated to the extent of N. Generally only 10 kg/ha was removed by the crop which indicated that P may not be as important a consideration for sweet sorghum as some other crops. Apparently, P is accumulated in the stalks early and translocated to the grain with maturity. This is supported by the fact that Dale and Rio, the earlier cultivars, had 50 percent or more of the accumulated P as the tops (grain), while the later maturing Wray with immature grain, retained a majority of the element in the stalks.

Sweet sorghum accumulated very high amounts of K in tissue. This may have been due to the high amounts of available K in the soils where the experiment was conducted. On the other hand, K is known to be essential in sugar biosynthesis, and these high sugar sorghums may have a need for large amounts of the element. Most of the K was accumulated in the stalk tissue. Varietal differences were also apparent in K uptake with Rio having substantially more K present than the other two varieties. This was due mostly to its higher stalk concentration rather than its biomass.

Trends for ADF and NDF tended to be similar. Greater amounts of NDF, however, were present than ADF since the NDF procedure removes hemicelluloses in addition to the constituents found with ADF (cellulose, lignin, lignocelluloses). Generally, about 25-30percent of the stalk tissue was ADF. Apparently about 15-20 percent additional material was in hemicellulose form. Row spacing had no effect on fiber content even though more live shoots of small diameter were harvested in the 50 cm spacing. Narrows rows and/or high populations often lead to a higher percentage of rind material in forage production. However, it could not be detected in this experiment.

Total nonstructural carbohydrates ranged from 33-40 percent in the stalk tissue. There appeared to be little difference among varieties or row spacings for this trait.

It can be generally concluded that, based on the 1979 data, sweet sorghum production in Nebraska was a marked potential. The crop appeared to yield comparable biomass, stalk sugar, and fiber in comparison to more temperate regions of the country where the crop might be better adapted. One of the most critical limitations to crop production appeared to be seed germination and good seedling vigor. Hybridization would alleviate some of this uncertainty. Also, little is known about the physiology of the crop in general. Interaction of water and minerals with yield with sugar production are some of the questions that should be investigated in order for proper management decisions to be made.

Fargo, North Dakota. Biomass production increased with an increase in maturity for all the cultivars. Biomass production was influenced by the late planting, slow erratic emergence due to drought, standing water, N deficiency, lodging from a severe thunderstorm in July, moderate aphid infestation, a dry August, a warm September, and frost about 10 days later than normal. The exact effect of each factor is unclear, but Schou (1970) found a 2-year average biomass of HS-50 corn in 50.8 and 101.6-cm row spacings at Fargo, ND to be 11.9 and 14.7 t/ha, respectively. Schou also reported maximum biomass of Rio in 50.8 and 101.6-cm row spacings at 11.4 and 13.4 t/ha, respectively, in 1968. These data are very similar to the sweet sorghum and male-sterile corn biomass given in this report; therefore, these data represent near average biomass yields obtainable under Fargo conditions with commercially available sweet sorghum cultivars or HS-50 male-sterile corn. Earlier maturing sweet sorghum or other male-sterile corn cultivars may increase the yield. For example, Schou (1970) found the yield of Northland male-sterile corn in 101.8-cm row spacings to yield superior to HS-50.

Maximum biomass was produced by HS-50 averaging 1.4 to 1.9 t/ha higher than the sweet sorghum. Ears contributed a significant component of HS-50's biomass even though the corn is male sterile. Pollination from surrounding corn fields resulted in approximately 50 percent seed set at all row spacings.

Biomass production of sweet sorghum at Fargo was considerably less than the yields reported at Belle Glade, Florida; Baton Rouge, Louisiana; Weslaco, Texas; Meridian, Mississippi; and Columbus, Ohio, in 1978 (Lipinsky et al., 1979). Low biomass from a warm-season crop like sweet sorghum would be anticipated in a northern location with a very short growing season.

Stalk yield was the highest for sweet sorghum. For HS-50, the translocation of dry matter to the ear accounted partially for its lower stalk yield. Schou reported similar yields among male-sterile corn and sweet sorghum when pollination was prevented by covering the ears (1970).

Total, stalk, and leaf biomass decreased from 13 to 20 percent with increasing row spacing. Whether the decreased yield is a row spacing, plant density, or row spacing by plant density interaction is unclear since plant density and row spacing were confounded. However, the results may represent a true row spacing effect since Schou (1970) found a similar row spacing effect when the plant density was held constant.

Maximum live shoots/ha (190,000) was produced by Wray in 50-cm row spacings at Fargo in 1979. The number of live shoots/ha produced at Fargo was higher than that produced in 1978 at Baton Rouge, Louisiana; Weslaco, Texas; or Columbus, Ohio, but is considerably less than that produced at Belle Glade, Florida, (Lipinsky et al., 1979).

Total plant N and stalk N removed by Wray sweet sorghum were 127 and 51 kg/ha, respectively, and were not affected by the row spacing. Lipinsky et al. (1979) found Wray to contain up to 220 kg N/ha in 50-cm row spacings but was significantly less at 102-cm row spacings. The added N requirement in Ohio was approximately proportional to the increased dry biomass. However, stalk N accounted for only 25 percent of the total N in Ohio, but 40 percent of the total N in North Dakota. The difference in N utilization by location may be associated with immaturity of Wray at Fargo.

The sweet sorghums removed less than 17 kg/ha total and 7 kg/ha stalk P, significantly less than HS-50 male-sterile corn. P utilization by sweet sorghum is minimal, especially if only the stalks are used as found by Lipinsky et al. (1979). Phosphorus fertilization should not be necessary on soils natively high in P, like Fargo clays.

Potassium uptake by Wray sweet sorghum averaged 246 kg/ha, substantially higher than MER 63-7 sweet sorghum and HS-50 corn. Lipinsky et al. (1979) also found significant genotypic differences in K removal in Ohio. Likewise they reported a significant increase in K utilization at narrow row spacings approximately proportional to increased dry matter yields.

Sweet sorghum averaged 18.8 percent stalk fiber as a percentage of the total dry biomass. The percent of total yield as fiber and total fiber yields were substantially lower than those reported at Belle Glade, Florida; Baton Rouge, Louisiana; or Weslaco, Texas in 1978 (Lipinsky et al., 1979).

Weslaco, Texas. The narrow row spacings maintained their initial population because the greater initial population inhibited tillering. The 100 cm row spacing provides far more area per plant, which encourages tillering. This caused an increase in population at the wider row spacing. The tillering produced plants at different ages and resulted in a delay in average maturity of the total plant population. Plants in the narrow rows matured faster than plants in the wide rows.

Plant height usually increased with narrow row planting early in the season, but plants grown in the wide rows were usually taller at the final harvest.

The close row spacing caused a slight decrease in stalk diameter, due in part to reduced leaf exposure to light and increased root competition. Wider spacing gave plants more area to expand to their maximum diameter. Some cultivars such as MN 1500 naturally produced larger stalks so their decrease in diameter would be less than others.

The moisture content MN 1500 was less than the other two cultivars and, therefore, it produces a higher percent of dry matter from fresh weight. The leaves tended to dry up at the lower part of the stalk, reducing the moisture percent. Wray and MER 71-1 demonstrated a greater response to row spacing. MN 1500 was later in maturity, which gave plants in the wider rows more time to make up the difference in tonnage. A greater response should be found in early maturation. This would help explain the greater increase in yield due to row spacing from Wray over the late maturing MN 1500.

Row spacing had very little effect on the concentration of sugars in specific cultivars. These was a greater effect due to cultivars themselves. Wray was higher in percent sucrose and lower in percent fructose and glucose. This cultivar has been bred for high sucrose production.

The yield of sugars depends on the difference in biomass since row spacing had no effect on percent sugars. Row spacing had a greater effect on yield of sugars in the early cultivars Wray and MER 71-1 than with the late cultivar MN 1500. This corresponds to the dry weight figures.

There is an increase in sucrose between boot and maturity. The total sugar content also increases from 50 percent flower stage to maturity.

Row spacing had a slight effect on percent N, P and K content. The biomass changes due to row spacing showed the greatest difference. The removal of N, P and K coincide with dry biomass. The N content is usually higher in the stalks. Phosphorus is approximately the same in all three fractions.

Sweet Sorghum Studies at Columbus, Ohio

Experiments to determine the optimum arrangement and population of sweet sorghum have been conducted over a number of locations in the Unites States during the past forty years (Lyons, 1956 and 1957; Broadhead et al., 1963; and Broadhead and Freeman, 1964). Over the past three years similar studies have been conducted by Battelle's Columbus Laboratories at West Jefferson, Ohio (Lipinsky et al., 1978 and 1979). Although many of the cultivars and cultural practices had been evaluated previously in southern localities, the 1979 studies were unique, based on the following points: (1) Previous studies were conducted to improve the potential of sweet sorghum as a source of sugar (sucrose) or syrup (fructose, glucose and sucrose). The desired sugar/syrup producing plant has a thick upright stalk with a minimum of leafy material and small seed head to minimize lodging. The stalk needs to contain either a high concentration of sucrose for crystalline sugar production, or a high level of total sugars (primarily glucose, fructose, and sucrose) for high quality syrup production. In either situation, low starch content is a preferred characteristic. The overall objective of this study has been to optimize the production of sweet sorghum for ethanol production. The plant characteristics desired for alcohol production are high contents of total fermentable solids (glucose, fructose, sucrose, and starch) along with high biomass production. (2) Sweet sorghum research was based and optimized for production in the southern United States (the Appalachian and Coastal Plant regions and the Texas Rio Grande Valley). Experimental studies at Battelle were designed to integrate sweet sorghum production for energy into conventional food and feed cropping systems in the Midwest.

Field studies at Battelle-Columbus Divisions' Bio Environmental Laboratory included three separate experiments: (1) cultivar selection studies, (2) plant configuration studies, and (3) nitrogen fertility studies. These experiments were designed with the following objectives in mind:

- Identify sweet sorghum cultivars for producing maximum biomass and sugar yields in the Midwest.
- Identify appropriate cultural practices for cultivating sweet sorghum in the corn-belt region.
- Determine the response of sweet sorghum to fertilizer nitrogen in the Midwest.

As is well documented in many agronomic production studies, the weather during the growing season greatly affects crop growth and in most instances is the factor which limits final yield. In 1979, weather adversely affected crop growth, particularly the percent sugars in the stalk and the stalk yield per unit land area. The factors which were most predominant were:

Tropical storm Frederick, responsible for 15 cm of rainfall and winds above 80 km/h during a three-day period, caused a tremendous amount of lodging in early September. Effectively, lodging decreased the light absorption surface, in turn limiting the plants' ability to assimilate carbon dioxide from the air. Further more, plant surfaces which once served as areas of carbon assimilation had become inactive to the point where they no longer assimilated carbon but instead required translocated photosynthate for maintenance. In other words, these once productive plant parts were transformed from "sources" to "sinks" of photosynthate.

(2) The number of heating degree days was approximately 5 percent lower in 1979 than 1978. This quantity may appear insignificant; however, sweet sorghum exhibits limited cold tolerance and the difference in heating degree days may more adversely affect it than a crop with the cold tolerance of corn.

(3) The rainfall during the growing season (April 1 - October 1) was approximately 25 cm above average in 1979. This excessive moisture

caused significant amounts of soil nitrogen loss through leaching, thereby possibly affecting biomass proeuction. Also, excess soil moisture may have inhibited stalk sugar accumulation.

In addition, the use of atrazine as a pre-emergence herbicide may adversely affect certain sweet sorghum cultivars (Freeman, personal communication). Certain cultivars encountered poor emergence and stand development and may have been susceptible to atrazine. Also the 1978 and 1979 studies were conducted on Brookston clay and Crosby silt loam soils; with the excessive rainfall. these heavy soils drained poorly. Sweet sorghum seedlings have problems with excessive wetness; therefore the poorly drained soils may too have adversely affected crop growth.

In general, the 1979 growing season was less conducive to good growth and maturity of sweet sorghum than the 1978 growing season. Thus, the 1979 crop yields are probably representative of a less than average growing season.

Cultivar Selection Studies

Plant Population. The cultivar selection experiments included three cultivars available commercially and five as yet unreleased. Commercially available cultivars (Dale, Wray, and Sugar Drip) generally performed better than the unreleased cultivars, with some notable exceptions. Much of the difference in cultivar performance is attributable to the number of live shoots produced per unit of area (Figure 19). The percent of the actual plant population relative to the expected* value of 180,000 plants/ha shown in Table 5. The expected population was not attained by any of the eight cultivars. The mean population for the five cultivars, which were not significantly different from one another, was 131,000 plants/ha; i.e., 73 percent of the expected population. *In vitro* germination tests

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* The expected plant population is the seeded rate corrected for the *in vitro* germination percentage.

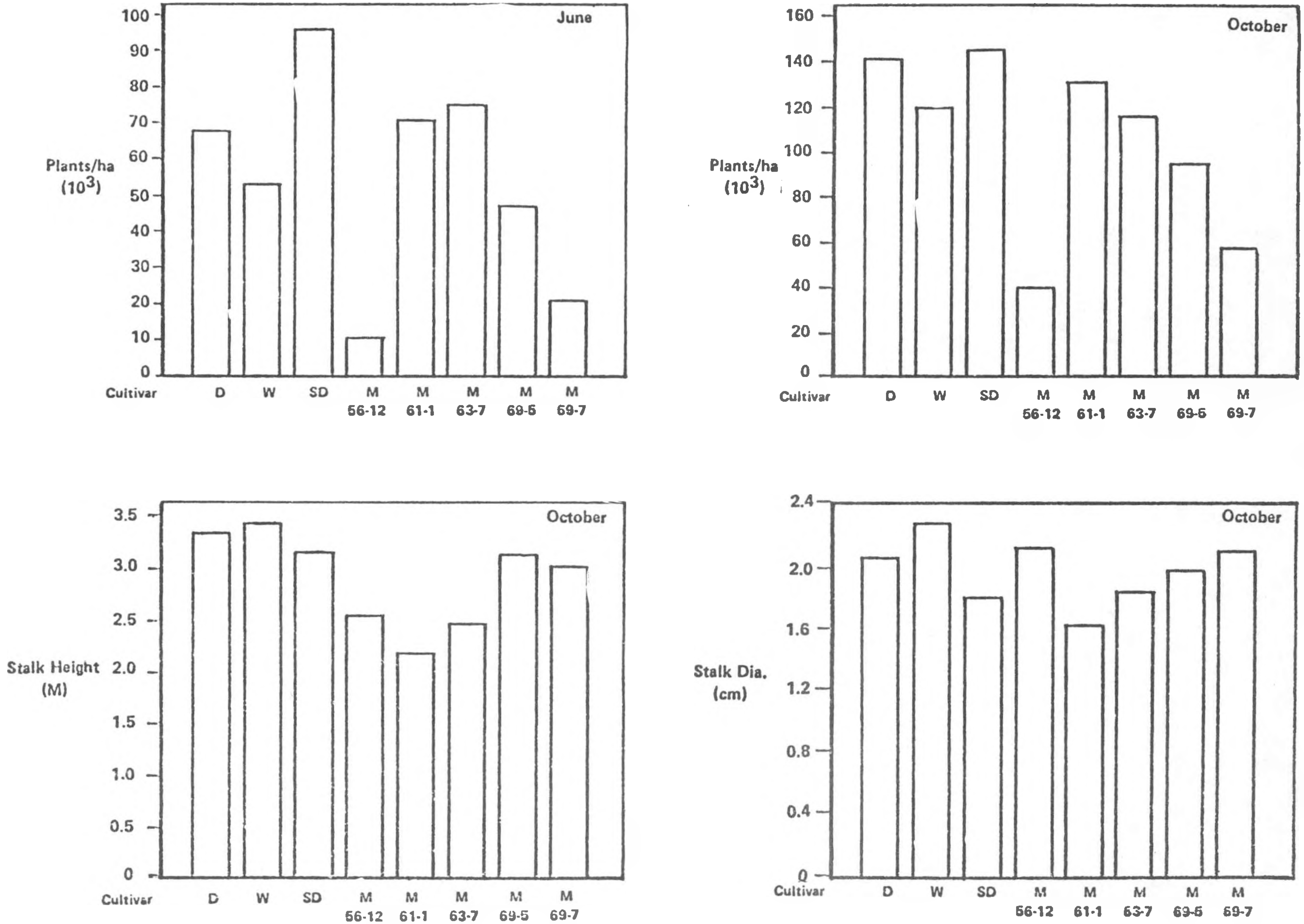


FIGURE 19. PLANT POPULATION (JUNE AND OCTOBER), STALK HEIGHT, AND STALK DIAMETER (OCTOBER) FOR DALE, WRAY, SUGAR DRIP, MER 56-12, MER 61-1, MER 63-7, MER 69-5, AND MER 69-7 CULTIVARS OF SWEET SORGHUM

showed 80-95 percent germination for all cultivars. In each case the in vitro germination rate was compensated for by over-seeding, eliminating this factor in the results.

TABLE 5 . PERCENT OF EXPECTED PLANT POPULATION FOR EIGHT CULTIVARS OF SWEET SORGHUM

Cultivar	% Expected
Sugar Drip	81
Dale	79
MER 61-1	73
Wray	67
MER 63-7	65
MER 69-5	53
MER 69-7	32
MER 56-12	22

Biomass. Biomass production ranged from 6.6 to 17.8 t/ha among the eight cultivars, with the commercial cultivars, Dale, Wray, and Sugar Drip, outyielding the five unreleased MER lines. MER 61-1 was the most productive MER line with a dry biomass of 14 t/ha.

Figure 20 illustrates the stalk portion of the sweet sorghum as pith and rind components. Rind and pith biomass expressed as a percent of the total is presented in Table 6 . Whole stalks as a proportion of total biomass are presented in Table 7 . Dale and Wray produced significantly more stalk biomass per hectare than any other cultivar. MER 69-5 and MER 61-1, the two cultivars which produced the most grain, had the lowest percentage of total biomass in the stalks. A similar result was observed in the case of percent biomass in leaves (Table 7). Wray and Dale produced a significantly greater quantity of leaf biomass than the other cultivars, yet the percentage of the total weight made up by the leaves is similar in most cultivars. Only MER 61-1 and MER 63-7 (the high grain producers) had reduced amounts of leaf biomass.

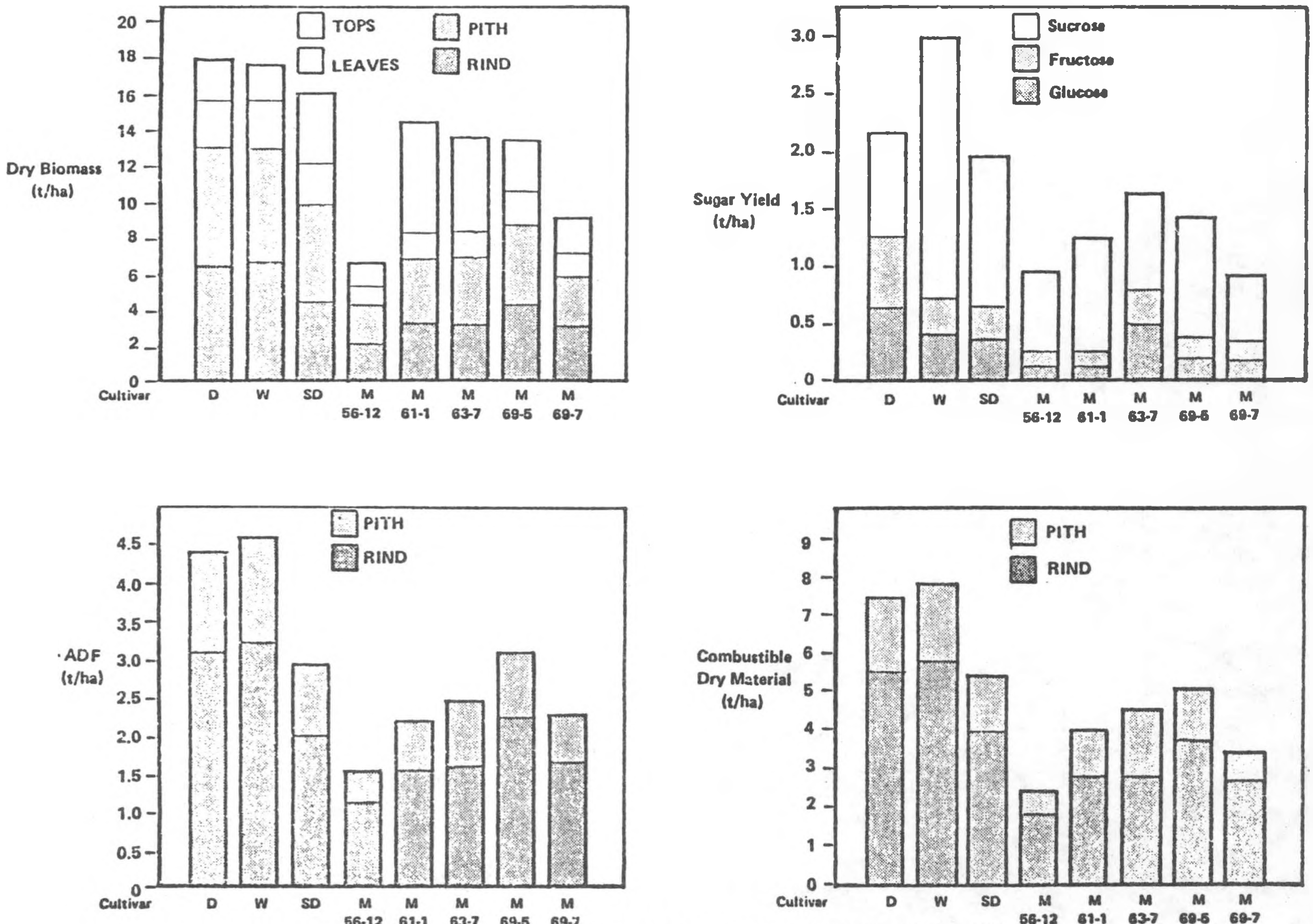


FIGURE 20. DRY BIOMASS, SUGARS, ACID DETERGENT FIBER, AND COMBUSTIBLE DRY MATERIAL IN ABOVE-GROUND BIOMASS (OCTOBER) OF DALE, WRAY, SUGAR DRIP, MER 56-12, MER 61-1, MER 63-7, MER 69-5, AND MER 69-7 CULTIVARS OF SWEET SORGHUM

TABLE 6. PERCENT OF TOTAL PLANT DRY WEIGHT COMPRISED BY RIND AND PITH, IN EIGHT CULTIVARS OF SWEET SORGHUM

Cultivar	Rind	Pith
	%	
Wray	38	36
Dale	36	37
Sugar Drip	28	34
MER 69-5	32	33
MER 61-1	22	25
MER 63-7	24	28
MER 69-7	34	30
MER 56-12	32	32

TABLE 7. DRY WEIGHT PERCENTAGE OF STALKS, LEAVES, AND TOPS OF EIGHT CULTIVARS OF SWEET SORGHUM

Cultivar	Stalks	Leaves	Tops
		%	
Dale	73	15	12
Wray	74	15	11
Sugar Drip	62	14	24
MER 69-5	65	14	21
MER 63-7	61	10	29
MER 61-1	48	10	42
MER 69-7	64	15	21
MER 56-12	64	16	20

Figure 20 illustrates the biomass production of the segregated plant parts from each cultivar. MER 61-1 and MER 63-7 produced significantly more grain than any of the other cultivars (Table 8). Approximately 4.5-5.5 percent of the dry weight of MER 61-1 and MER 63-7 is contained in the grain portion, while Wray and Dale contained 0.7 percent of their dry weight in the form of grain. The mean dry weight as grain for the eight cultivars was 3.2 percent of the total plant biomass, while about 24 percent of the plant weight was in the entire top portion. This implies that approximately 87 percent of the top portions was cellulosic materials, referred to as threshed tops.

TABLE 8. DRY GRAIN YIELD AND PERCENT OF TOTAL BIOMASS FOR SWEET SORGHUM CULTIVARS

Cultivar	Grain Yield t/ha	Percent Grain
MER 63-7	0.75	5.5
MER 61-1	0.65	4.5
Sugar Drip	0.45	2.8
MER 69-7	0.42	4.6
MER 69-5	0.42	3.1
MER 56-12	0.27	4.0
Wray	0.13	0.7
Dale	0.11	0.6

The cultivars which produced the most grain (MER 63-7 and MER 61-1) produced less stalk biomass than did the other cultivars. Wray and Dale, which produced the least grain, produced significantly higher yields of both rind and pith. In general, yields of plant parts were proportional to total yield on a per unit basis.

These various results indicate that a "typical" sweet sorghum plant in Ohio partitions its dry weight approximately as follows:

Plant Component	% of Total Dry Weight
Grain	3
Threshed Tops	20
Stalk { Pith	32
Stalk { Rind	31
Leaves	14

A significant block effect was observed because field plots were established on both Brookston and Crosby soil types. One block, entirely on Brookston soil, produced a significantly greater mean yield of 17.4 t/ha than cultivars in the other three blocks having a mean yield of 12.2 t/ha.

Sugar Yield. In this study, eight cultivars were selected on the basis of (1) having relatively good yield responses in other locations and (2) having the ability to mature within the Midwestern growing season. Table 9 illustrates the differences in percent glucose, fructose, and sucrose. Results indicate that a wide diversity of characteristics exist within this selection of eight genotypes. Among the eight cultivars, significant differences ($P \leq 0.05$) in the makeup of the total sugar were noted (Table 9). However, there was no difference in the percent total sugars among cultivars. The data concerning percent glucose and fructose should be contrasted with those of percent sucrose among the cultivars. As shown in Table 9 , in general, there was an inverse relationship between percent simple sugars and percent sucrose in the selected material. In most cultivars, sucrose in the stalk was found in greater concentrations than the combination of the simple sugars (glucose and fructose).

TABLE 9 . PERCENT GLUCOSE, FRUCTOSE, SUCROSE, AND TOTAL SUGARS OF THE STALK OF EIGHT CULTIVARS OF SWEET SORGHUM

Cultivar	Glucose	Fructose	Sucrose	Total Sugars
		Mean Percent[(a)]		
Dale	1.18 ab	1.13 a	1.68 d	3.99
Wray	0.71 c	0.56 bc	4.03 ab	5.30

TABLE 9. (Continued)

Cultivar	Glucose	Fructose	Sucrose	Total Sugars
Sugar Drip	0.84 bc	0.63 bc	3.10 abcd	4.57
MER 63-7	1.51 a	0.91 ab	2.59 bcd	5.01
MER 69-7	0.79 bc	0.65 bc	2.48 cd	3.92
MER 61-1	0.49 c	0.44 c	3.88 abc	4.82
MER 69-5	0.63 c	0.55 bc	3.04 abcd	4.22
MER 56-12	0.68 c	0.62 bc	4.26 a	5.56

(a) The letters following the means refer to the results of the Duncan's Mean Separation Test (if the analyses of variance demonstrated that the means were significantly different at the 95 percent level). To compare any specific part of means, the two means can be considered significantly different from one another if they are not followed by any common letter. Conversely, they are considered "similar" (not significantly different) if they share at least one common letter.

Because the sugar yields are a function of both the percent sugars in the stalks and the yield of stalks per hectare, the total sugar yields are similar to those of the dry weight of stalks because there was no significant difference in the percent total sugars (Figure 20). Dale yielded significantly more glucose and fructose per hectare than any other cultivar. The highest yield of total sucrose per hectare was obtained with the cultivar Wray.

As expected, the highest sugar yields were obtained from the commercially released cultivars (Wray, Dale, and Sugar Drip). These three cultivars yielded 2.98, 2.15, and 1.95 t/ha of fermentable sugars, respectively. Of the non-released lines MER 63-7 yielded most favorably. Due to the poor stand development cultivars MER 69-7 and MER 56-12 performed quite poorly.

Acid Detergent Fiber Yield. In the past, one of the criteria for breeding sweet sorghum was to develop germplasm with a lower percent stalk fiber. This, in turn, facilitated conventional milling operations. However, with the development of the Tilby Cane Separator, increased fiber becomes an asset rather than a problem. The fiber component of the stalk is a valuable product which may be used in a number of economic ways, i.e. in the production of building materials, as a feedstock for a cellulose to ethanol facility, or as a boiler feed in a process facility.

In the 1979 cultivar selection trial, the percent acid detergent fiber of both the pith and rind was determined. There was no difference in the percent fiber of the stalk pith among any of the cultivars (values ranged from 17-24 percent). However there was a difference ($P \leq 0.05$) noted in percent rind fiber among the cultivars (Table 10).

TABLE 10. PERCENT ACID DETERGENT FIBER OF THE STALK RIND OF SELECTED SWEET SORGHUMS[(a)]

Cultivar	% Fiber of the Stalk Rind
MER 56-12	52.7 a
MER 69-7	51.9 ab
MER 69-5	51.3 ab
MER 63-7	49.3 bc
Wray	48.6 bc
Dale	48.6 bc
MER 61-1	47.4 cd
Sugar Drip	44.7 d

(a) See footnote for Table 9.

The unreleased cultivars were highest in percent fiber of the stalk rind. This is not surprising in that one of the criteria for releasing a new cultivar of sweet sorghum is low stalk fiber.

The total ADF yield was a function of both the total fiber percentage of the stalk and the dry stalk per hectare. Because of the large differences in stalk yield among cultivars, there were highly significant ($P \leq 0.001$) differences in fiber yield among the eight cultivars (Table 11).

TABLE 11. YIELD OF RIND, PITH, AND TOTAL FIBER AMONG EIGHT CULTIVARS OF SWEET SORGHUM[(a)]

Cultivar	Rind Fiber	Pith Fiber	Total Stalk Fiber
		t/ha	
Wray	3.21 a	1.37 a	4.58 a
Dale	3.08 a	1.32 a	4.40 a
MER 69-5	2.20 b	0.83 b	3.03 b
Sugar Drip	1.99 bc	0.93 b	2.92 b
MER 63-7	1.55 cd	0.86 b	2.41 b
MER 69-7	1.60 cd	0.62 bc	2.22 bc
MER 61-1	1.52 cd	0.64 bc	2.16 bc
MER 56-12	1.11 d	0.42 c	1.53 c

(a) See footnote for Table 9 .

The commercially released cultivars, Dale and Wray, yielded much more fiber than the other lines.

Combustible Biomass. In 1979, the percent combustible dry materials within the stalk was determined among cultivars in the selection trials. The stalk was partitioned into the rind and pith prior to analyses. Results indicated no difference in the percent combustible dry matter of the pith (values among cultivars ranged from 30-49 percent). However, differences in percent combustible dry matter of the rind

($P \leq 0.05$) were recorded among the cultivars (Table 12). There were no major differences between released and unreleased lines.

Because of the higher total yields of biomass, the released cultivars Dale, Wray, and Sugar Drip, also produced the highest amoung of combustible dry matter per hectare (Figure 20). The highest yielding released cultivar was Wray at 7.78 t/ha while MER 69-5 was the leading non-released line with a yield of 5.02 t/ha.

TABLE 12 . PERCENT COMBUSTIBLE DRY MATTER OF THE RIND AMONG EIGHT CULTIVARS OF SWEET SORGHUM[a]

Cultivar	% Combustible Dry Matter
Sugar Drip	87.20 a
MER 69-5	87.19 a
MER 69-7	87.07 a
Dale	86.84 ab
MER 56-12	86.78 abc
Wray	86.54 bcd
MER 63-7	86.44 cd
MER 61-1	86.00 d

(a) See footnote for Table 9 .

Summary. The results of the cultivar selection study indicate that the commercially-released cultivars, Dale, Wray, and Sugar Drip outperformed the five unreleased MER cultivars. Of the released lines Dale yielded the highest of 17.8 tons of dry biomass per hectare. MER 61-1 was the leading producer of the MER lines at 14 t/ha. Because of poor stand development the yields of MER 69-7 and MER 56-12 were only 9.1 and 6.6 t/ha, respectively.

Similarly, the highest dry stalk yield was recorded by Dale and Wray with 12.9 t/ha and the lowest being MER 56-12, which yielded only 4.2 t/ha.

As stated previously, adverse weather delayed maturity of all cultivars. This, in turn, had a direct impact on grain production. Grain yield was highest with MER 63-7 at 0.75 t/ha and, Dale yielded the lowest at 0.11 t/ha. Overall, grain yields were lower than normally expected at other sites.

Based on sugar content, the cultivar selection trial produced results similar to the row spacing/plant population study. No difference in percent total sugars of the stalk was recorded among the cultivars; however sugar compositions did vary. Therefore, the yield of total sugar per hectare was a function of the stalk yield of the tested cultivars. The commercial cultivars, Wray, Dale and Sugar Drip, were the highest producers with total sugar yields of 2.98, 2.15, and 1.95 t/ha, respectively. Leading candidates of the non-released lines included MER 69-5 and MER 63-7. The lowest yielding cultivars, MER 69-7 and MER 56-12, had poor stand development (possibly due to a susceptibility to atrazine herbicide) and never achieved the plant population level of the other cultivars.

The cultivar selection study demonstrates the need for developing new germplasm for the midwestern environment. This is highlighted by the fact that the percent total sugars in the tested cultivars ranged from 4-6 in Ohio, while these same lines average 10-15 percent total sugars at Meridian, Mississippi. In the Midwest, since sweet sorghum biomass production is comparable to other locations in the country, the future key will be to develop lines which "ripen" (accumulate stalk sugars) as well as in the southern locations of the United States.

Plant Configuration Studies

Plant Population. Three cultivars were grown in four spatial configurations: (1) 76 cm interrow, 15 cm intrarow; (2) 46 cm interrow, 15 cm intrarow; (3) 46 cm interrow, 7.5 intrarow; and (4) 15 cm interrow and 15 intrarow, 92 cm between groups of 4 rows. Three significant effects on plant population resulted from spacing, cultivar, and spacing by cultivar interaction (Figure 21).

Sugar Drip produced the highest plant population with an overall mean population of 203,000 plants per hectare. Dale and Wray were not significantly different from one another, with an overall mean of 131,000 plants per hectare.

The highest overall plant population was produced in 46 cm interrow, 7.5 cm intrarow spacings. For all cultivars at this spacing, the overall population mean was 215,000 plants per hectare. Other spacings were not significantly different from each other, with an overall mean of 136,000 plants per hectare. Sugar Drip at the 46 cm interrow, 7.5 cm intrarow spacing produced significantly more plants per hectare than any other cultivar at any spacing (Figure 21). The expected plant population at this spacing was 360,000 plants/ha. Thus, Sugar Drip produced 85 percent of the expected population, while Dale and Wray at this spacing produced only 53 percent and 41 percent, respectively. Sugar Drip at the very narrow spacings and Dale at the 46 cm interrow, 7.5 cm intrarow, produced a mean population of 196,500 plants/ha, significantly greater than all but Sugar Drip at the 46 cm interrow, 7.5 intrarow spacing.

Results of the plant spatial configuration studies indicate that as plants are spaced closer together their capacity for tillering is apparently reduced (Table 13).

At the widest spacing, the mean population for all cultivars (120,000 plants/ha) was 133 percent of the expected plant population of 90,000 plants/ha. In fact, the greatest tillering was observed with Sugar Drip at the widest spacing, where the population was 176 percent of the expected population. Dale and Wray at the widest spacing produced 119 percent and 104 percent of the expected population, respectively.

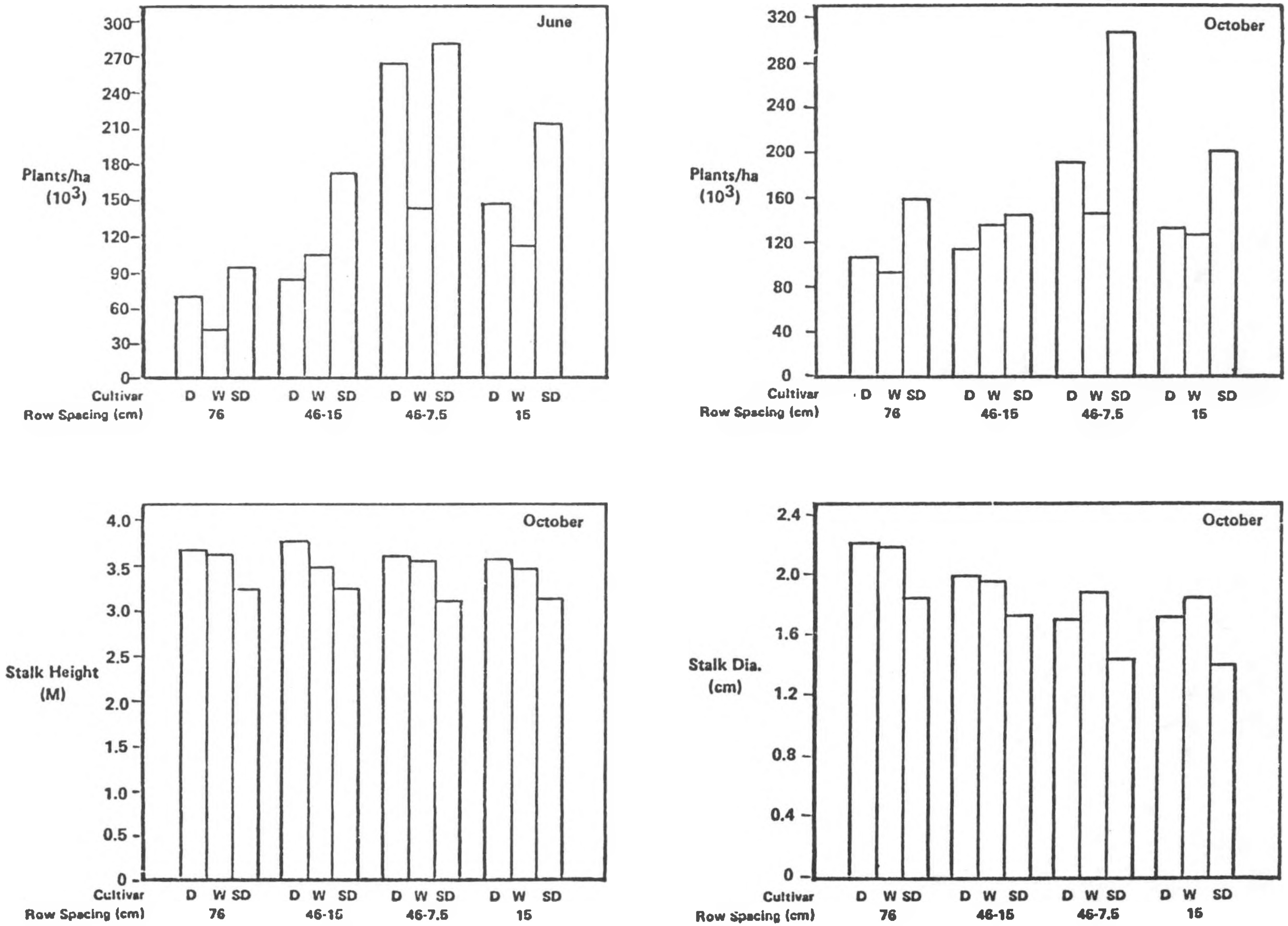


FIGURE 21. PLANT POPULATION (JUNE AND OCTOBER), STALK HEIGHT, HEIGHT, AND STALK DIAMETER (OCTOBER) FOR DALE, WRAY, AND SUGAR DRIP GROWN AT 4 SPATIAL CONFIGURATION

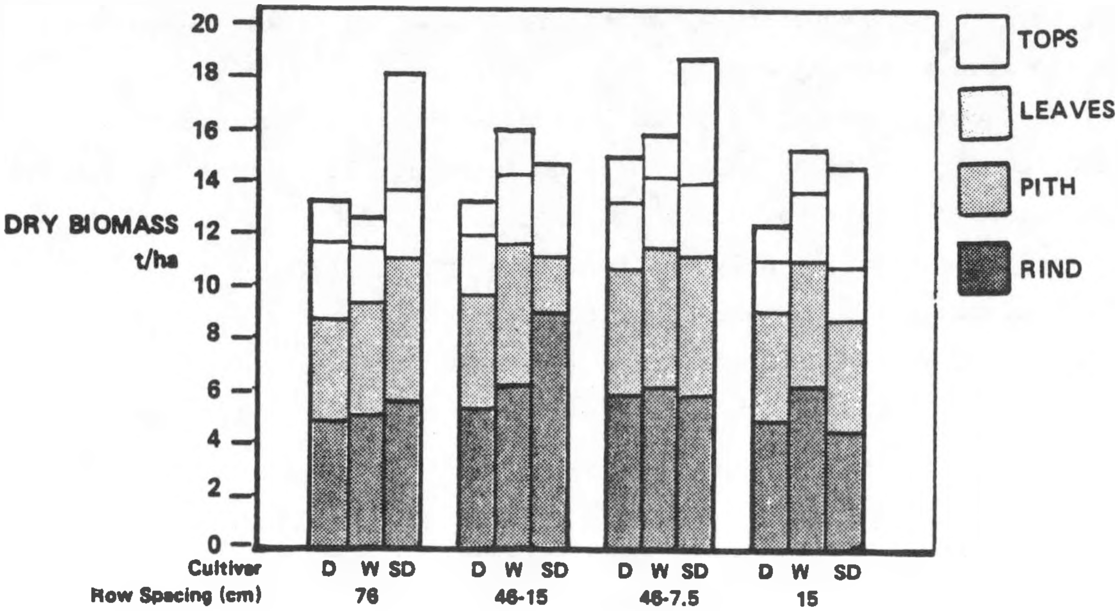
TABLE 13. MEAN PLANT POPULATIONS FOR FOUR SPACING CONFIGURATIONS AND PERCENTAGE OF THE EXPECTED POPULATION FOR EACH SPACING

Spacing	Mean Population (× 1000 plants/ha)	Expected (× 1000 plants/ha)	Percent of Expected
76 cm	120	90	133
46 cm - 15 cm	131	180	73
46 cm - 7.5 cm	215	360	60
15 cm - 15 cm	153	240	64

Stalk Height. The stalk height data for the plant spatial configuration experiment are presented Figure 21. The only significant result is a cultivar-dependent difference in stalk height. Dale and Wray, with a mean height of 3.58 m, were significantly taller than Sugar Drip, with a mean height of 3.17 m. These results are consistent with those of the fertility studies.

Stalk Diameter. Figure 21 illustrates the stalk diameters for the three cultivars of the configuration studies. As expected, spacing significantly affected stalk diameter. The widest interrow spacing, 76 cm, resulted in a mean stalk diameter of 2.08 cm, significantly greater than the other three spacings. The 46 cm interrow, 15 cm intrarow spacing produced stalks of 1.90 cm; the other two spacings were not significantly different (mean diameter of 1.67 cm). Consistent with the other experiments, stalks of Dale and Wray were greater in diameter (mean diameter of 1.94 cm) than Sugar Drip stalks (1.61 cm).

Biomass. The biomass yields for the plant configurations are presented in Figure 22 . Overall, all three cultivars were significantly different from one another. Sugar Drip, Wray, and Dale produced overall mean yields of 16.4, 14.8, and 13.3 t/ha, respectively. A spacing by



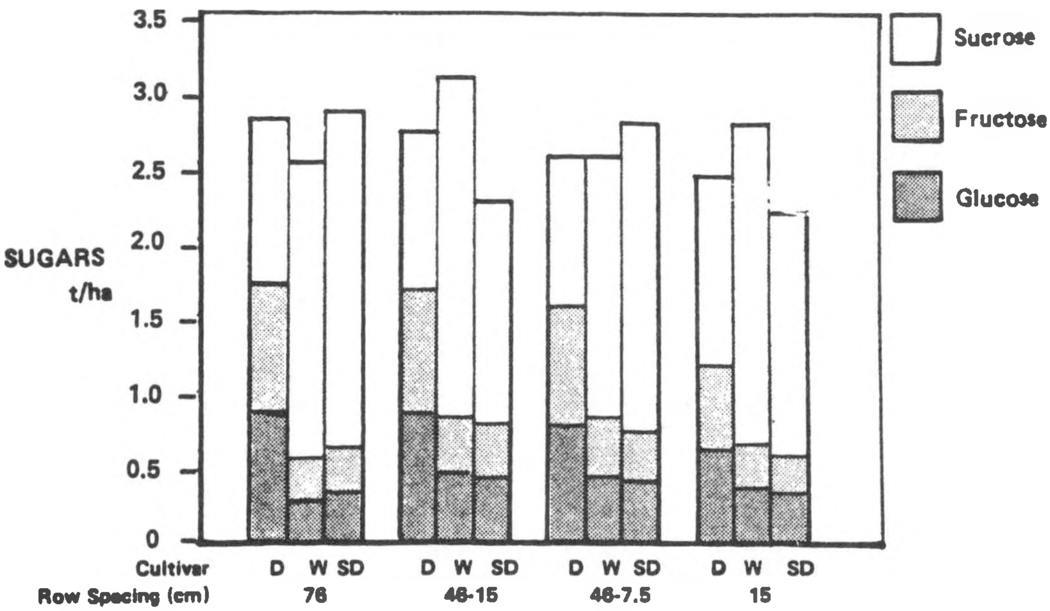


FIGURE 22. DRY BIOMASS AND SUGARS IN DALE, WRAY, AND SUGAR DRIP (OCTOBER) GROWN AT 4 SPATIAL CONFIGURATIONS

cultivar interaction proved to be statistically significant. Sugar Drip at both the widest spacing and the 46 cm interrow, 7.5 cm intrarow spacing, produced a mean yield of 18.3 t/ha, significantly greater than all other results. Wray at both the 46 cm interrow, 15 cm intrarow and 46 cm interrow, 7.5 intrarow spacings, produced a mean yield of 15.8 t/ha, significantly greater than only the two lowest yields (Figure 22).

Despite the fact that Sugar Drip at the 46 cm interrow, 7.5 cm intrarow spacing produced more plants per hectare (Figure 22), no difference in yield was observed between the 46 cm - 7.5 cm spacing and the widest spacing (Figure 22). However, at the narrower spacings, Wray produced more biomass than at the wider spacing. Thus, an advantageous effect due to narrow rows appears to be cultivar dependent.

A significant cultivar effect was found on biomass of tops, and a cultivar by spacing effect on total grain yield. Table 14 illustrates the significantly greater dry weight of Sugar Drip tops compared to Wray and Dale.

TABLE 14. PERCENT OF TOTAL DRY BIOMASS IN TOPS OF THREE SWEET SORGHUM CULTIVARS

Cultivar	Percent Tops
Sugar Drip	25
Wray	10
Dale	11

Table 15 shows the total grain yield of each cultivar as well as the percentage of total dry biomass made up by the grain. Sugar Drip produced significantly more grain per hectare than either Wray or Dale.

In general, cultivars grown in the widest spacing produced more grain (overall mean of 0.250 t/ha) compared to the other three spacings. The least amount of grain (0.186 t/ha) was produced in cultivars grown at 46 cm interrow, 7.5 cm intrarow spacing.

TABLE 15. TOTAL DRY GRAIN YIELD AS A PERCENTAGE OF TOTAL BIOMASS FOR THREE SWEET SORGHUM CULTIVARS

Cultivar	Grain (t/ha)	Percent Grain
Sugar Drip	0.434	2.6
Wray	0.128	0.8
Dale	0.086	0.6

Varying the plant spatial configurations had no significant effect on either leaf dry biomass or total stalk biomass. However, overall stalk yields varied due to cultivar selection. Stalk yields for Wray, Sugar Drip, and Dale were 10.7, 9.88, and 9.44 t/ha, respectively. As more biomass is partitioned as grain, less is partitioned as stalk biomass. These results are consistent with the cultivar selection experiment described earlier.

Wray produced significantly more rind (5.83 t/ha) than Dale or Sugar Drip (mean = 5.09 t/ha). However, Wray and Sugar Drip produced similar amounts of pith (mean = 4.87 t/ha), while Dale produced significantly less pith (4.27 t/ha). Wray and Dale appear to have more fibrous stalks than Sugar Drip which produced a significantly greater quantity of grain (Table 15).

Sugar Yield. In this study, there was no difference in percent total sugars between any of the row spacings. Furthermore, there was no difference in percent total sugars between any of cultivars at any row spacing. Mean percent total sugars for each cultivar at each spacing are listed in Table 16 .

Results indicate no difference ($P \leq 0.05$) in the composition of the percent total sugars between any spacing. However, a difference was noted in the relative composition of sugars between cultivars. Dale cultivar (a syrup-type of sweet sorghum) was highest in percent glucose and fructose and lowest in percent sucrose ($P \leq 0.05$), relative to Wray and Sugar Drip.

The total sugar yield in the 1979 row spacing/plant population trial followed the same trend as the percent sugar data. There was not significant difference in total sugar yield between any of the spacings (Figure 22). In addition, there were no cultivar spacing interactions encountered. Total sugar yields ranged from 2.16 to 3.05 t/ha between the 12 treatments. Among the cultivars, Dale yielded the highest quantities of simple sugars (glucose and fructose) and the lowest quantities of sucrose.

TABLE 16. MEAN PERCENT TOTAL SUGARS IN WET SWEET SORGHUM STALKS

Spacing	Cultivar	Average % Total Sugars
76 cm-15 cm	Dale	5.73
	Wray	5.20
	Sugar Drip	5.85
46 cm-15 cm	Dale	5.44
	Wray	5.84
	Sugar Drip	5.23
46 cm-7.5 cm	Dale	5.70
	Wray	5.00
	Sugar Drip	5.96
15 cm-15 cm	Dale	5.86
	Wray	5.34
	Sugar Drip	5.79

Summary. Biomass yields for the various cultivars grown at the different row spacing/plant population combinations were lower than those reported in 1978 (Lipinsky et al., 1979). These results were possibly due to the adverse weather conditions encountered in 1979. In response to the adverse weather, the cultivars matured at a slower rate than normal. In fact, some cultivars were not mature at harvest in October. The immaturity of the cultivars are reflected in the relatively low percent sugars of the stalk and the low grain yields. In 1979, the highest dry biomass yield for Wray in narrow rows was 17.5 t/ha, approximately 80 percent of the 1978 yield at a similar spacing. However, the 1979 yield of Wray on narrow rows was 35 percent greater than the 1978 yield at a conventional row spacing of 1.02 m.

Data reported in 1978 and in the present report indicate that sweet sorghum dry biomass yields may be increased significantly by planting in rows substantially narrower than the conventional interrow spacing of 102 cm. The optimum spacing for some cultivars may prove to be 76 cm, while for others 46 cm may provide highest biomass yields. The configuration of choice may ultimately depend on harvesting, processing, and conversion schemes, since stalk diameter is significantly affected by some spatial configurations (Figure 21). The widest interrow spacing resulted in stalks of significantly greater diameter, which may offer increased lodging resistance. If thick stalks prove to be most amenable to a variety of processing and conversion schemes, the optimum configuration may be an intermediate spacing like 76 cm. If, however, stalk diameter is not a significant factor in terms of harvesting, processing, and conversion, spatial configurations which produce the highest yields of biomass and sugars should be employed. Additionally, plants in the 76 cm interrow spacing produced significantly more grain than plants in the other spacings, regardless of cultivar. Thus, if grain production is an important consideration in producing sweet sorghum for energy purposes, e.g. as a livestock feed by-product credit or as a source of storable feedstock for alcohol production, an intermediate spacing (76 cm) may be more desirable than a very narrow (46 cm or less) spacing.

In general, total sugar yield was affected more by poor growing conditions than was the total biomass production. The 1979 row spacing/ plant population trial yielded a number of interesting results. There was no significant difference in the precent total sugars of the stalk of any of the cultivars at any of the spacings. This implies that two directions exist to increase the total sugar yield per unit land area; these include (1) identifying cultivars with a higher percent total sugars while maintaining biomass yield levels, and (2) identifying cultivars which grow and mature at a faster rate in the midwestern environment.

Total sugar yields followed the same trend as the percent sugars, in that there was no difference among any of the row spacings or cultivars. The range of total sugar yields varied from 2.16 t/ha with Sugar Drip at the 15 cm interrow - 15 cm interplant spacing to 3.05 t/ha with Wray at the 46 cm interrow - 15 cm interplant spacing. Treatments in the 1978 row spacing trials yielded from 2-6 t/ha.

The advantageous effect of planting sweet sorghum at narrower spacings is based on certain morphological characteristics which aid in light interception, i.e., plant height, leaf area, leaf arrangement and orientation. As new hybrids are developed with these morphological characteristics, further row spacing/plant population experiments will be essential.

Nitrogen Fertility Study

Plant Population. Three cultivars, Dale, Wray, and Sugar Drip, were grown with four different levels of nitrogen fertilizer (0, 112, 224, and 336 kg N/ha). There were no significant differences in plant population due to fertilization. However, as in the previous two experiments, a significant cultivar effect was observed (Figure 23). Sugar Drip had an overall mean plant population of 146,000 plants/ha, significantly greater than either Dale at 119,000 plants/ha or Wray at 105,000 plants/ha. Table 17 illustrates the percent of the expected population of 180,000 plants/ha for the three cultivars.

TABLE 17 . PERCENT OF THE EXPECTED PLANT POPULATION FOR THREE SWEET SORGHUM CULTIVARS FROM FERTILITY EXPERIMENTS

Cultivar	Percent of Expected
Sugar Drip	81
Dale	66
Wray	58

Stalk Height. Significant stalk height effects occurred due to both fertility level and cultivar (Figure 23). Stalk height was greater in all plots which received nitrogen compared to no nitrogen fertilization. However, no significant difference occurred between the nitrogen treatments. The overall mean height for the fertilized plants was 3.40 m, approximately 13 percent greater than the unfertilized plants. Dale and Wray cultivars had a mean height of 3.40 m, significantly greater than Sugar Drip, with a height of 3.1 m.

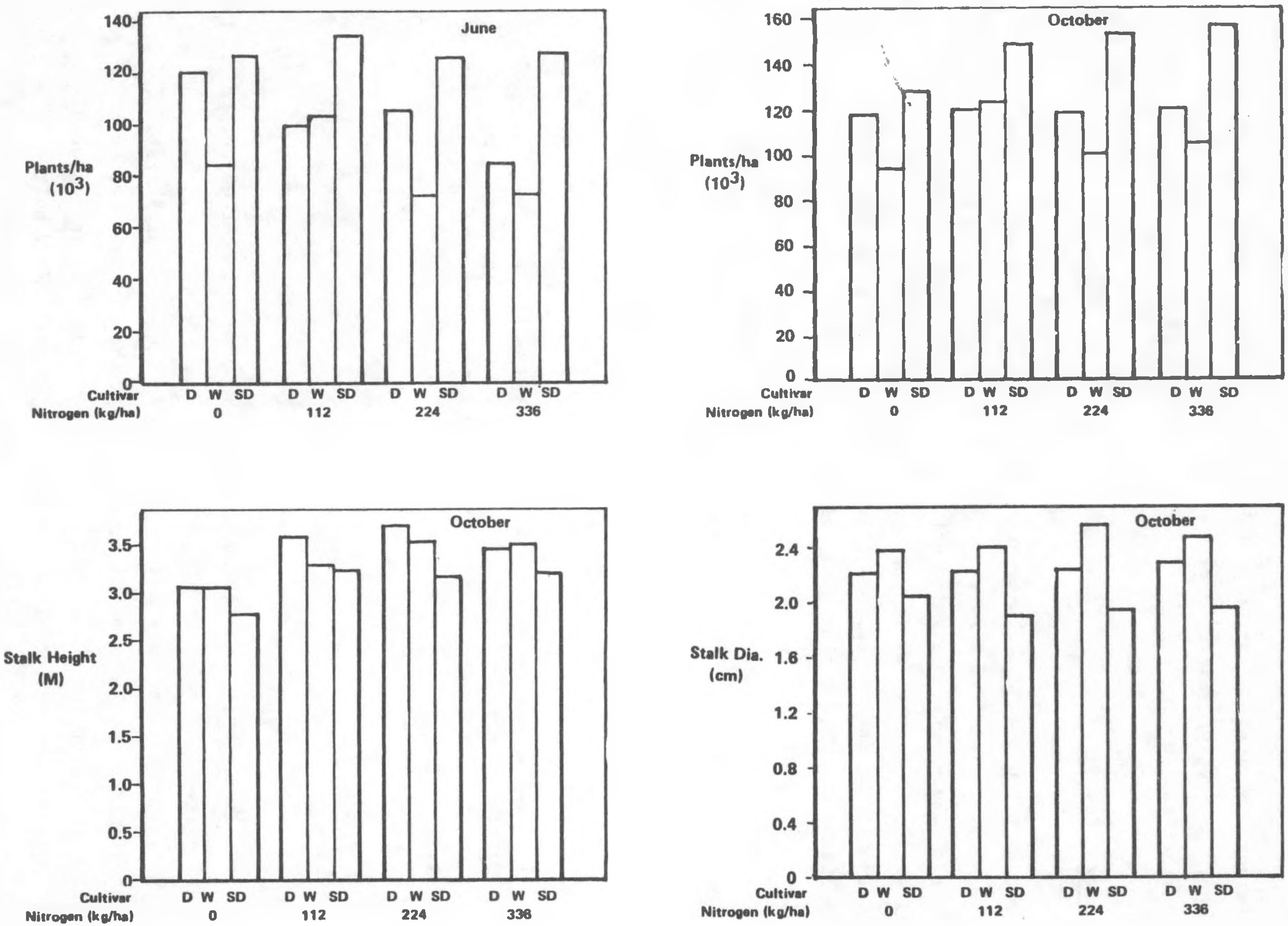


FIGURE 23. PLANT POPULATION (JUNE AND OCTOBER), STALK HEIGHT, AND STALK DIAMETER (OCTOBER) FOR DALE, WRAY, AND SUGAR DRIP WHICH RECEIVED 4 LEVELS OF FERTILIZER N

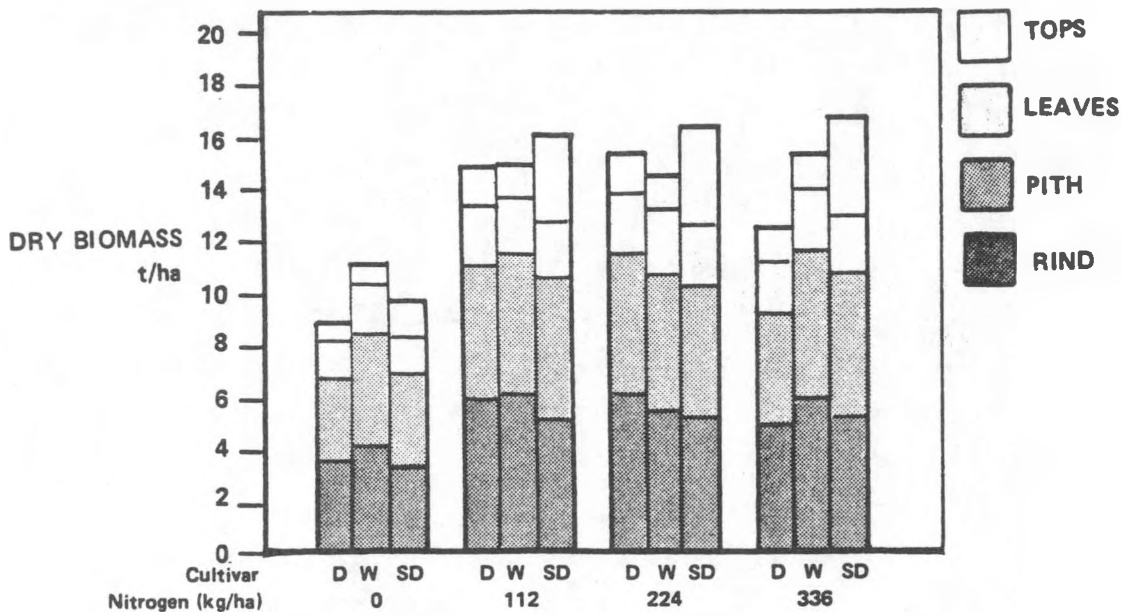
Stalk Diameter. Figure 23 illustrates the stalk diameters of the three cultivars in the fertility trial. All three cultivars were significantly different from one another, but no effect occurred due to nitrogen fertilization.

Biomass. The most striking result of the fertility trial is the lack of response in biomass production to N inputs greater than 112 kg/ha (Figure 24). The three cultivars were not different from each other within any fertilizer treatment, though all N treatments were significantly greater than with no application of N. The overall mean for N-fertilized sorghum was 15.1 t/ha, while that of unfertilized sorghum was 9.9 t/ha.

Total biomass was significantly affected by location in the field, i.e. by block. Unlike the cultivar selection experiment, in which cultivars grown in Brookston soil had the highest biomass yield; the mean for the two blocks encompassing Crosby soil was 15.3 t/ha, compared to 12.4 t/ha for the two blocks composed of Brookston soil.

Figure 24 indicates Sugar Drip had tops of significantly greater biomass due to the three fertilizer treatments. The overall biomass mean for Sugar Drip tops was 3.02 t/ha, significantly greater than the mean of 1.21 t/ha for Dale and Wray, results consistent with the cultivar selection and row spacing experiments. Additionally, the mean for Sugar Drip tops from the three fertility treatments was 3.56 t/ha, significantly greater than all other responses. Sugar Drip receiving fertilizer N produced a mean of 0.4 t/ha of grain, significantly greater than the overall mean grain yield of 0.17 t/ha. Table 18 reveals that N fertilization increased the proportion of grain produced by an approximate factor of two.

Nitrogen fertilization affected only the proportion of grain produced, since no other effects in biomass partitioning were noted. The overall mean for dry stalk yield from N fertilized plots (10.7 t/ha) was significantly greater than stalks from unfertilized plots (7.35 t/ha). Nevertheless, the proportion of total dry biomass composed of stalks ranged from 71 to 74 percent of all cases. Similar results were observed



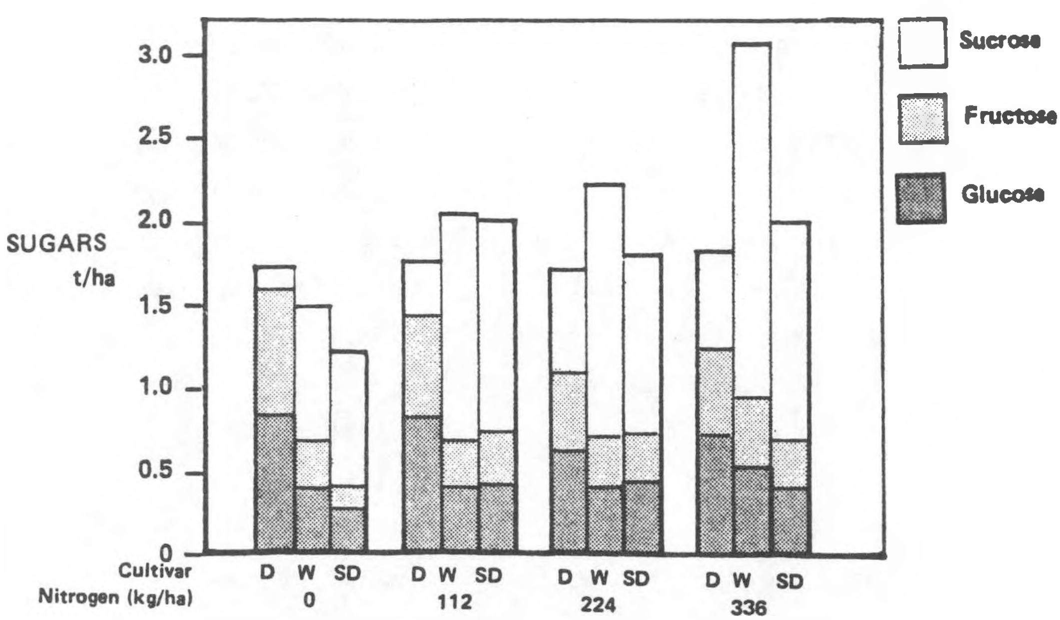


FIGURE 24. DRY BIOMASS AND SUGARS (OCTOBER) IN DALE, WRAY, AND SUGAR DRIP WHICH RECEIVED 4 LEVELS OF FERTILIZER N

TABLE 18. DRY WEIGHT OF GRAIN PRODUCED AND PERCENT OF TOTAL BIOMASS AS A FUNCTION OF NITROGEN FERTILIZATION

Fertilization (kg/ha)	Grain (t/ha)	Percent Grain
0	0.070	0.7
112	0.184	1.2
224	0.207	1.4
336	0.210	1.4

for dry rind and pith yields. The proportion of the total biomass of pith and rind ranged from 34 to 38 percent for each component in all cases, regardless of the level of N fertilization. Similarly, leaf biomass was significantly greater for N fertilized plots, but the proportion of biomass in the leaves ranged from 14 to 16 percent regardless of treatment.

Roots from the 48 plots of this experiment were sampled to determine if N fertilization affected underground biomass. No significant differences in root biomass were observed for any of the N treatments.

Sugar Yield. The content of simple sugars, glucose and fructose, were significantly higher ($P \leq 0.001$) in the plots which received no nitrogen applications (Table 19).

TABLE 19 MEAN PERCENT GLUCOSE, FRUCTOSE, AND SUCROSE CONTAINED IN STALKS OF THE CULTIVARS DALE, WRAY, AND SUGAR DRIP WITH RESPECT TO NITROGEN FERTILITY LEVEL[(a)]

Nitrogen Added (kg/ha)	% Glucose	% Fructose	% Sucrose
0	1.68 a	1.28 a	1.84 c
112	1.17 b	0.86 b	2.19 b
224	1.15 b	0.85 b	2.24 b
336	1.01 b	0.73 b	2.83 a

(a) See footnote for Table 9.

The percent glucose and fructose were highest in the cultivar Dale at each of the fertility levels, as expected. On the other hand, the highest percent sucrose was obtained at the highest nitrogen level (Table 19). Percent sucrose was highest in the cultivar Wray (3.11 percent). This percent sucrose of Wray was not different from that of Sugar Drip (2.82 percent) but was higher ($P \leq 0.05$) than Dale (0.89 percent).

There was no difference in the total glucose or fructose yield per hectare with respect to any of the fertility levels. A cultivar response was encountered with Dale yielding higher levels of the simple sugars than either Sugar Drip or Wray (Figure 24). Sucrose yield responded to both fertility and cultivar (Tables 20-21). The only significant response of total sugar yield to fertility level was that between 0 and 112 kg N/ha (Table 22).

As in the cultivar selection study, Wray yielded significantly higher levels of total sugars across N fertility levels than either Dale or Sugar Drip.

Plant Nutrient Uptake.

Nitrogen. Figure 25 illustrates the effect of N fertilization on plant uptake of soil nitrogen. Plants receiving 336 kg/ha N removed quantities greater than those receiving other levels of N fertilization (120.2 kg/ha). Plants receiving no fertilizer N produced a mean N uptake of 51.4 kg/ha, significantly lower than fertilized plots. No cultivar differences were found in any treatment.

Overall, approximately 7 kg of N were required to produce each ton of dry, above-ground biomass in N-fertilized plots. In plots receiving no N, 5.2 kg of N were required to produce each ton of dry biomass. These results compare favorable with those from other sites and with 1978 results obtained in Columbus. Since biomass yields were lower this year compared to 1978, less total nitrogen was required to produce the crop.

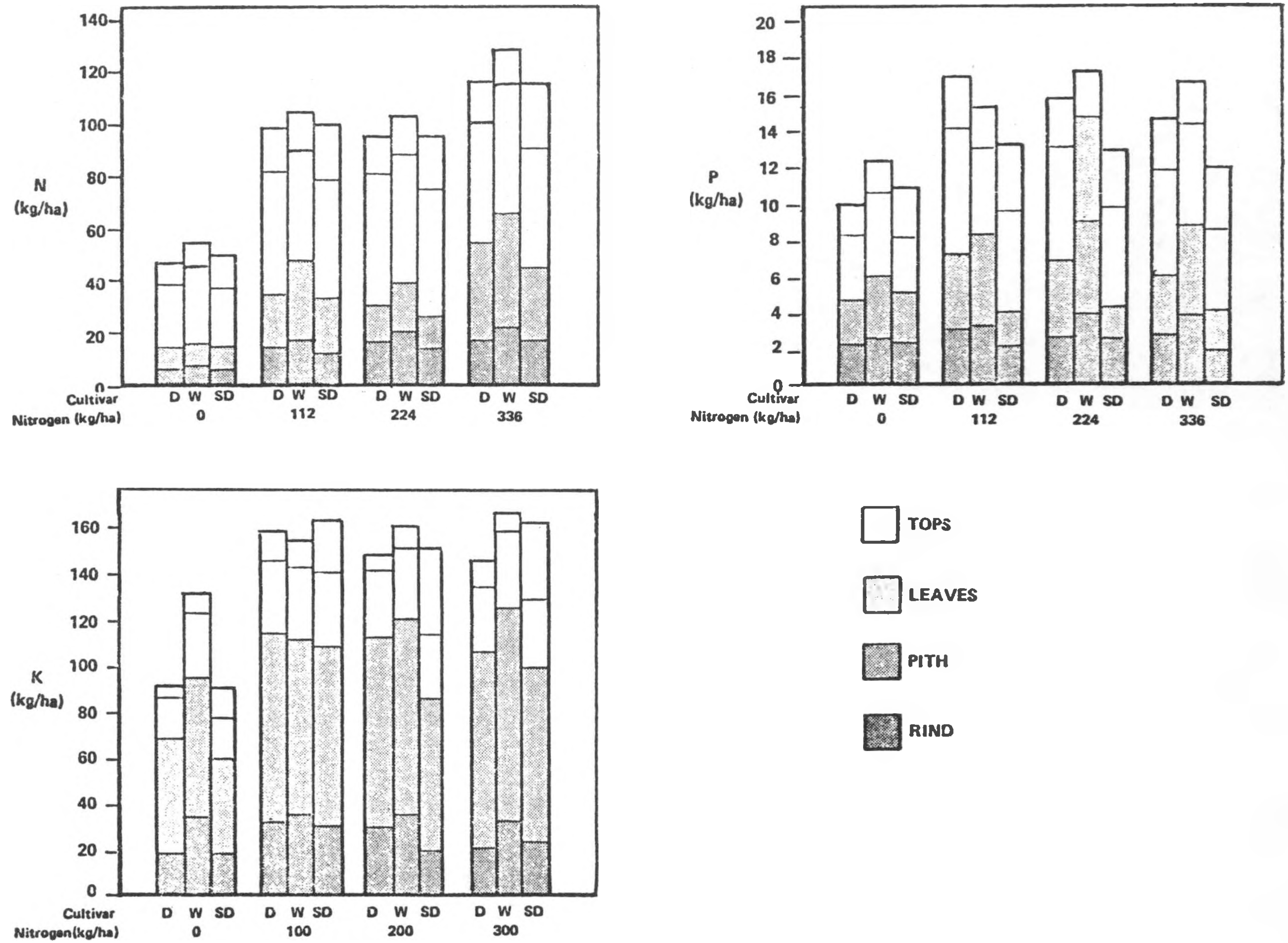


FIGURE 25. N, P, AND K (OCTOBER) IN ABOVE-GROUND BIOMASS OF DALE, WRAY, SUGAR DRIP WHICH RECEIVED 4 LEVELS OF FERTILIZER N

TABLE 20. YIELD OF SUCROSE WITH RESPECT TO FERTILITY LEVELS[a]

Nitrogen Added (kg/ha)	Sucrose Yield (t/ha)
0	0.57 c
112	0.99 b
224	1.07 b
336	1.34 a

(a) See footnote for Table 9 .

TABLE 21. YIELD OF SUCROSE WITH RESPECT TO CULTIVAR[a]

Cultivar	Sucrose Yield (t/ha)
Wray	1.45 a
Sugar Drip	1.11 b
Dale	0.42 c

(a) See footnote for Table 9 .

TABLE 22. YIELD OF TOTAL FERMENTABLE SUGARS OF THE STALK AS A RESPONSE TO FERTILITY LEVEL[a]

Nitrogen Added (kg/ha)	Total Sugar (t/ha)
0	1.46 b
112	1.90 a
224	1.93 a
336	2.29 a

(a) See footnote for Table 9 .

Figure 25 also illustrates the partitioning of N in the plant. Plants receiving 336 kg/ha of fertilizer N partitioned a significantly greater proportion of nitrogen into pith (30 percent) and only 39 percent into leaves. All other plots resulted in approximately 19 percent of the plant N contained in the pith and approximately 48 percent contained in the leaves. For alcohol fuels production, N should be returned to the soil in the form of leaves and trash whenever possible. Thus, 336 kg/ha fertilizer N results in increased nitrogen loss (removal of pith for fermentation) and no increase in biomass yield.

Figure 26 illustrates plant N contained in dry roots. Overall, Wray contained significantly more (24.7 kg/ha) plant N in roots than either Dale or Sugar Drip (11.3 kg/ha), though no differences were found in root biomass or in above-ground N-uptake by Wray compared to the other cultivars. The reason for this effect is not apparent. Wray in plots which received 112 kg/ha fertilizer N contained significantly more root N than all but Dale receiving 336 kg/ha fertilizer N. Plots receiving no fertilizer N contained significantly less N in roots than N-fertilized plants.

Phosphorus. The effect of N fertilization of P uptake from soil is illustrated in Figure 25. In terms of total above-ground biomass, N fertilization produced no effect. However, Wray (16.0 kg/ha) removed significantly more P than did Sugar Drip (12.8 kg/ha). Overall, Dale removed soil P at the rate of 14.9 kg/ha.

N fertilization significantly affected plant partitioning of P. N-fertilized plants had significantly greater levels of P in leaves and tops than did plants receiving no N. Approximately 35 percent of the removed P is contained in the leaves, which can be returned to the soil in a biomass fuel system to reduce phosphorus inputs.

Figure 26 illustrates the effect of N fertilization on plant P contained in roots. No effect from added N was found. However, Wray contained significantly more P (3.25 kg/ha) in roots than did Dale and Sugar Drip (1.59 kg/ha).

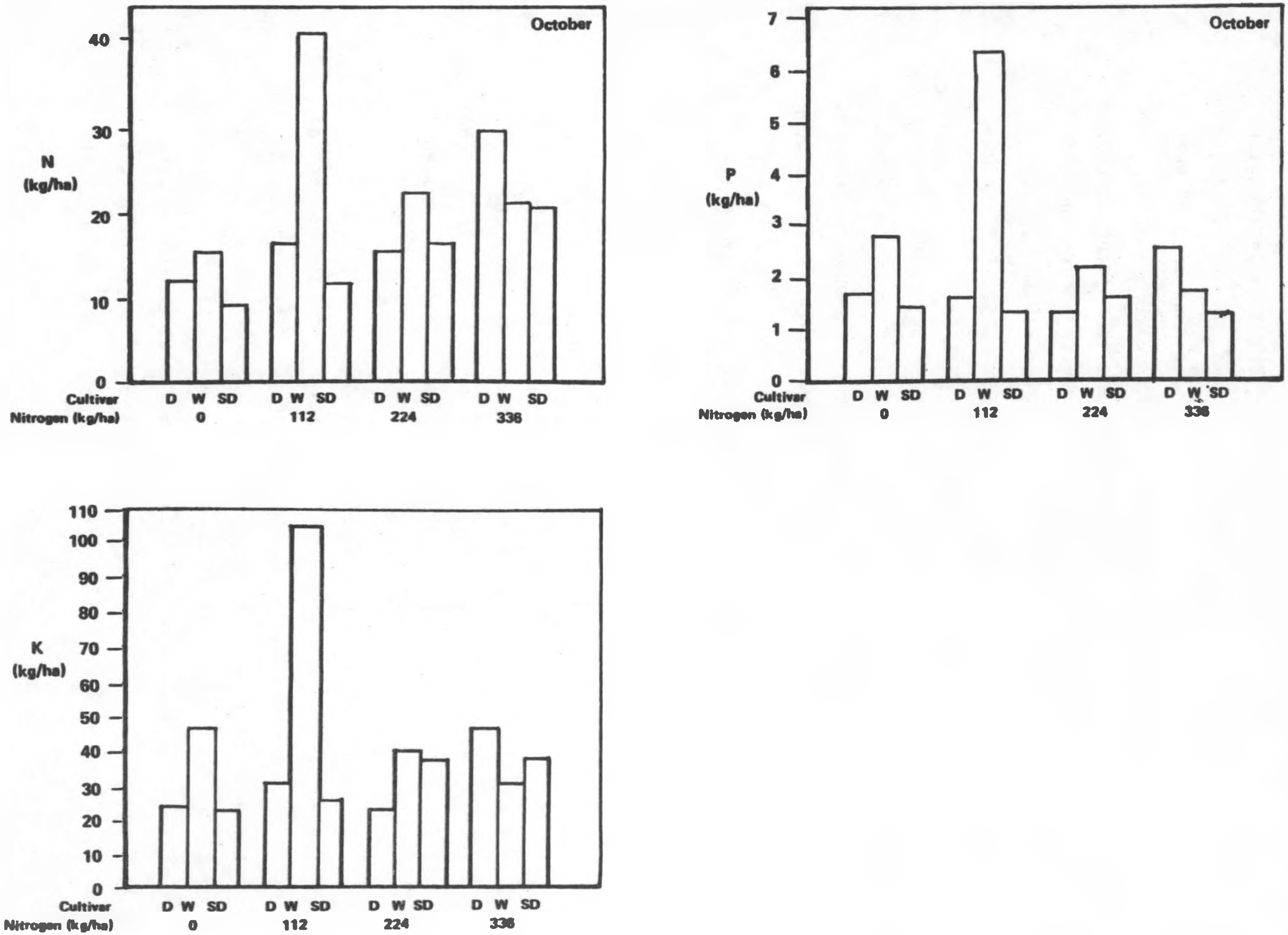


FIGURE 26. N, P, AND K (OCTOBER) IN THE DRY ROOTS OF DALE, WRAY, AND SUGAR DRIP WHICH RECEIVED 4 LEVELS OF FERTILIZER N

Potassium. K uptake by N-fertilized sweet sorghum is illustrated in Figure 25 . N-fertilized plants (overall mean = 159.0 kg/ha) contained significantly more K than did unfertilized plants (mean = 103.8 kg/ha). This same significant effect was found in leaves, tops, and pith but not in rind. Additionally, a cultivar effect occurred in K contained in tops and rind. Sugar Drip tops in fertilized plots incorporated K at the rate of 35.5 kg/ha compared to a mean of 10.5 kg/ha for the tops of the other cultivars in both fertilized and unfertilized plots. Rind of the Wray cultivar contained significantly more K (33.6 kg/ha) than rind from Dale and Sugar Drip (mean = 24.8 kg/ha).

Table 23 illustrates that 52 percent of the K in the above-ground biomass was contained in the pith. Thus, sweet sorghum stillage following fermentation is likely to contain a high concentration of K salts and must be handled in an environmentally appropriate manner.

TABLE 23. K UPTAKE BY N-FERTILIZED SWEET SORGHUM

	kg/ha	% Total
Leaves	29.8	19
Tops	19.5	13
Rind	24.8	16
Pith	80.7	52
Above-ground Total	154.8	

Figure 26 illustrates K contained in sweet sorghum roots. Wray roots in plots which received 112 kg/ha fertilizer N contained 103.8 kg/ha K, significantly greater than all other measurements (overall mean = 32.0 kg/ha). Across all treatments, roots from the Wray cultivar contained a mean of 53.7 kg/ha K, significantly greater than Dale and Sugar Drip roots (mean = 30.1 kg/ha).

Soil Nutrients. Pourous cup lysimeters were installed in plots of the N fertility studies at Columbus, Ohio. Soil water was collected in the spring and fall and analyzed for N, P, K, and dissolved organic carbon (DOC). In addition, soil samples in the spring, summer, and fall were extracted and analyzed for N, P, K, and DOC.

Overall, nitrogen levels in soil and soil water varied most dramatically (Figures 27-28). Soil water from N-fertilized plots in the spring samples contained significantly more N than water from the unfertilized plots (Figure 27). Soil water from N-fertilized plots contained a mean of 101.3 ppm N, while water from plots receiving no N contained only 34 ppm N. By fall, however, no significant differences were found in soil water N between any of treatments. Similar results in soil occurred for extractable N (Figure 28). Spring samples revealed significant differences in soil extractable N as a function of N fertilization and depth, with most N present in the top 15 cm of soil (Figure 28). By summer, only those plots fertilized with 336 kg/ha N and containing Dale contained significantly more N than other treatments (Figure 28). The fall sampling revealed no significant differences in soil extractable N between any of the 48 plots in the fertility trials (Figure 28). These results show that nitrogen was leached from the soil early in the growing season, which is not surprising considering the excessive rainfall experienced in Ohio in 1979. Since sweet sorghum grows slowly in the spring, a top dressing of N when the plants are 15-20 cm high would probably lead to more efficient N use by the crop.

Spring lysimeter data for P is shown in Figure 29 . Despite the apparent high concentration of P available in plots which received no N, no significant differences in P concentration were found. Figure 29 reveals similar findings from the fall sampling. Soil extraction in the spring also showed no differences in available P, but by fall more P was available in the top 15 cm of soil (53.9 kg/ha) than in the lower 15 cm (21.6 kg/ha). These results suggest that soil P availability is affected by increasing N fertilization and is relatively immobile in the soil profile.

Soil water K concentration from spring samples is illustrated in Figure 30 . Water from plots which received 336 kg/ha fertilizer N

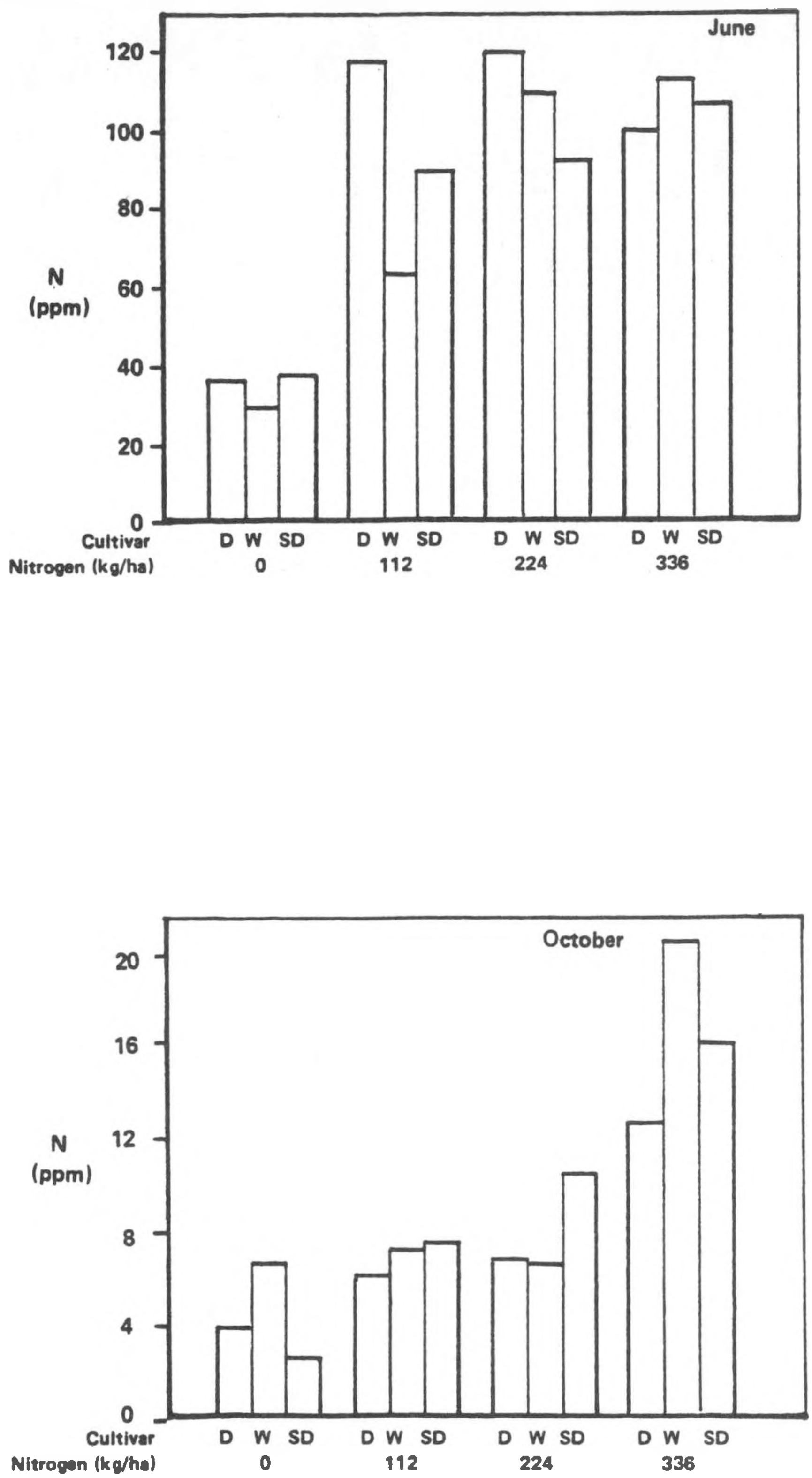


FIGURE 27. SOIL WATER N (JUNE AND OCTOBER) FROM PLOTS IN WHICH DALE, WRAY, AND SUGAR DRIP RECEIVED 4 LEVELS OF FERTILIZER N

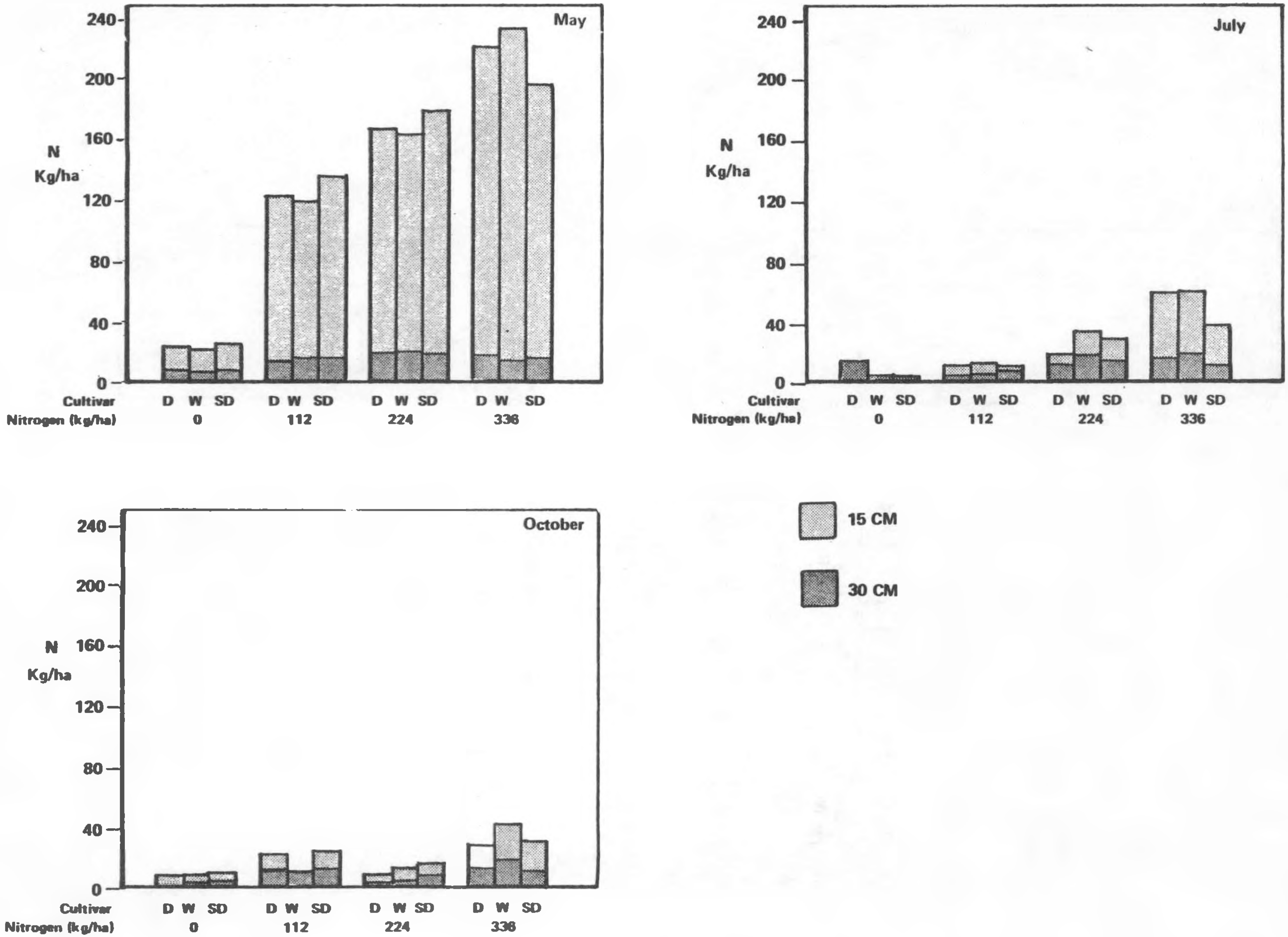
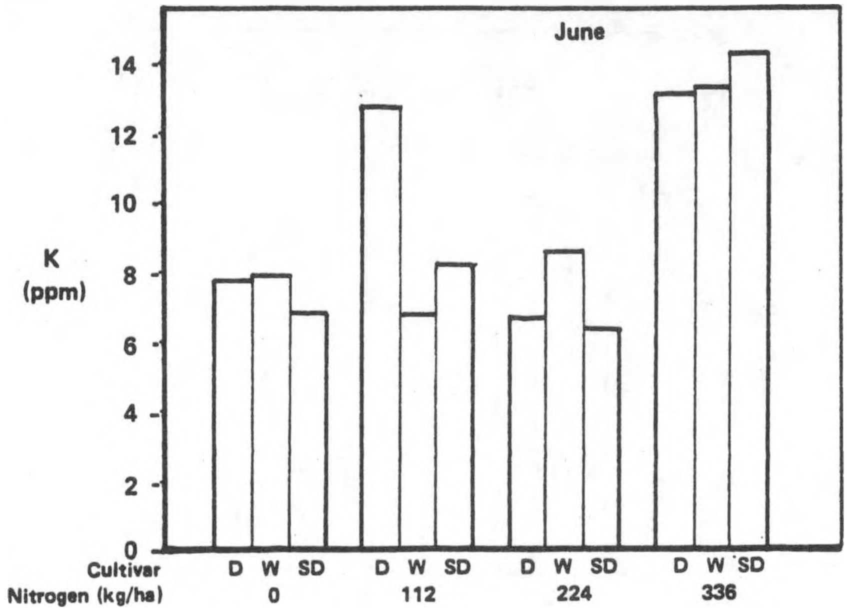


FIGURE 28. SOIL N AT DEPTHS OF 15 AND 30 CM IN MAY, JULY, AND OCTOBER IN PLOTS IN WHICH DALE, WRAY, AND SUGAR DRIP RECEIVED 4 LEVELS OF FERTILIZER N



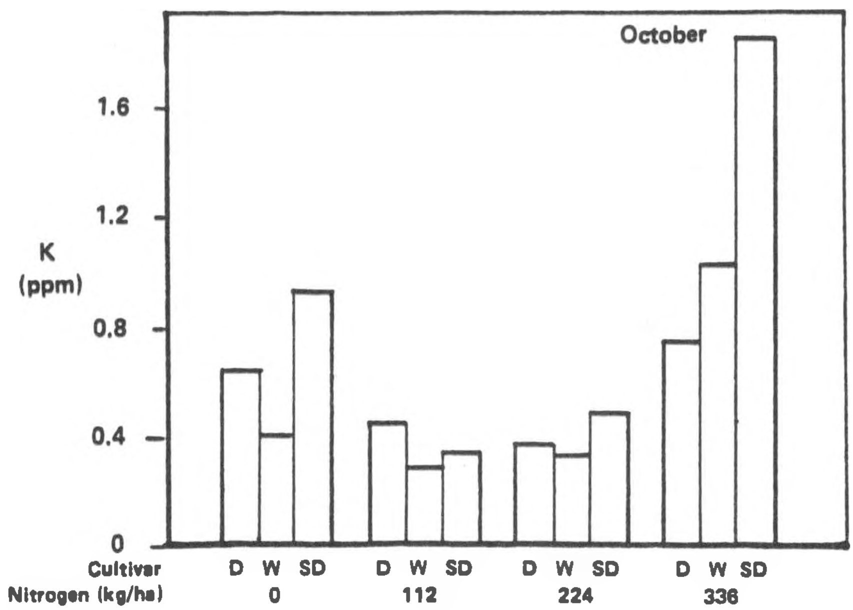


FIGURE 29. SOIL WATER K (JUNE AND OCTOBER) FROM PLOTS IN WHICH DALE, WRAY AND SUGAR DRIP RECEIVED 4 LEVELS OF FERTILIZER N

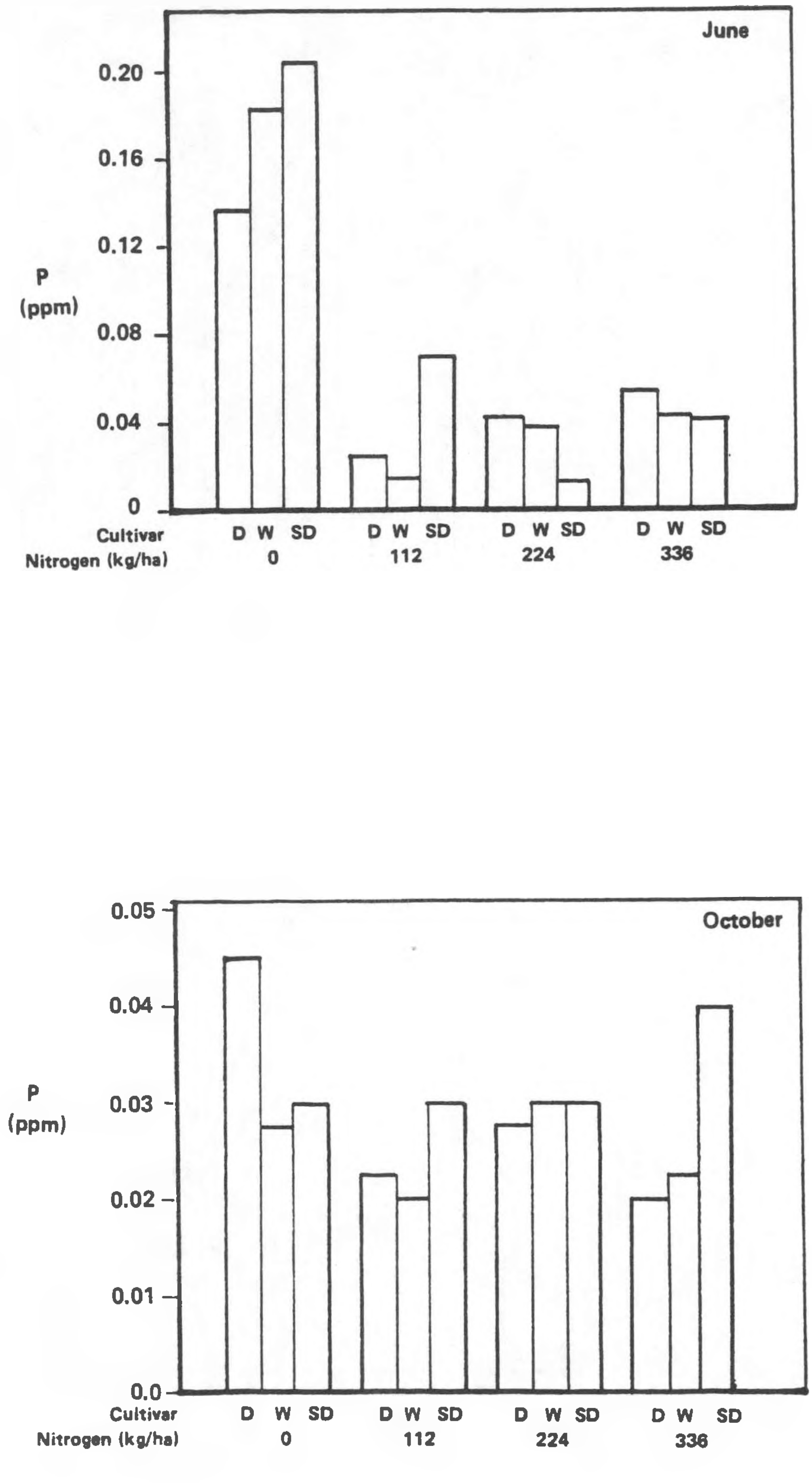


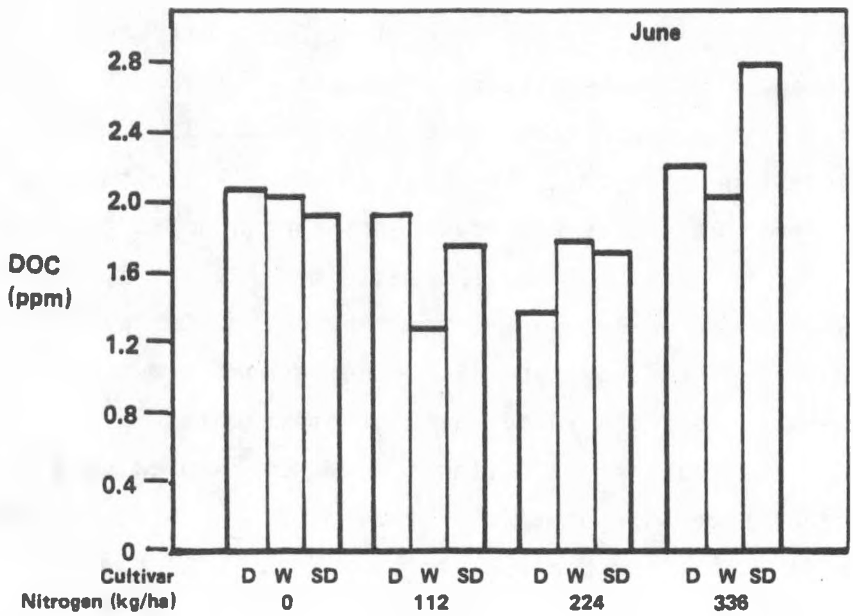
FIGURE 30. SOIL WATER P (JUNE AND OCTOBER) FROM PLOTS IN WHICH DALE, WRAY, AND SUGAR DRIP RECEIVED 4 LEVELS OF FERTILIZER N

contained significantly more K (13.5 ppm) than did water from other plots (overall mean = 7.93 ppm). By fall, no significant differences in K in soil water between treatments were found (Figure 30). Spring soil extraction revealed a higher concentration of K in the top 15 cm of soil (365 kg/ha) than in the next 15 cm (239 kg/ha) across all treatments. By fall, however, the top 15 cm across all treatments contained only 303 kg/ha while the next 15 cm contained significantly more K (327 kg/ha). No differences were observed due to N-fertilization. K is apparently more mobile than P through the soil profile. The excessive rainfall experienced in 1979 undoubtably contributed to the K gradient observed in the fall.

DOC concentrations in spring soil water samples were not significantly different across treatments (Figure 31). By fall, however, (Figure 31) soil water from plots containing Sugar Drip contained an average of 9.3 ppm DOC, significantly greater than water from plots containing Dale had a mean DOC concentration of 7.5 ppm. DOC concentrations in spring and fall soil extractions showed significant differences due only to depth. The top 15 cm and next 15 cm of soil across all treatments contained 1.70 and 1.12 kg/ha DOC, respectively. By fall, the top 15 cm and next 15 cm contained 2.11 and 1.95 kg/ha DOC, respectively. Thus, N-fertilization had no effect on DOC.

<u>Summary</u>. The nitrogen fertility study yielded information highly integral to the development of sweet sorghum as a feedstock for energy production. There was no biomass response to nitrogen applications greater than 112 kg/ha. Among the three cultivars tested, no differences in yield were recorded within any fertilizer treatment; however all nitrogen treatments were higher yielding ($P \leq 0.05$) than those with no nitrogen application. The overall mean yield of dry biomass (across cultivars) for N-fertilized sorghum was 15.1 t/ha, while that of the control was 9.9 t/ha. Nitrogen fertilization also increased the proportion of grain produced by a factor of two.

The nitrogen fertility trials yielded important information concerning the relationship between soil N and percent total sugar of the stalk (and consequently, total sugar yield). The percent simple sugars of stalk were highest when no nitrogen was added. Conversely,



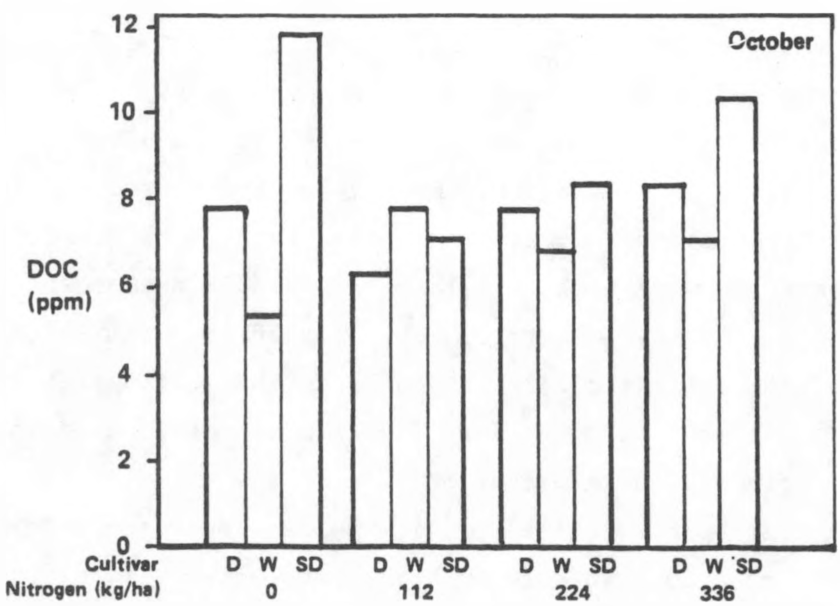


FIGURE 31. SOIL WATER DOC (JUNE AND OCTOBER) FROM PLOTS IN WHICH DALE, WRAY, AND SUGAR DRIP RECEIVED 4 LEVELS OF FERTILIZER N

the highest percent sucrose was encountered at the highest level of nitrogen application (336 kg/ha). The highest yield of total sugars occurred with the highest fertility level (2.29 t/ha at the application rate of 336 kg/ha N). However, this was not statistically significant from the two other application rates. In other words, the total sugar yield, like the dry biomass, was not affected by nitrogen fertilization above 112 kg/ha. In less intensive production studies researchers from the USDA Sugar Crops Field Station in Meridian, Mississippi, have reported that sweet sorghum grown in rotation with soybeans responds optimally to approximately 45 kg N/ha. For energy (ethanol) production a feedstock is more desirable if it has a low dependency of energy-intensive inputs such as nitrogen fertilizer. For example, as much as 40 percent of the total energy required to produce and harvest corn is contained in the energy required to produce the nitrogen fertilizer.

Overall, approximately 7 kg of nitrogen were required to produce each ton of biomass in the N-fertilized plots. In plots receiving no nitrogen, 5.2 kg of N were required to produce each ton of dry biomass. Nitrogen fertilization greater than that required for maximum biomass production may lead to luxury consumption by the plants.

The complications of adverse weather in 1979 make definitive conclusions from this study tenuous. However, as a general conclusion, best results are likely from a top dressing application of N when the plants are large enough to utilize the nutrient more quickly. Further, fertility testing of sweet sorghum should be made to better define the optimum quantity and time of application for the midwest.

Investivation of Mycorrhizal Infections of Sweet Sorghum

Background. Mycorrhizae are symbiotic root-fungus structures found in many plant species worldwide. Mycorrhizae constitute a very specific, ecologically adapted group of fungi which enhance plant growth in spoiled, nutritionally sub-optional, and drought stressed soils (Ruehle and Marx, 1979). Phosphorus uptake is especially enhanced due to the fungal-release of phosphatases which mobilize normally very immobile soil phosphorus. Additionally, many mycorrhizal fungi produce antibiotics which inhibit plant pathogenic fungi.

There are two basic types of mycorrhizae: ectomycorrhizae and endomycorrhizae. The first type is common in Gymnosperms and is extremely important in forest ecosystems. Many of the fungi responsible for ectomycorrhizae formation have been cultured in vitro. Endomycorrhizae, on the other hand, are important components of agroecosystems. Knowledge of their growth and physiology, however, has been limited since the infecting fungi are obligate or near-obligate parasites. In the Gramineae family, Gerdemann (1968) states that the only grasses likely to be non-mycorrhizal are those grown in very wet soils, e.g. rice. Included in this family are agronomically important species like wheat, oats, corn, and sugarcane, all of which are endomycorrhizal. Whether sweet sorghums [Sorghum bicolor (L.) Moench] are mycorrhizal has not been reported. Sudangrass (S. biocolor var. sudanense), a related species, is known to be mycorrhizal (Jackson et al., 1972).

Mosse (1973), Khan (1975), and others have suggested that specific mycorrhizal inocula may ultimately replace the need for fertilizers in some crops. Nitrogen fertilizers are becoming increasingly energy intensive and expensive and ideally should be avoided in growing crops for renewable energy supplies. Sweet sorghum responds to relatively low levels of nitrogen fertilizers, a phenomenon sure to involve several complicating factors, one of which may be mycorrhizal fungi. Smith (1974) and Hayman (1975) have shown that increased soil nutrient availability, including nitrogen and phosphorus, inhibit mycorrhizae formation. Thus, the lack of growth response to increased levels of N fertilization in sweet sorghum may be due to extensive mycorrhizae formation in plants receiving low levels of nitrogen. Inoculation of sweet sorghum with the proper mycorrhizal fungus,, similar to the common practice of specific Rhizobium inoculation of legumes, may reduce or eliminate the need for energy-intensive artificial nitrogen inputs.

Roots from eight cultivars of sweet sorghum were qualitatively examined for endomycorrhizae formation by the method of Phillips and Hayman (1970). Examinations involved cultivars from the Cultivar Selection and the Nitrogen Fertilization studies in attempts to determine (1) whether sweet sorghum is mycorrhizal; and (2) whether N fertilizer affects mycorrhizal formation.

Results. Endomycorrhizae were observed in virtually all cultivars of sweet sorghum examined (Figure 32), including the eight cultivars grown in Ohio and in roots from sweet sorghums grown in Kansas, North Dakota, Nebraska, Louisiana, Texas, and Mississippi. This presumably is the first reported observation in sweet sorghum. Photomicrographs of these endomycorrhizal roots are shown in Figure 32).

Even though no quantitative evaluation of roots for mycorrhizae formation was attempted, it was visually obvious that various root sections were differentially affected. A very rough quantitative evaluation revealed that MER 77-5, obtained from the USDA Sugar Crops Field Laboratory in Meridian, Mississippi, contained the most extensive endomycorrhizae observed. This may be the result of many years of growing sweet sorghum at Meridian for purposes of sultivar selection studies, thus optimizing conditions for propagation of sorghum-infecting fungi. Similarly, Keller roots from the USDA Sugarcane Field Laboratory in Houma, Louisiana, contained extensive mycorrhizae. In contrast, roots from cultivars grown at Columbus, Ohio, where sweet sorghum has been grown only in the past three years, contained fewer endomycorrhizae, compared to roots from Meridian or Houma.

It was not possible to discern whether N fertilizer affected the extent of endomycorrhizae formation in sweet sorghum. Some level of infection was noted regardless of the degree of N fertilization. Similarly, the effect of endomycorrhizae formation on utilization of soil P is not clear. Wray removed significantly more soil P than did Dale or Sugar Drip, and in most cases appeared to contain extensive endomycorrhizae. To quantitatively assess the effect of endomycorrhizae on P uptake in sweet sorghum, however, would require rigorous experiments employing radioactively labelled phosphorus.

The numbers of soil-borne fungal spores found in the 48 plots from the N fertilization studies showed that there was no effect of N fertilizer on spore numbers. However, block 4, composed entirely of Crosby silt-loam (3-5 percent organic matter), contained 5,400 spores per kg of soil, significantly more than contained in blocks 1, 2, and 3 (overall mean = 2,800 spores per kg soil). Blocks 1 and 2 contained Brookston soil (5-7 percent organic matter) and block 3 contained a mixture

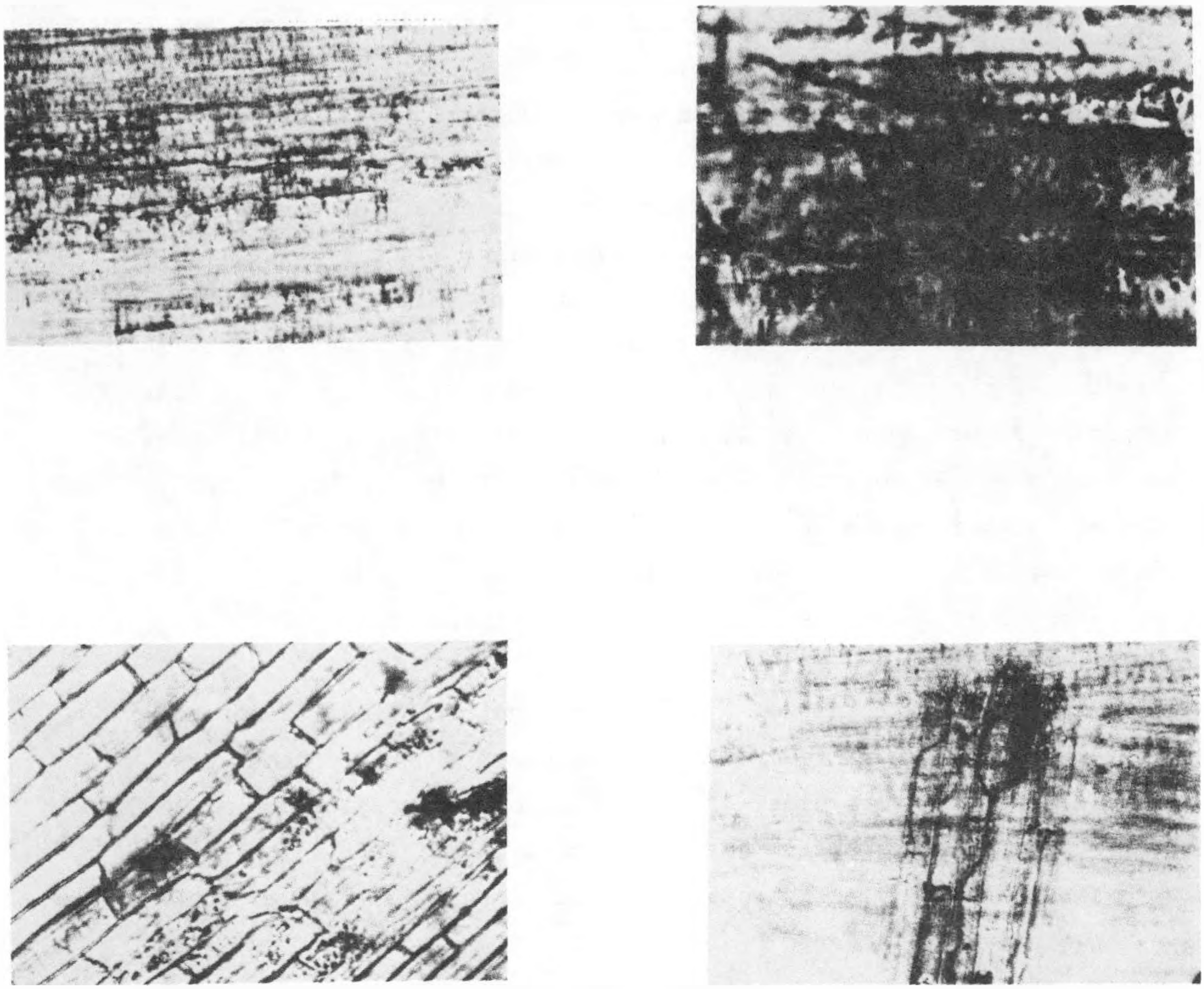


FIGURE 32. MYCORRHIZAE FORMATION IN ROOT SECTIONS OF SWEET SORGHUM

of Crosby and Brockston soils. Additionally, the degree of soil water movement (drainage) appeared to increase from block 1 to 4. Thus, soil type and soil water movement may significantly affect numbers of soil-borne mycorrhizae-forming spores.

Table 24 illustrates spore numbers from soil samples collected from sites other than Columbus, Ohio. No analysis of variance of these data was performed since n = 1 in most cases. Even though roots of MER 77-5 from Meridian, Mississippi contained extensive endomycorrhizae, the number of mycorrhizae-forming spores from Meridian soil varied little from spore numbers at other locations. The overall mean for spore numbers from the five locations where either grain or sweet sorghums have been cultivated for many years is 4,000 spores/kg soil. The overall mean for spore numbers from Columbus, Ohio soils is 3,500 spores/kg. Thus, numbers of endogenous mycorrhizae-forming spores beneficial to sweet sorghums may be independent of long-term sorghum cultivation.

Table 24. SOIL-BORNE MYCORRHIZAE-FORMING SPORES FROM SOILS OBTAINED AT FIVE LOCATIONS

Site	Spores/kg Soil
Lincoln, Nebraska	3,200
Meridian, Mississippi	3,400
College Station, Texas	4,200
Manhattan, Kansas	5,200
Fargo, North Dakota	3,800
Mean	4,000

Sweet Sorghum Growth Regulator Analysis

Background. Because of the high yield of fermentable sugar and relatively low production costs, ethanol production from sweet sorghum appears economically feasible. Improvements in crop production, primarily in the midwestern United States, will further improve the economics of ethanol production.

An area which deserves further investigation is the improvement of sweet sorghum seedling growth. Through previous studies (Lipinsky et al., 1978) it was noted that sweet sorghum demonstrates low seedling vigor, especially in the midwestern United States where spring soil temperatures remain cool (12-17 C) until late May. It was hypothesized that the use of a plant growth regulator may enhance the ability of the sweet sorghum seedling to better establish itself under less-than-optimal conditions. This improved seedling growth may lead to earlier canopy closure, which may manifest itself at harvest with increased yields of biomass and fermentable sugar.

Very little research has been conducted on the effects of growth regulators on sweet sorghum. The work which has been done deals with the tolerance of sweet sorghum to selected pesticides and no work has been done on the use of chemicals to stimulate growth. Therefore, this feasibility test was an initial trial in the determination of the value of growth regulators in enhancing sweet sorghum seedling growth.

Results. Results of both the wet and dry yield of this study are highlighted in Table 25 .

Surprisingly, no treatment was better than the control. Possibly due to the lower radiation levels and cooler temperatures, the treated sorghum plants were under some type of physiological limitation that the growth regulator could not overcome. It was also noted that a large amount of variation occurred within each treatment group. Rather than being a function of experimental error it may be hypothesized that a large variation (e.g. vigor, emergence) exists in the sweet sorghum germplasm itself.

TABLE 25. WET AND DRY YIELD PER POT OF THE NINE TREATMENTS PLUS CONTROL[a]

Compound	Solution Concentration ppm	Wet Weight	Dry Weight
		g/pot	
Gibberellic Acid	2.5	21.65 a	3.95 a
	25	16.70 a	3.12 a
	250	24.54 a	4.49 a
Round-Up®	0.04	5.49 b	0.94 b
	0.4	- b	- b
	4	- b	- b
Triacontanol	0.01	22.55 a	4.23 a
	0.1	19.86 a	3.34 a
	1	18.94 a	3.32 a
CONTROL	----	25.59 a	4.44 a

NOTE: All plants died which were treated with 0.4 and 4 ppm Round-Up.

(a) See footnote for Table 9.

Dilute solutions of certain herbicides, such as Polaris® and 2,4-D, have been shown to stimulate plant growth; however in this study the Round-Up® solutions were not dilute enough because with two treatments plants were killed and with the third plants were severely stunted.

In previous studies which utilized plant growth regulators as early season growth enhancer, results were mixed. Over a short period (one or two weeks) plant growth tended to increase, but as the plant further developed growth rates were slowed (Alexander, 1979). Perhaps during the early growth spurt all reserve substrates are utilized and then exhausted; therefore, a stagnant period follows until supplies are replenished.

No differences were exhibited in percent dry weight among treatments (values ranged from 16.9 to 18.6 percent). Tillering ability appeared to decrease with the use of higher concentrations of gibberellic acid whereas triacontanol did not affect tillering.

Results indicate that gibberellic acid, triacontanol, and dilute solutions of Round-Up® have little value as early-season growth enhancers for sweet sorghum in the Midwest. Much more work is needed on enhancing vigor in sorghum; however this should be done through breeding rather than the utilization of early-season growth regulator applications.

Sweet Sorghum Studies at Belle Glade, Florida

Plant Population and Height

The plants were grown on Pahokee muck. Plant population was higher for the evenly spaced 71 cm rows than for the double rows (Figure 33). Plant height to the flag leaf was not significantly affected by row configuration (Figure 33).

Biomass and Sugar Yield

Dry biomass was significantly higher for the evenly spaced rows than for the double rows (Figure 33). Up to 11 t/ha of dry biomass were obtained. Sugar was significantly higher for the evenly spaced rows than for the double rows (Figure 33). Up to 5 t/ha of sugar were obtained.

Fiber

Higher fiber was obtained from the evenly spaced than from the double rows (Figure 33). The top production was 5.65 t/ha. The trash contributed up to 1.19 t/ha fiber.

Plant Nutrients

Nutrients removal by sweet sorghum was approximately 65, 9, and 81 kg/ha of N, P, and K, respectively. It was in proportion to the biomass harvested for the two row configurations (Figure 33).

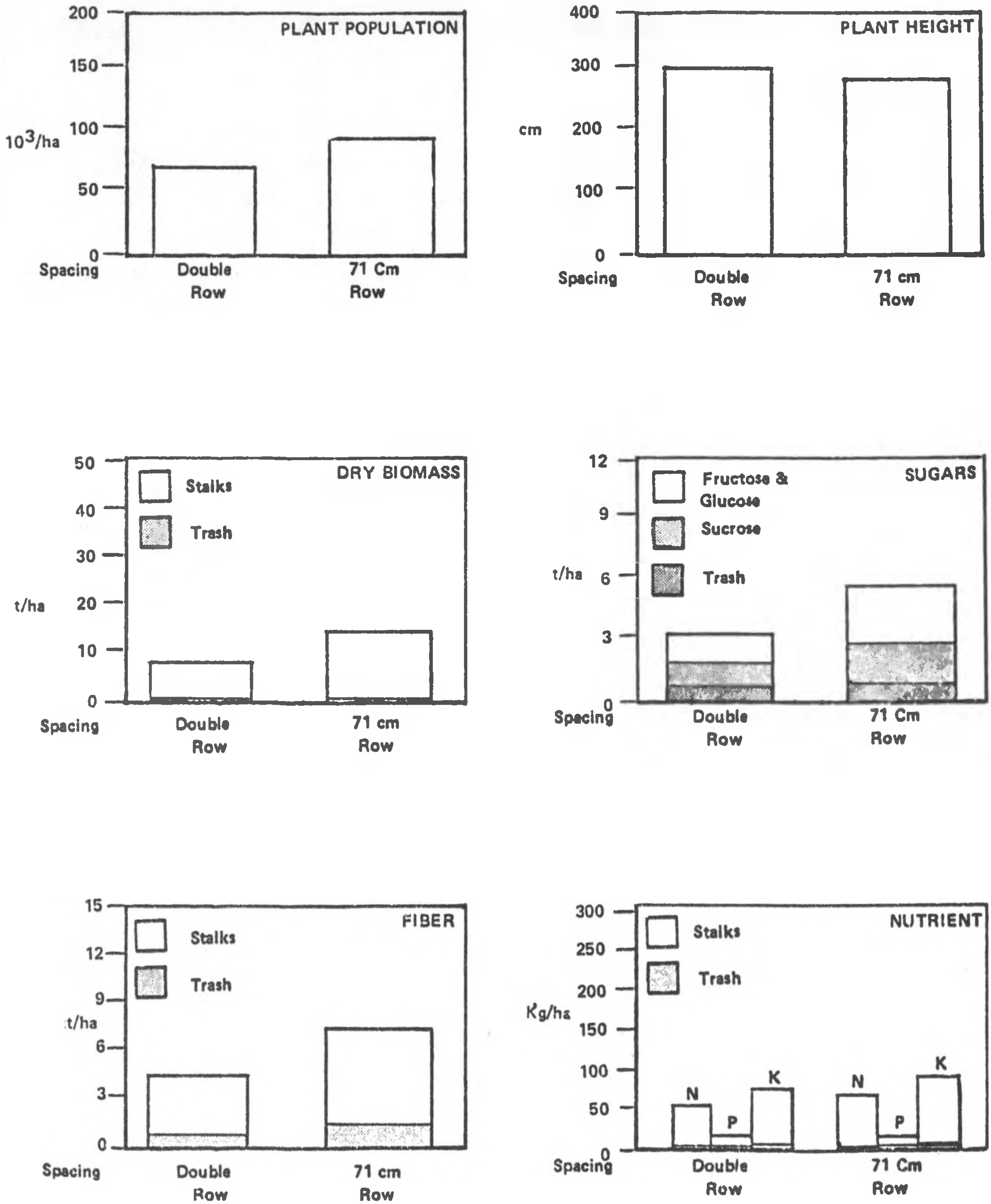


FIGURE 33. PLANT POPULATION, PLANT HEIGHT, DRY BIOMASS, TOTAL SUGARS, FIBERS, AND NUTRIENT ACCUMULATION OF SWEET SORGHUM AT MATURITY, BELLE GLADE, FLORIDA

Sweet Sorghum Studies at Manhattan, Kansas

Cultivar Selection

Observations for 18 cultivars of sweet sorghum grown primarily to determine general adaptation to Kansas are shown in Table 26.

There is considerable variation in flowering date among the eighteen cultivars. All varieties except Sart reached the soft dough stage and all except Sart and Brandes reached the ripe stage. Sugar content was determined by a hand held refractometer on October 20 and November 20. Unreplicated yields from a single row are also shown. These observations indicate that most of these cultivars of sweet sorghum could be grown successfully in Kansas.

TABLE 26. AGRONOMIC OBSERVATIONS FOR 18 VARIETIES OF SWEET SORGHUM, MANHATTAN, KANSAS, 1979

Cultivar	Dates for Selected Growth Stages					% Sugar		Dry Biomass (kg/row)
	Boot	Flower	Milk	Soft Dough	Ripe	Oct. 20	Nov. 20	
Sart	9/12	9/22	10/20	---	---	16.3	14.4	10.6
Ramada	9/7	9/17	10/1	10/10	10/20	15.6	18.3	16.9
Roma	9/2	9/8	9/18	10/1	10/15	14.0	16.6	97.1
MER 63-7	8/13	8/25	9/5	9/18	10/1	10.7	14.9	49.6
MER 69-5	8/16	8/24	9/5	9/21	10/1	13.3	12.9	54.1
Thesis	9/12	9/21	10/2	10/10	10/20	15.8	15.8	82.0
MER 61-1	8/27	9/5	9/21	10/3	10/15	9.2	14.6	120.2
Wray	8/28	9/5	9/15	10/2	10/14	17.9	20.1	81.4
MER 69-7	8/22	8/29	9/12	10/3	10/15	12.4	13.2	102.8
Collier	8/12	8/23	9/5	9/12	10/1	17.4	18.7	82.9
Rio	8/22	8/31	9/10	10/1	10/13	20.0	19.8	137.6
Sugar Drip	8/22	8/29	9/5	9/19	10/1	14.9	17.0	102.0
Rex	8/16	8/23	9/5	9/20	10/1	19.6	19.1	105.8
Brawley	8/13	8/22	9/5	9/20	10/3	19.3	19.3	95.4
MER 56-12	8/22	8/26	9/6	9/21	10/3	12.8	16.9	99.9
Keller	8/22	9/2	9/10	9/28	10/10	22.0	20.8	105.4
Dale	8/28	9/5	9/10	9/28	10/10	16.7	17.6	107.7
Brandes	9/5	9/15	10/1	10/15	---	17.7	18.6	162.4

Lodging

Plant height and stalk diameter are two of several factors related to standability in the field. Based on these two factors, Wray should be most resistant to lodging because it was shorter and had larger stalks. In 1979 very little lodging occurred, but some was noted, particularly in rows adjacent to those removed by sampling at the boot and 50 percent flower stages. The visual lodging data in Table 27 were taken August 16 as percent of the plot lodged. These data show that Wray lodged most, and Dale, least, in this study.

TABLE 27. WIND DAMAGE AS ESTIMATED BY MEANS OF PERCENT LODGING OF 4 REPLICATIONS OF SWEET SORGHUM, MANHATTAN, KANSAS

Cultivar	Row Spacing (cm) 50	75	100	Mean
	% Lodged			
Wray	14.2	11.5	15.0	13.6
Dale	1.0	0.5	6.5	2.7
Rio	1.5	9.0	18.7	9.7
Mean	5.6	7.0	13.4	8.7

Most of the lodging occurred as stalk breakage during a severe wind and rain storm when the plants were in the boot stage of head development. Lodging generally decreased as the space between rows increased (Figure 35). Wray was superior to Rio in resistance to lodging, especially for stalk breakage.

Sweet Sorghum Row Spacing Trial at Meridian, Mississippi

Biomass and Sugar Yields

Rows spaced 46, 61 cm and two lines of plants centered on 107-cm produced more dry stalks than those spaced 107 cm. Rows spaced 76, 91, and 107 cm were similar in dry stalk biomass (Fig. 34). The row spacing x cultivar interaction was highly significant. Row width affected dry stalk production more with Wray than Rio.

Rows spaced 46, 61 cm and two lines of plants centered on 107-cm produced more dry leaf biomass than those spaced 107 cm (Figure 34). Rows spaced 76, 91, and 107 cm were similar in dry leaf biomass. Rio produced more dry leaf biomass than Wray. Dry top biomass is discussed in the section below.

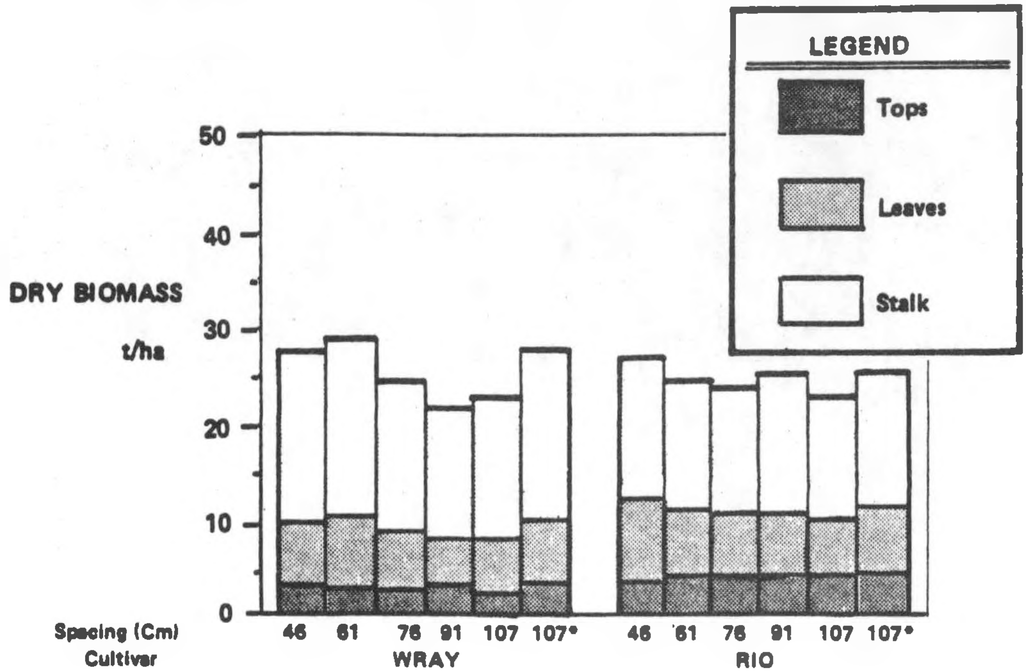
Juice Brix and sucrose were not affected by row spacing (Figure 34). Wray was superior to Rio in Brix and sucrose. Row spacing did not affect yield of sucrose and fermentable sugar per ton of stalks or per hectane. Wray was superior to Rio in yield of sucrose and fermentable sugar per ton of stalks and per hectare.

Stalk Weight

Rows spaced 46, 61 cm and two lines of plants centered on 107 cm produced lighter stalks than those spaced 107 cm. Rows spaced 76, 91, and 107 cm produced stalks with similar weight. Wray produced heavier stalks than Rio on all row widths.

Dry Top Yield

Row spacing had no significant effect on yield of dry tops and seed. Rio produced more dry tops and seed than did Wray.



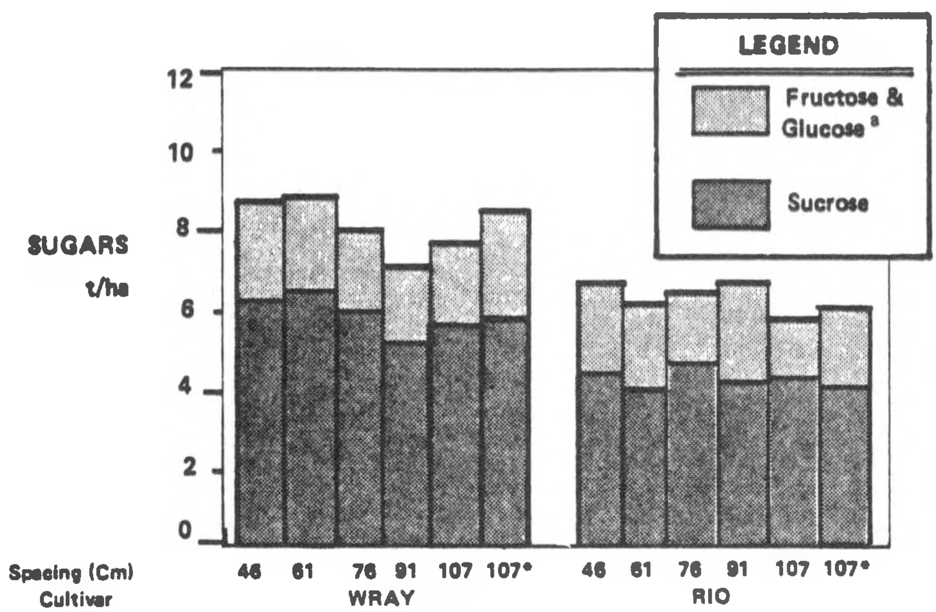


FIGURE 34. DRY BIOMASS AND TOTAL SUGARS IN STALKS OF SWEET SORGHUM AT MATURITY, MERIDIAN MISSISSIPPI

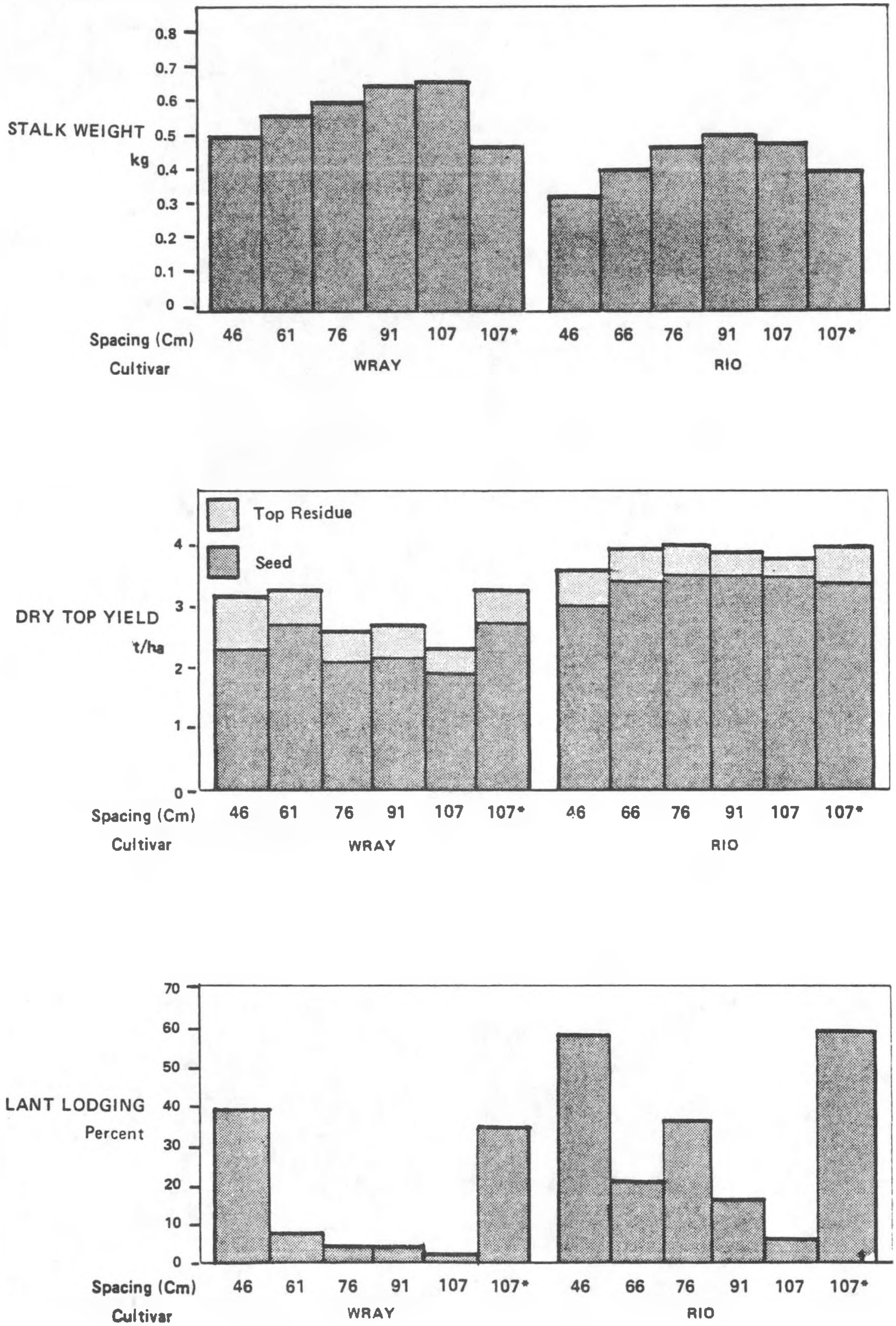


FIGURE 35. STALK WEIGHT, DRY TOP YIELD, AND PLANT LODGING OF SWEET SORGHUM AT MATURITY, MERIDIAN, MISSISSIPPI

Sweet Sorghum Cultivar Selection at Lincoln, Nebraska

Fifty cultivars of sweet sorghum were planted in short one-row plots to screen for high biomass and sugar yields (Table 28). Several cultivars were above 15 t/ha for biomass and 4 t/ha for total sugar yield. Thus, sweet sorghum is highly adaptable to growth in the Lincoln area.

Sweet Sorghum Studies at Fargo, North Dakota

Cultivar Selection

Sweet sorghum is a warm-up season crop adapted to the temperate climates of the world. Most sweet sorghum genotypes available in the United States were developed and grown in the humid South with little information available on genotypic response under northern climatic conditions. Therefore, our objective was to evaluate sweet sorghum's genotypic response to the very short growing season, long daylength climate typical of Fargo.

The plant density and maturing rating for 17 sweet sorghum genotypes grown at Fargo, in 1979 are presented in Table 29. Stands were excellent for all genotypes except Ramada, Sart, Wray, and MER 63-7. The plant density may be a reflection of seed availability rather than stand establishment since all seed supplied was planted and stands thinned to approximately 4.4 plants/m. MER 61-1 and MER 63-7 were the earliest maturing sweet sorghums with 30-70 percent anthesis on September 11, but

TABLE 28. BIOMASS AND SUGAR YIELDS FOR 50 SELECTED CULTIVARS OF SWEET SORGHUM, LINCOLN, NEBRASKA

Variety	Biomass	Sugar Yield			
		Glu	Fru	Suc	Total
	t/ha				
76-60 x 63	18.1	2.05	1.13	2.11	5.29
76-66 x 67	21.1(a)	1.44	1.28	2.51	5.23
76-185 x 188	15.4	1.06	1.03	4.12	6.21
76-197 x 201	12.7	1.06	.89	1.64	3.59
76-209-211	17.9	.79	.78	2.73	4.30
76-305 x 308	16.9	.55	.52	3.45	4.52
Wray	13.2(a)	1.21	1.03	2.67	4.91
N48A x EH (ROX) R	10.5	.84	.74	2.26	3.84
N48A x EH (WS) R	8.9	.41	.35	1.42	2.18
N48A x WC	8.6(a)	.36	.33	2.06	2.75
N4692A x EH (SART) R	18.1(a)	.74	1.82	3.09	5.65
N4692A x EH (ROX) R	7.9	.48	.42	1.38	2.28
N4692A x EH (WS) R	7.9	.36	.38	2.76	3.50
N4692A x WC	10.3(a)	.62	.61	2.87	4.10
Dale	15.8(a)	2.25	2.07	1.00	5.32
CK-El (T) A x EH (ROX) R	7.8(a)	.33	.33	.87	1.57
CK-El (T) x WC	7.9(a)	.29	.38	1.01	1.68
CK-AT (T) A x EH (SART) R	12.5	.51	.62	2.39	3.52
CK-AT (T) A x EH (WS) R	11.2	.50	.44	2.34	3.28
CK-AT (T) A x WC	8.8	.42	.43	2.01	2.86
African Millet	10.5	.35	.44	2.07	2.86
78-1612	9.3	.36	.35	2.86	3.57
Brawley (Ne)	16.1(a)	.38	.34	5.48	6.20
Honey	10.9	.64	.53	1.27	2.44
Coleman	12.0	.59	.43	2.68	3.60

TABLE 28. CONTINUED

Variety	Biomass	Sugar Yield			
		Glu	Fru	Suc	Total
	t/ha				
Hastings	15.5	.75	.63	3.50	4.88
Kansas Sourless	9.9	.38	.34	2.87	3.58
Early Folgers	8.0	.35	.34	2.25	2.94
Sugar Drip (Ne)	15.5	.74	.64	4.27	5.65
Waconia	10.9	.67	.50	3.32	4.49
Iceberg	11.8	.90	.77	2.83	4.50
Atlas	12.2	1.07	.79	1.72	3.58
Katengo	16.1	.73	.62	3.09	4.44
Basuto Rio	7.0(a)	.30	.27	1.16	1.73
Red X	10.5	.60	.48	3.02	4.10
Sugar Drip (Miss)	13.9	.88	.73	3.75	5.36
Rex	14.4	.48	.53	4.44	5.45
Collier	13.5	.63	.70	2.54	3.97
Brawley (Miss)	14.3(a)	.61	.40	5.49	6.50
MER 56-12	10.2(a)	.46	.44	2.33	3.23
MER 63-7	7.7	.86	.70	1.15	2.71
Keller	20.0	.59	.74	5.13	6.46
MER 61-1	17.0(a)	.79	.74	3.24	4.77
MER 69-5	12.8	.72	.66	2.40	3.78
MER 69-7	9.3(a)	.56	.69	.82	2.07
Brandes	13.8	1.16	.97	2.49	4.62
Sart	15.1(a)	.62	.66	3.35	4.63
Theis	17.4(a)	1.83	1.66	2.13	5.62
Rio	14.7(a)	.37	.21	4.90	5.48
Roma	14.2(a)	.71	.89	2.40	4.00

(a) One replication.

even those varieties were only approaching the soft dough growth stage when a killing frost occurred October 4, about 1 week later than normal. Six genotypes - Wray, MER 69-7, Keller, Dale, Rex, and Collier - were in the late jointing to boot stage, and five genotypes - Brandes, Sugar Drip, Brawley, Rio, and Rex - were in the late boot to heading growth stage when harvested. A late planting date and a cool August were experienced in 1979 which might influence the sweet sorghum's maturity. Conversely, September was 2.3 C above normal. These data suggest that an earlier maturing sweet sorghum variety may be necessary to grow sweet sorghums effectively under Fargo conditions.

Biomass was not significantly different among 10 of the 17 genotypes tested (Figures 36-37). Sugar Drip, MER, 63-7, Rio, and MER 69-5 were the only genotypes yielding above 12 t/ha. MER 69-7, Dale, Sart, Roma, and Ramada genotypes yielded from 9.0 to 10.4 t/ha and were the lowest yielding genotypes. Biomass was not necessarily associated with the maturity of the sweet sorghum. Sugar Drip was a high yielding, late maturing genotype while MER 63-7 was an early maturing, high yielding genotype. Conversely, MER 69-7 was an early maturing, high yielding genotype while Roma and Ramada were low yielding, average maturing genotypes.

Dry stalk yields were not significantly different among 12 of the 17 genotypes tested (Figure 36). MER 63-7, Sugar Drip, Rio, and Keller produced 7.0 t/ha dry stalk yields. MER 69-7, MER 61-1, Dale, and Brandes produced the lowest stalk yields with less than 6.0 t/ha. Stalk yields tended to follow total dry biomass yield with exceptions like Brandes and MER 61-1. Stalks comprised an average 57 percent of the biomass ranging from 45 to 64 percent depending on the genotype. Dry leaf yields ranged from 2.9 t/ha for Roma to 5.2 t/ha for Brandes and Sugar Drip. Immature genotypes tended to have the highest leaf yields. Tops contributed significantly to dry matter yields of only early maturing genotypes like MER 61-1 and MER 63-7.

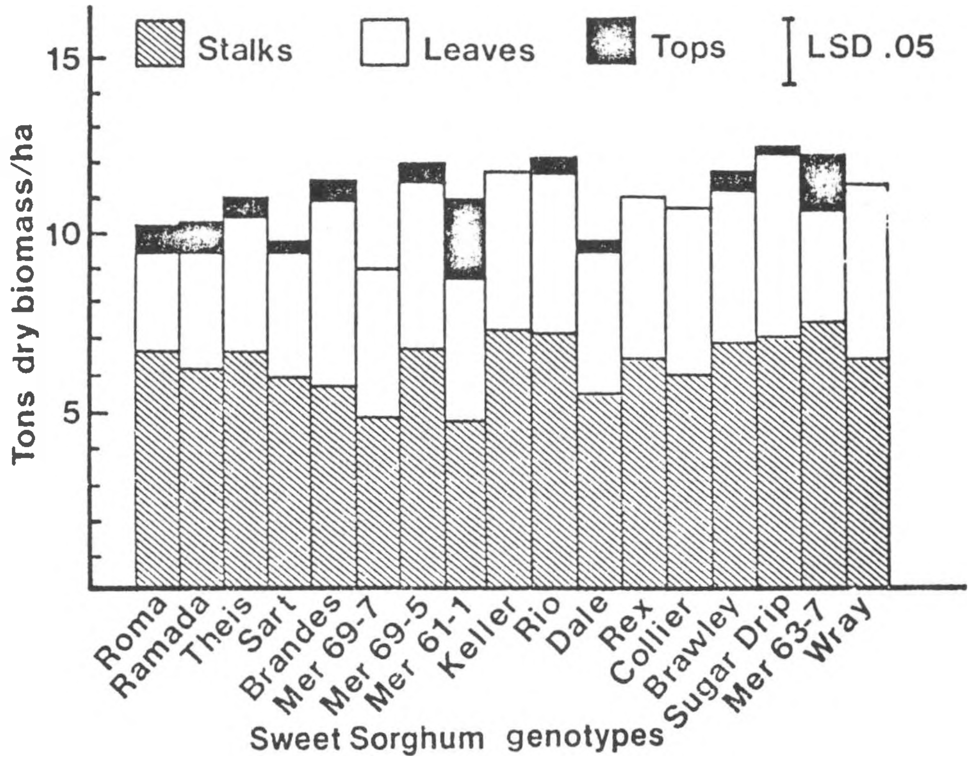


FIGURE 36. DRY BIOMASS YIELD BY PLANT FRACTION FOR 17 SWEET SORGHUM GENOTYPES GROWN IN LINCOLN, NEBRASKA

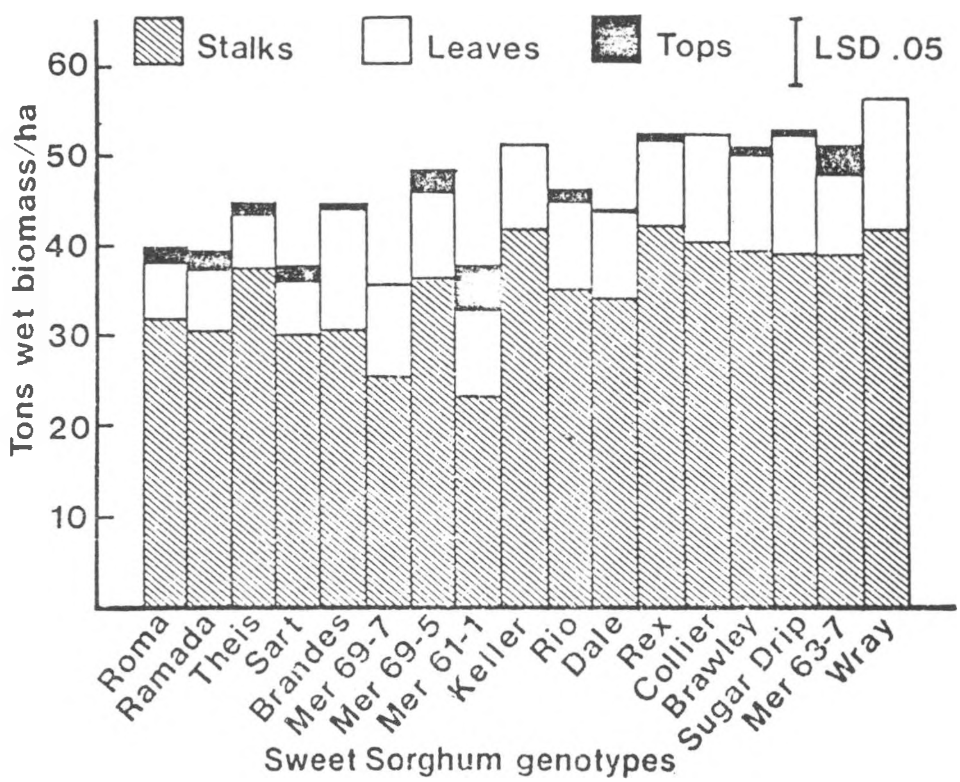


FIGURE 37. WET BIOMASS YIELD BY PLANT FRACTION FOR 17 SWEET SORGHUM GENOTYPES GROWN IN NORTH DAKOTA

Wet biomass averaged 45.1 t/ha with seven genotypes; Wray, Sugar Drip, Keller, Rex, Collier, MER 63-7, and Brawley (Figure 37). Wet stalk yields were near 40 t/ha in the same seven varieties.

Plant height and stalks/ha harvest for 17 sweet sorghum genotypes grown at Fargo in 1979 are presented in Figure 38. Keller and Theis were substantially taller than the other genotypes. Theis may be photoperiod sensitive since it was tall and nonflowering. MER 61-1 and Brandes were the shortest genotypes even though Brandes had just begun heading prior to the frost. Brandes, Brawley, and Sugar Drip produced the most stalks/ha averaging over 200,000 or about 2.9 stems/established plant. Sart produced only 109,000 stalks/ha. Sart's low stem number may be partially due to its poor initial stand (Table 29).

Keller, Theis, Rio, and MER 69-5 genotypes produced the highest per hectare fiber yields averaging 2.47 t/ha (Figure 39). Brandes, MER 69-7, and MER 61-1 were the lowest fiber producing genotypes. Percent fiber averaged 33.2 and ranged from 29.1 for Brandes to 38.8 for Theis.

The 17 genotypes differed significantly in percentage glucose and sucrose, but not in fructose, found in the stalks (Figure 40). Ramada had the highest percentage (29.5 on dry basis) sucrose. Roma, Theis, and Sugar Drip were other genotypes high in glucose percentage. The 17 genotypes did not differ in fructose percentage.

Total sugar/ha averaged 2.14 t/ha but ranged from 1.24 to 2.97 t/ha for MER 69-7 and MER 73-7, respectively (Figure 41). Genotypes yielding equal to or higher than Sugar Drip were not significatly different from MER 63-7 in total sugar yields. Rio produced 2.37 t/ha total sugar in 1979, substantially higher than the 1.76 t/ha reported by Schou in 1970. The predominant sugar comprising the majority of the total sugars varied with the genotype. Sucrose was the predominant sugar in all genotypes but Brandes, MER 69-7, Dale, Sugar Drip, and MER 63-7.

TABLE 29. PLANT DENSITY AND MATURITY RATINGS FOR 17 SWEET SORGHUM GENOTYPES GROWN AT FARGO, NORTH DAKOTA

Entry	No. of Plants/6.8 m July 18, 1979	Maturity Stage September 11, 1979	Maturity Stage October 10, 1979
Roma	30.8	Late boot to early heading	Early flowering
Ramada	23.5	Heading	Early flowering
Theis	29.5	Late jointing to early boot	Heading to early flowering
Sart	25.5	Early heading	Early flowering
Brandes	28.5	Jointing	Boot to early heading
MER 69-7	28.0	Late jointing	Boot
MER 69-5	29.0	Late boot to early heading	Flowering
MER 61-1	28.5	50-70 percent anthesis	Milk to soft dough
Keller	29.0	Late jointing	Boot
Rio	30.0	Late jointing to early boot	Early heading
Dale	28.8	Late jointing	Boot
Rex	29.8	Late jointing to early boot	Boot to flowering
Collier	28.8	Late jointing	Boot
Brawley	30.5	Late jointing	Early heading
Sugar Drip	29.5	Late jointing to early boot	Boot to early heading
MER 63-7	26.8	30-50 percent anthesis	Soft dough
Wray	25.7	Jointing to late jointing	Late jointing-early boot

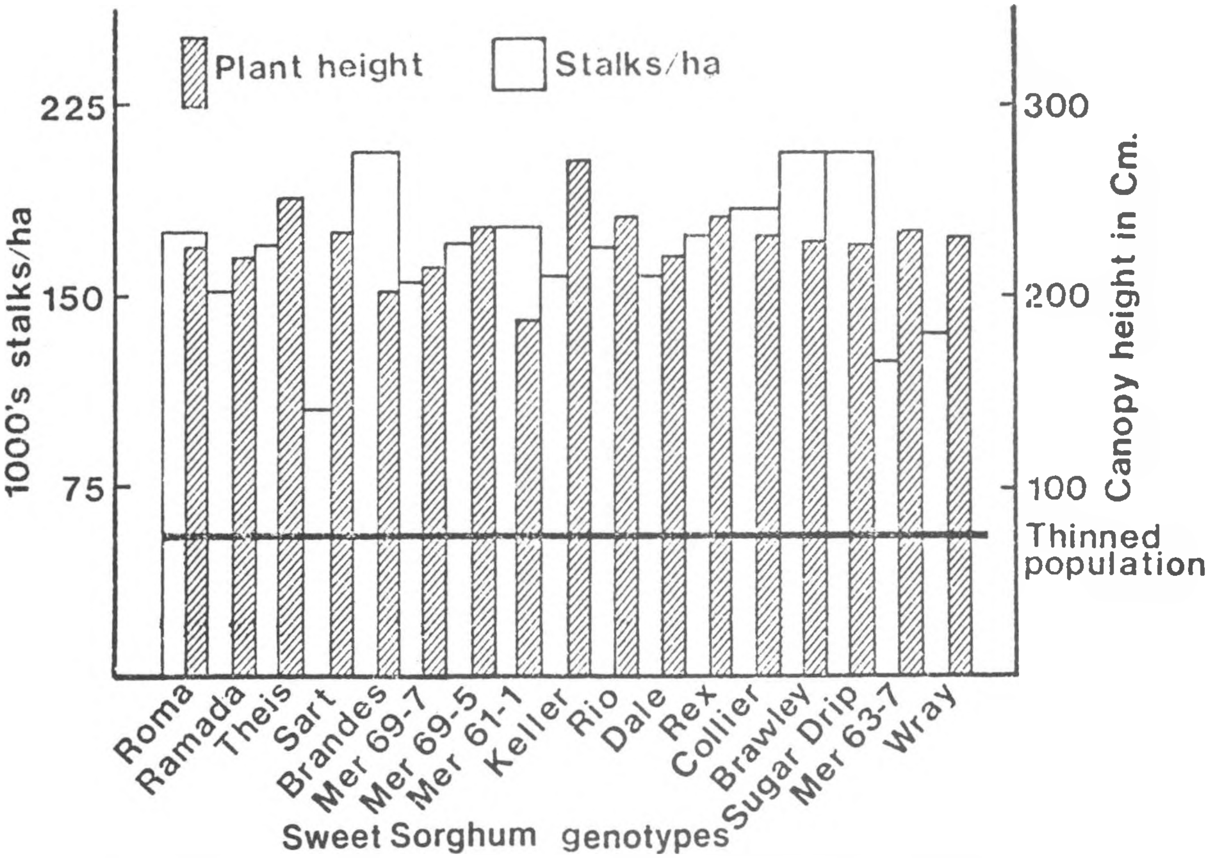


FIGURE 38. STALKS/HA AND PLANT HEIGHT AT THE FINAL HARVEST FOR 17 SWEET SORGHUM GENOTYPES GROWN IN NORTH DAKOTA

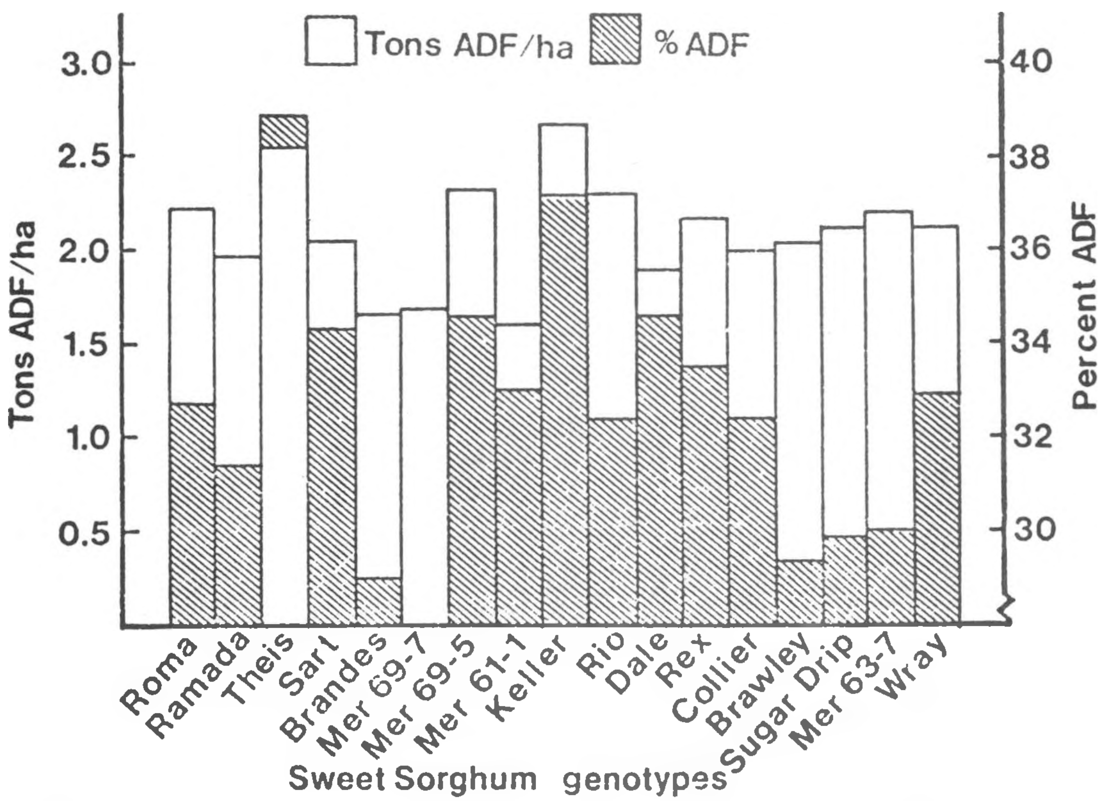


FIGURE 39. FIBER YIELD AND PERCENTACE IN STALKS OF 17 SWEET SORGHUM GENOTYPES GROWN IN NORTH DAKOTA

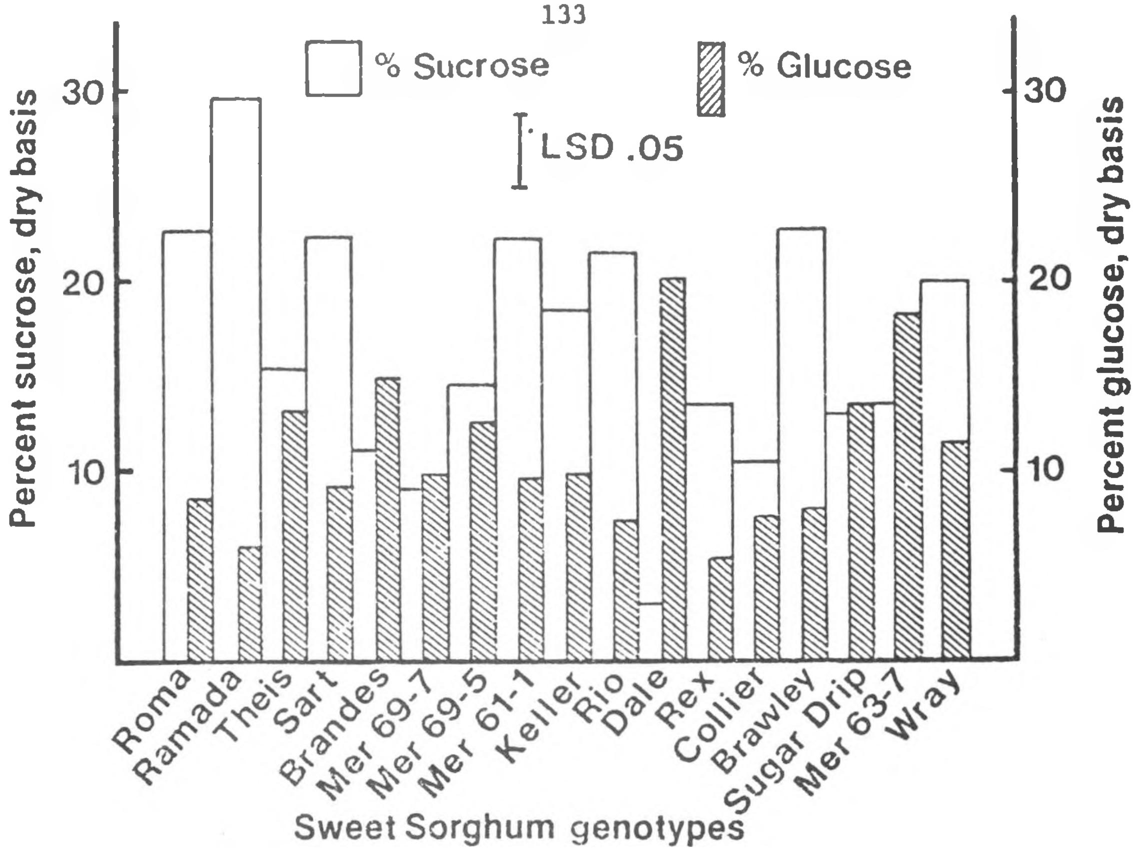


FIGURE 40. PERCENT SUCROSE AND GLUCOSE IN THE STALKS OF 17 SWEET SORGHUM GENOTYPES GROWN IN NORTH DAKOTA

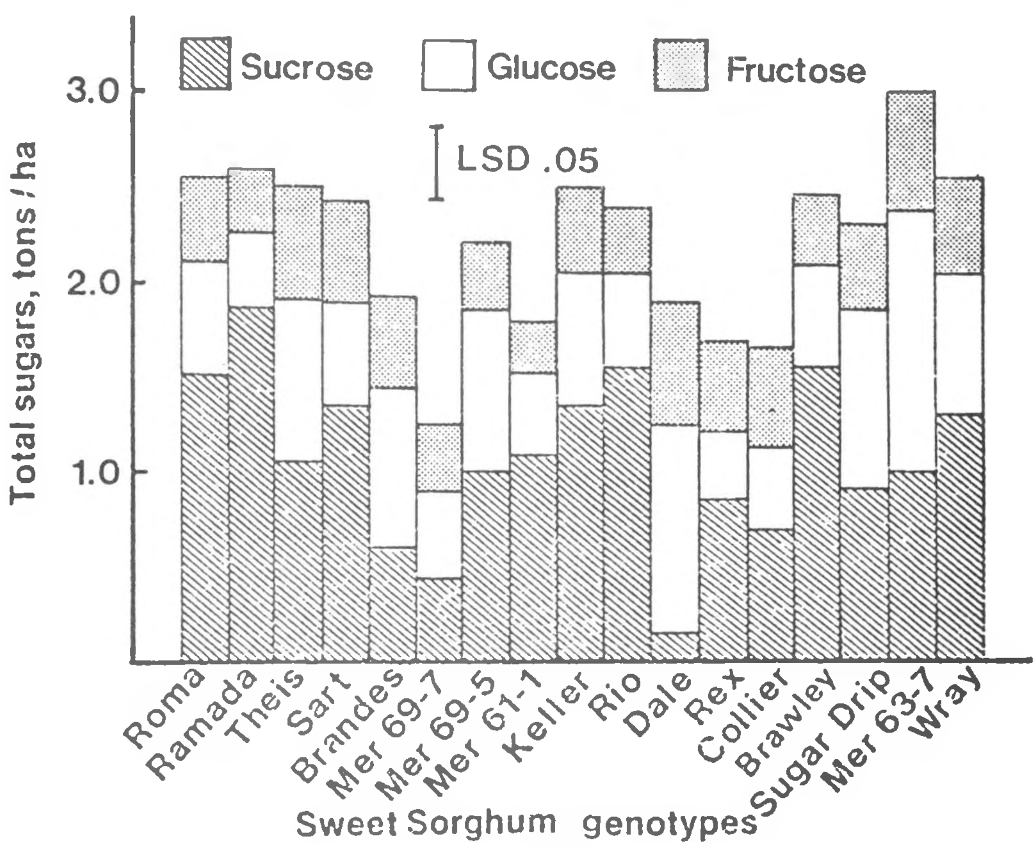


FIGURE 41. TOTAL SUGARS (SUCROSE, GLUCOSE, AND FRUCTOSE) IN STALKS OF 17 SWEET SORGHUM GENOTYPES GROWN IN NORTH DAKOTA

Nitrogen Fertilization Trials

One major requirement to facilitate sweet sorghum as a viable energy crop is a faborable relationship between the BTU's necessary to grow and convert the crop to fuel and the BTU's produced by the crop. The amount of commercial N applied to sweet sorghum fields will affect this relationship since commercial N production requires large quantities of natural gas. However, N is an essential element necessary for economical production of sweet sorghum. Therefore, the objective was to preliminarily evaluate the effect of N fertilization rate on biomass, sugar production, and nutrient removal by sweet sorghum.

Increasing the nitrogen rate increased the wet and dry sweet sorghum biomass (Figure 42A). Applying 50 kg N/ha increased the dry biomass 1.32 t/ha above the unfertilized treatment. The next N increment increased the yield only 0.54 t/ha, the next two increments increased the yield only 0.33 t/ha. Stalk yields increased linearly for the first two N increments which increased the stalk yield from 4.56 t/ha for the unfertilized treatment to 5.64 t/ha for the 100 kg N/ha treatment. Leaf yields increased about 15 percent with the first N increment but increased only slightly at higher rates. Tops yield appeared to increase slightly for the first N increment but the increase was not statistically significant. The percentage stalk, leaf, or top fraction of the total biomass was unaffected by the N fertilization rate.

Percent N in the stalk, leaf, or top fraction was not affected by the fertilization rate (Figure 42B). Leaves and tops contained about twice the percentage N as stalks. Nitrogen fertilization increased the amount of N/ha removed in the stalk or top fraction or the total removal. If only stalks were harvested, less than 50 kg N/ha was removed. If the whole plant was harvested, 100 to 135 kg N/ha was removed.

Total and percentage P in three sweet sorghum plant fractions as influenced by the N fertilization rate is shown in Figure 42C.

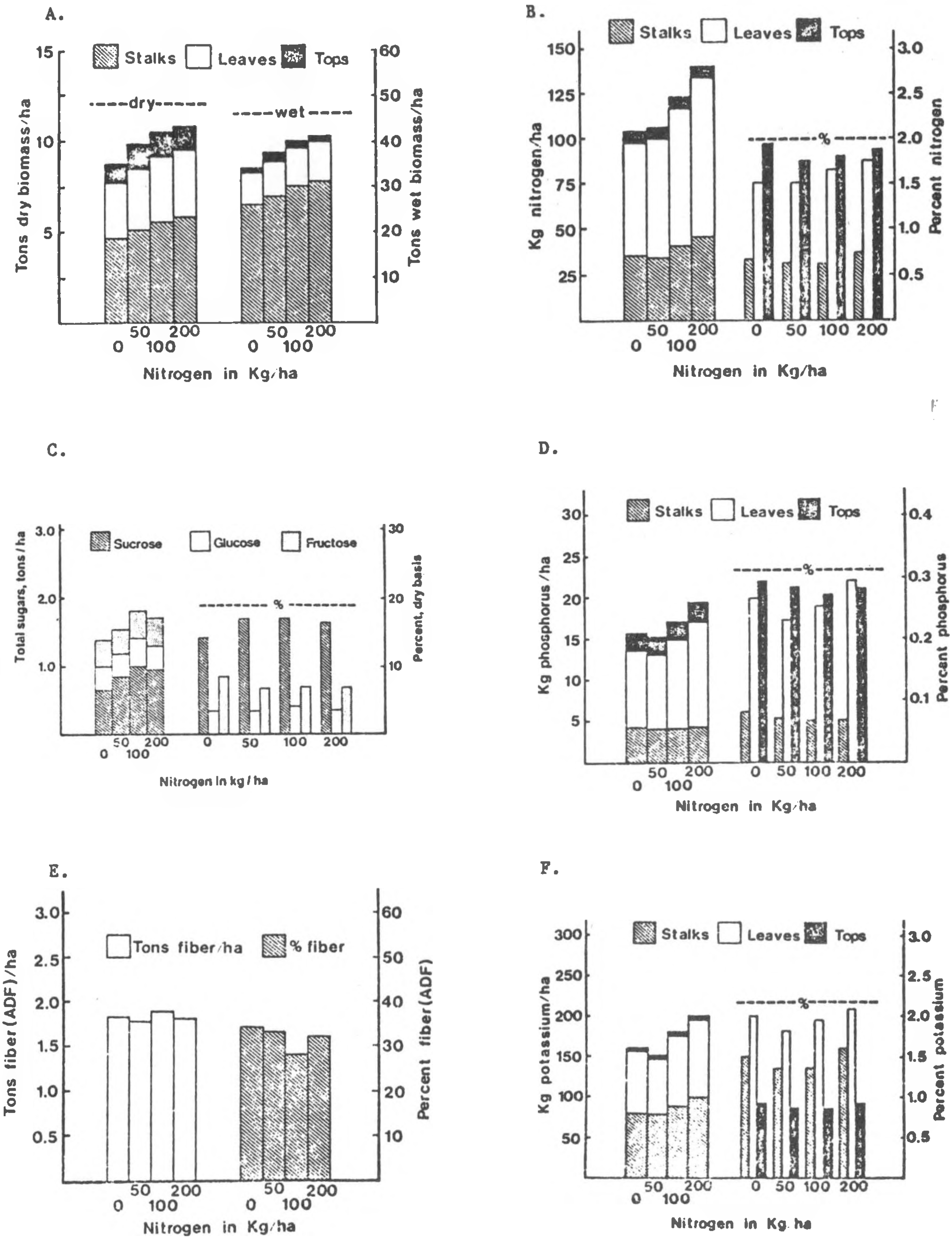


FIGURE 42. NITROGEN FERTILIZATION TRAILS, FARGO, NORTH DAKOTA

Percentage stalk and top P was unaffected by the N rate. Leaf P percentage decreased with the initial N increment and increased with additional increments. Leaf and top P percentages were 3.9 times higher than the additional stalk level. Phosphorus usage increased at high N rates primarily due to increased dry biomass and increased leaf P percentages. Removal of P by stalks was unaffected by the N rate and averaged less than 5 kg/ha annually.

Percentage and total K in three sweet sorghum plant fractions were not affected significantly by the N fertilization rate; however, the general trend was increased K usage with 100 and 200 kg N/ha treatments (Figure 42D). Leaves averaged about 2.0 percent, stalks 1.5 percent, and tops 0.9 percent K. Harvesting stalks only would remove about 80 to 100 kg K/ha.

Nutrient removal by sweet sorghum was not influenced extensively by the N fertilization rate in 1979. These data are affected undoubtedly by the high availability of soil nutrients in Fargo clay soils and possibly by partial leaching of mobile nutrients such as N by the heavy June 28 thunderstorm. Sweet sorghum can be grown with minimal N additions (50 to 100 kg/ha) and little, if any, P and K fertilization, especially if only stalks are harvested.

Percent fiber and fiber yield in stalks of sweet sorghum as influenced by the N fertilization rate are presented in Figure 42E. Percent fiber and fiber yield were not affected by the N rate.

The N fertilization rate did not affect the glucose, sucrose, or fructose percentage in stalks of MER 56-12 sweet sorghum (Figure 42F). Total sugar yield increased 1.0 mt/ha with 100 lbs N/ha compared to unfertilized sweet sorghum, but this difference was significant at the 10 percent level only. The level of sugar production with N rate followed the dry matter yields.

Deferred Processing Experiment

Sweet sorghum harvest under Fargo conditions would normally begin after a killing frost. It is not uncommon for temperatures to remain cool following a killing frost. Thus, the effect of delayed harvest on the sugar level of stored stalks was determined.

Total sugars in stalks of sweet sorghums as influenced by the time of processing is shown in Table 30. Standing samples of Wray had sugar levels on November 5 similar to the level of October 4. Delayed harvest to November 5 by letting the sweet sorghum stand in the field probably would be impractical since severe lodging occurred October 17 which could hinder harvesting. Delayed harvest to December 6 decreased total sugars and resulted in an apparent conversion of some sucrose to simpler sugars.

Piled samples of MER 63-7 sweet sorghum decreased slightly in total sugar primarily due to a decrease in glucose levels with storage from October 4 to November 5. Dry matter samples were nearly similar with the November 5 sampling about 1.5 percent above the 19 percent average at the October 4 harvest. Storage until December 6 resulted in a loss of 20 percent of the total sugars with an apparent conversion of some sucrose to glucose and fructose.

TABLE 30. TOTAL SUGARS, SUCROSE, GLUCOSE, AND FRUCTOSE LEVELS IN STALKS OF SWEET SORGHUM AS INFLUENCED BY THE DATE OF HARVEST AT FARGO, NORTH DAKOTA IN 1979

Harvest Date	Total Sugars	Sugar in mg/ml Sucrose	Glucose	Fructose
	Standing Wray			
October 4	12.20	5.76	3.90	2.54
November 5	12.37	6.42	3.80	2.15
December 6	10.24	2.88	4.08	3.28
	Piled MER 63-7			
October 4	16.39	6.00	7.18	3.21
November 5	15.04	6.90	4.82	3.32
December 6	13.24	3.27	5.77	4.20

High-Energy and Sweet Sorghum Field Trials at Weslaco, Texas

Total Carbohydrate Production of Selected High-Energy Sorghum Cultivars. Interpreting the need for superior crops for energy production, there is required a necessary restructuring of the plant to maximize the total energy contained in that plant - the leaves, stems and grain. The present crop plants have been bred for very specific uses. As new traits are identified and proven, they are added to those already used in the production of food, feed and fiber. The use of known genes which cause an increase of sucrose and other carbohydrate storage in the stem of some *Sorghum bicolor* (L.) Moench cultivars has not yet been completely accomplished. There is much diversity within this species that should allow for major improvement in "total fermentables" contained within the stem. The ramifications of diverting photosynthate from grain production, and the role of non-senescence on carbohydrate buildup in the stem after grain maturation need major research.

A high-yielding grain sorghum having a sweet stalk has been suggested as a potential candidate as a source of food and energy. Such a high energy-sorghum (H.- E. sorghum) would allow for the production of alcohol from carbohydrates contained in both stalks and grain. In addition, production of fuel H.-E. sorghum can be used as a food and fiber source. For example, H.-E. sorghum grain is of adequate quality for human food, while both the grain and stalk can be used as livestock feed, and stalk fibers are suitable for use in pressed board, 2 × 4's or paper. Thus, a H.-E. sorghum might provide a grower much greater marketing flexibility. Several candidates were planted at the Texas Agricultural Experiment Station at Weslaco for screening in 1979. Seed stocks of other lines are being increased for testing in 1980.

A breeder's nursery was planted at Weslaco as a means of observing a large selection of hybrids for their potential as a H.-E. sorghum. Cultural practices are outlined in Table 31. Figure 43 compares five selections from these observation plots. A striking feature is the ratio of glucose-fructose to sucrose. This indicates there is the needed genetic variability for the development of a high energy sorghum that could potentially meet the needs of a sugar

TABLE 31. CULTURAL PRACTICES APPLIED TO H.-E. SORGHUM PLOTS AT WESLACO, TEXAS, 1979

Row Width	68 cm
Date Planted	March 7 and 8 on moisture
Date Thinned	April 6
Fertilizer	2 kg liquid N 32 applied January 24 pre-plant 45 kg applied April 19
Herbicide	0.68 kg Igran/acre
Insecticide	0.45 kg Sevin. May 20, May 23, May 29, May 31. Sevinal applied June 2, 4, and 6 by plane
Harvested	July 2

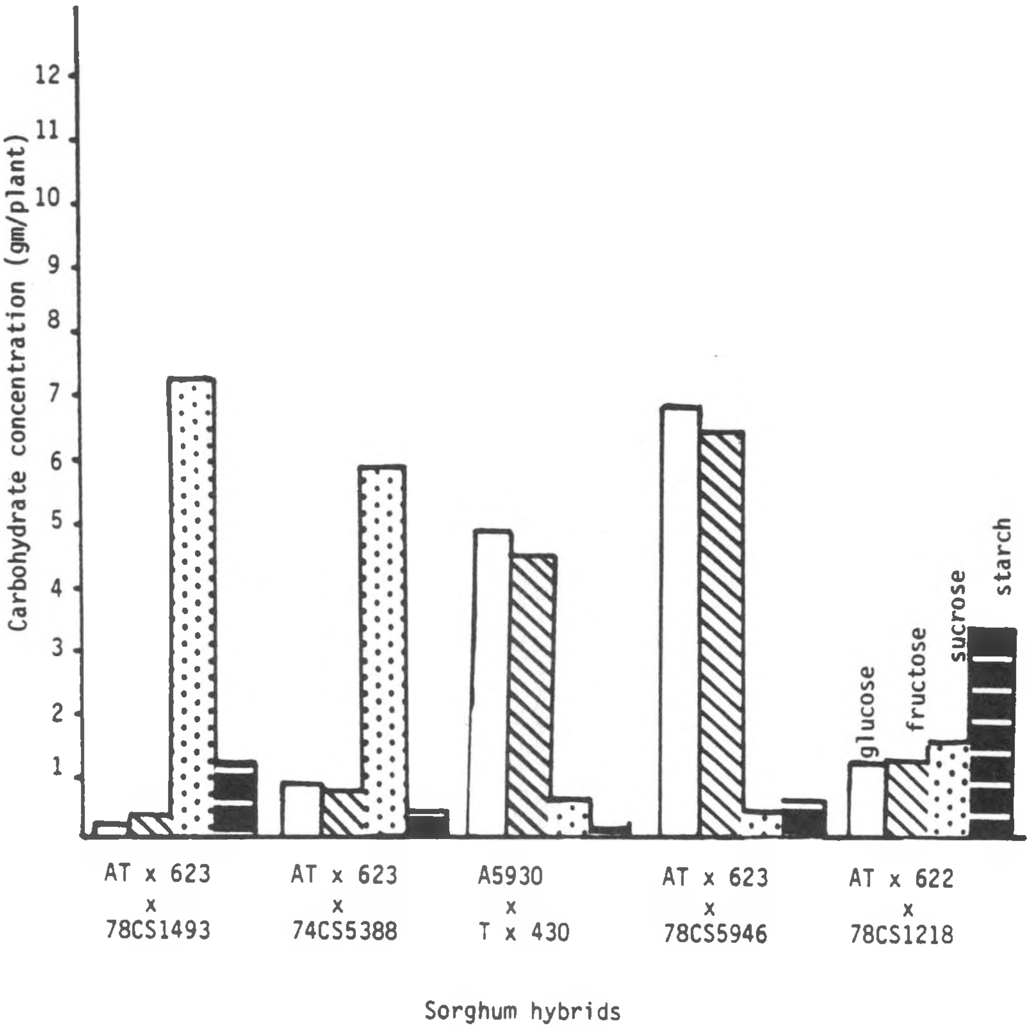


FIGURE 43. GLUCOSE, FRUCTOSE, SUCROSE, AND STARCH IN STALKS OF FIVE SELECTED EXPERIMENTAL H.-E. SORGHUM HYBRIDS AT WESLACO, TEXAS, IN 1979

industry. These sorghums also had grain yield ranging from 5,605 to 7,847 kg/ha (Table 32). Mean daily carbohydrate accumulation, including starch and sugars, ranged from 52.6 to 64.2 kg/ha resulting in a total carbohydrate yield of 5,469 to 6,680 kg/ha. Carbohydrate yields per day can be compared with 62.9 kg/ha for Rio.

A replicated biomass test was planted to determine grain yield, stalk sugars, and potential alcohol yield of eleven breeding lines and hybrids (Table 33). The greatest daily total carbohydrate accumulations were 63 and 61 kg/ha for Rio, a sweet sorghum, and for ATx623xRTx430, a H.-E. sorghum, respectively. A large percentage of the carbohydrate yield for ATx623 x RT2430 was due to the 7,419 kg/ha grain yield while Rio produced only 5,736 kg/ha of grain. Atlas had the highest sugar yield (Figure 44) but yielded only 1,680 kg/ha of grain. This low grain production limited total carbohydrate yield from Atlas.

Preliminary screening for H.-E. sorghum indicates there is adequate genetic material to increase stalk carbohydrate concentrations while maintaining high grain yield. Results indicate that not only can high stalk carbohydrate levels be maintained, but the ratio of glucose/ fructose to sucrose can be altered to meet the needs of industry.

H.-E. sorghum will be capable of producing fermentable carbohydrates at a rate equal to or higher than sweet sorghums, thus providing a good energy crop in areas with short growing seasons. An added advantage of H.-E. sorghum is the production of stable carbohydrates in the grain (starch) which can be stored and used when needed).

<u>Cultivar vs. Post-Harvest Treatment of Rio and Rio SC</u>. Both cultivar and treatment effects were significant for stalk yields, juice yields, and Brix (Table 34). Cultivar-by-treatment interaction was significant for juice weight only. Duncan's multiple range test on treatment means indicated for stalk and juice yield that immediate harvest (no storage) was significantly greater than either of the 2-week storage treatments. For Brix 2-week storage (field) and no stroage treatments were significantly greater than 2-week storage (shed).

TABLE 32. SELECTED CHARACTERISTICS OF FIVE H.-E. SORGHUM RESULTING IN ESTIMATED YIELDS OF ALCOHOL PER HECTARE[(a)]

H.-E. Sorghum Hybrid	Grain Yield kg/ha	Starch Yield @ 75% of Grain Weight	Total Stalk Carbohydrate gm/plant		Total Daily Carbohydrate kg/ha	Total Carbohydrate kg/ha	Total Estimated l/ha Alcohol Yield @14:1
			Starch	Sugars			
ATx623x70CS1493	6,726	5,045	1.22	7.52	60	6,628	3,732
ATx623x74CS5388	7,847	5,885	0.30	7.65	64	6,680	3,981
ATx623x78CS5946	6,950	5,213	0.60	13.81	63	6,509	3,879
A5930xTx430	5,605	4,204	0.03	9.71	53	5,469	3,260
ATx622x78CS1218	6,614	4,961	3.21	3.42	55	5,723	3,410

(a) Data collected from nonreplicated observation plots.

TABLE 33. SELECTED CHARACTERISTICS OF SORGHUM BREEDING LINES AND HYBRIDS IN BIOMASS TEST RESULTING IN ESTIMATED YIELDS OF ALCOHOL PER HECTARE

Hybrid	Grain Yield kg/ha	Starch Yield @ 75%	Total Stalk Sugars kg/ha	Days to Maturity	No Plants/ha	Total Carbohydrate kg/ha	Total Carbohydrate kg/ha/day	Total Estimated Alcohol l/ha @14:1
BTx3197[a]	2,776	3,082	83	95	207,000	2,165	23	1,290
BTx623[a]	4,299	3,224	420	97	143,300	3,644	38	2,171
ATx623xRTx430[a]	7,420	5,565	312	96	143,300	5,877	61	3,501
ATx378xRTx7000[a]	3,116	2,337	114	85	135,300	2,450	29	1,460
Rio[b]	5,736	4,302	2,054	101	175,100	6,356	63	3,787
M 35-1[a]	3,823	2,875	850	100	111,400	3,725	37	2,219
Tracy[b]	1,393	1,045	440	101	135,300	1,384	14	825
Sugar Drip[b]	1,809	1,357	461	101	143,300	1,818	18	1,083
Atlas[b]	1,680	1,260	1,920	100	151,200	3,181	32	1,895
ATx623xBrandis[a]	3,654	2,741	231	100	143,300	2,971	30	1,770
Sart[b]	6,769	5,077	1,080	105	199,000	6,158	59	3,668

(a) H.-E. sorghum.

(b) Sweet sorghum

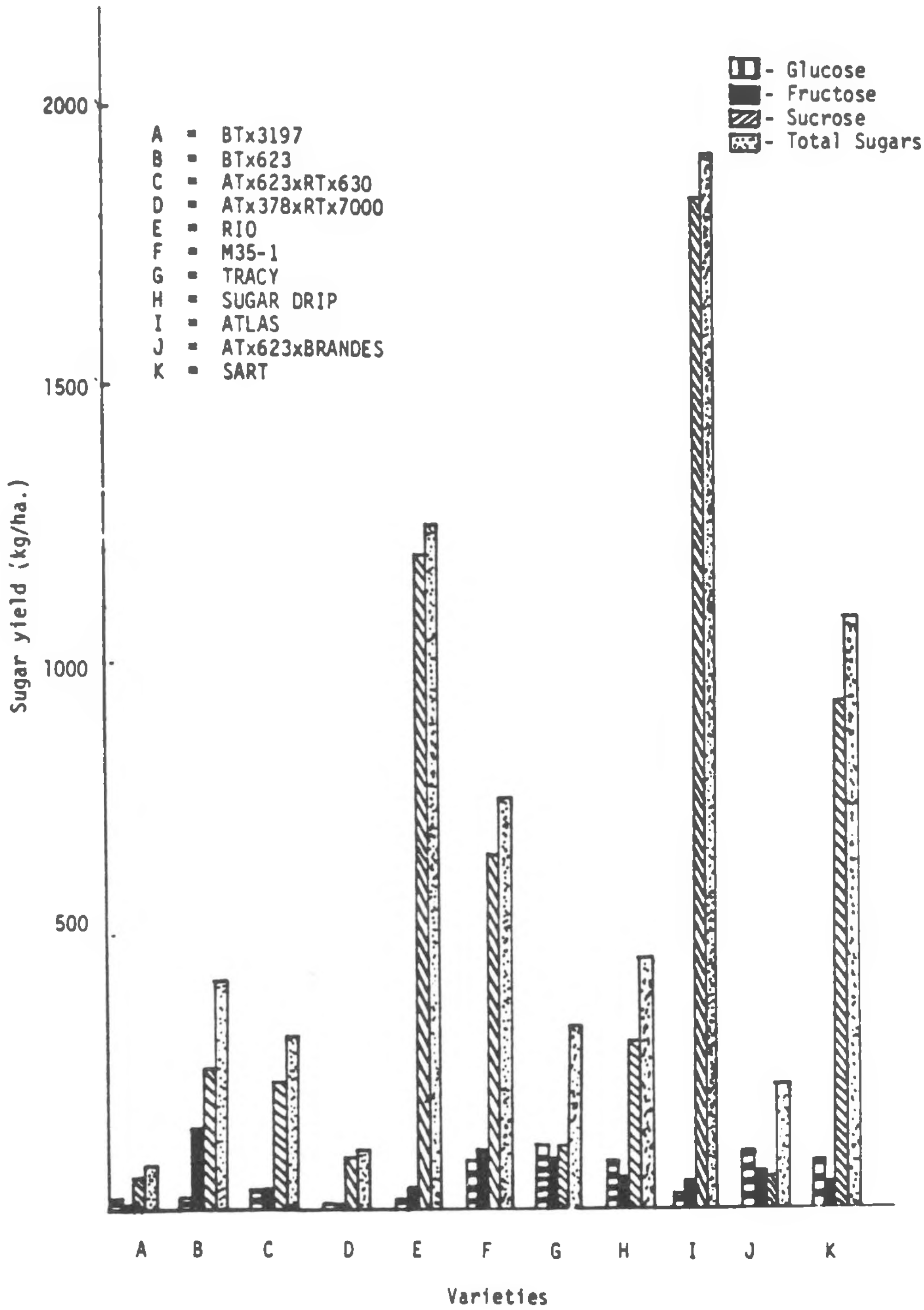


FIGURE 44. GLUCOSE, FRUCTOSE, SUCROSE, AND TOTAL SUGAR YIELD OF ELEVEN SORGHUM-BREEDING LINES AND HYBRIDS ENTERED IN BIOMASS TEST AT WESLACO, 1979

TABLE 34. EFFECT OF STORAGE TIME ON SWEET SORGHUM BIOMASS AND SUGAR CONTENT, WESLACO, TEXAS

	Stalk Weight (g)	Juice Weight (g)	Brix
<u>Cultivar</u>			
Rio	1,934.8a	194.5a	14.8a
Rio SC	175.9b	6.5b	2.6b
<u>Treatment</u>			
No Storage	1,174.6a	139.1a	10.7a
2-wk Storage (Shed)	1,019.1b	83.9b	6.9b
2-wk Storage (Field)	971.4b	78.6b	9.7a

(a), (b) See footnote, Table 9.

The data show clearly that Rio produced an overwhelming (at least 10 fold) stalk and juice yield compared to its converted derivative (Rio SC). Theoretically, the backcrossing procedure of the conversion process produces a derivative which is nearly isogenic (identical genes) except for the recessive dwarf genes, although as much as 10-15 percent of the genes may be different because of linkage blocks. Therefore, the primary difference between a line and its converted derivative can be attributed to the effect of height and dwarfing genes. The average height of Rio was 270 cm compared to 105 cm for Rio SC. Rio was also later in maturing (88 days to anthesis) compared to 61 days for Rio SC.

The analysis also shows that a 2-week delay in milling of harvested stalks resulted in a substantial reduction in stalk yield, juice yield and Brix. The decrease in stalk weight and juice yield was probably due to evaporation of juice from the cut stems. Natural fermentation would account for the decrease in Brix. Harvest occurred soon after physiological maturity of Rio, while harvest of Rio SC occurred almost 50 days after maturity and considerable fermentation had occurred. Brix values of about 11 degrees were obtained at anthesis with Rio SC. At harvest the average value had dropped to about 3 degrees.

Evaluation of Insect Pests

The yellow sugarcane aphid, *Sipha flava*, occurred in relatively low numbers in 1978 and high numbers in 1979. Only the plot planted on February 28 was infested during 1978. Populations were low, reaching a maximum of 6,464 aphid/ha on April 13.

Population trends of aphids infesting sweet sorghum during 1979 are shown on Figure 45. Aphids infested plots planted on February 27, March 12, April 2 and April 16 for 8, 4, 5, and 2 weeks, respectively. Populations peaked at 235,941/ha on the February 27 planting and 281,190/ha on the April 2 planting. Aphids were noted in all infested sweet sorghum plots only after the sorghum had been planted for approximately one month. This perhaps explains why aphid damage was not as severe in this study as that reported by various other authors working on grain sorghum. No plant deaths due to yellow sugarcane aphids were noted during this study. However, yelloe sugarcane aphids must be considered as an important pest of sweet sorghum in Texas, especially if plants are attached at an early stage. Aphids apparently are more of a threat to early planted sweet sorghum, especially during cool springs when plants are not growing vigorously.

Flea bettles reached high populations during both 1978 and 1979, Figures 46-47. Populations normally reached higher levels on later planting dates. Flea beetle damage was characterized by chlorotic spots and streaks in sorghum leaves. The relationship between flea beetle damage and sweet sorghum growth and/or yield was not determined. Populations exceeding 30,000/ha during each season may be considered potential pests.

The sugarcane borer, *Diatraea saccharalis*, is perhaps the key insect pest of sweet sorghum in the lower Rio Grande Valley of Texas. Larval populations generally increased as planting dates were delayed (Figure 48). Sugarcane borer damage followed a similar trend (Table 35).

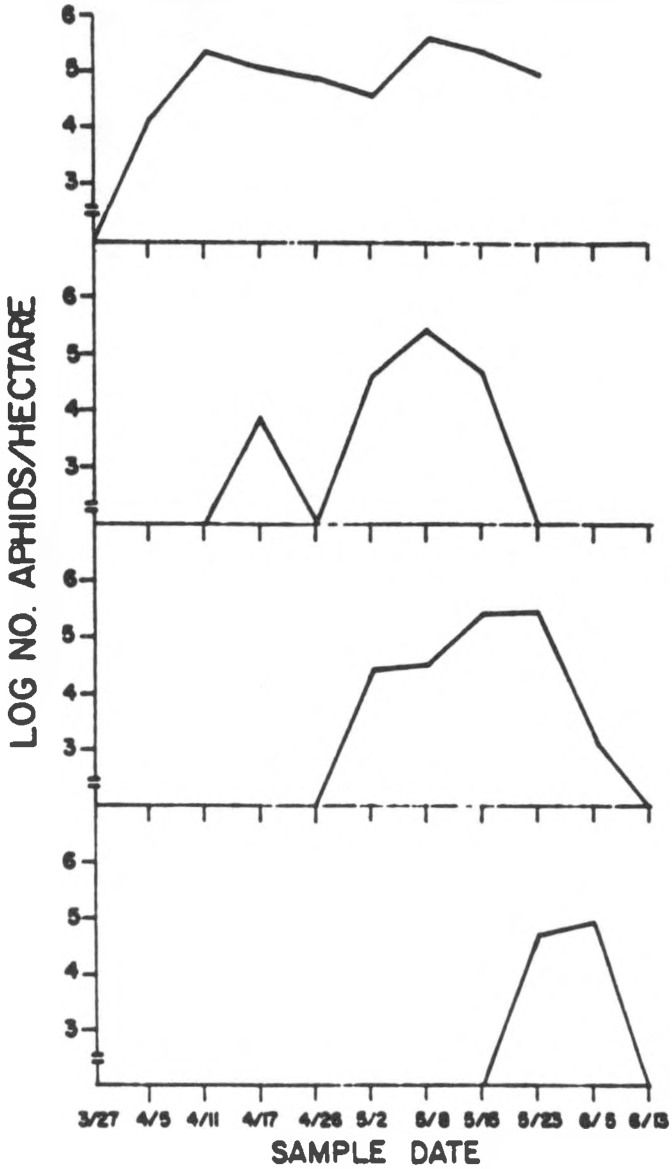


FIGURE 45. SEASONAL ABUNDANCE OF YELLOW SUGARCANE APHIDS INFESTING SWEET SORGHUM PLANTED ON FEBRUARY 27, MARCH 12, APRIL 2, AND APRIL 16, 1979, WESLACO, TEXAS

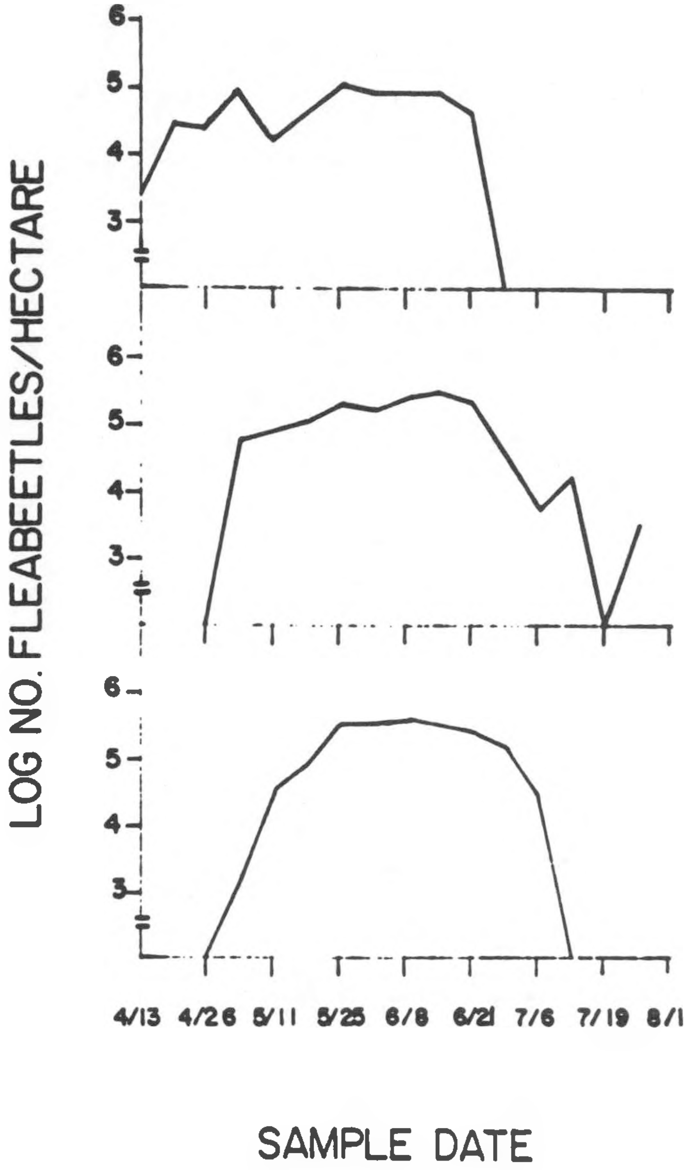


FIGURE 46. SEASONAL ABUNDANCE OF FLEA BEETLES INFESTING SWEET SORGHUM PLANTED ON FEBRUARY 28, APRIL 4, AND APRIL 17, 1978, WESLACO, TEXAS

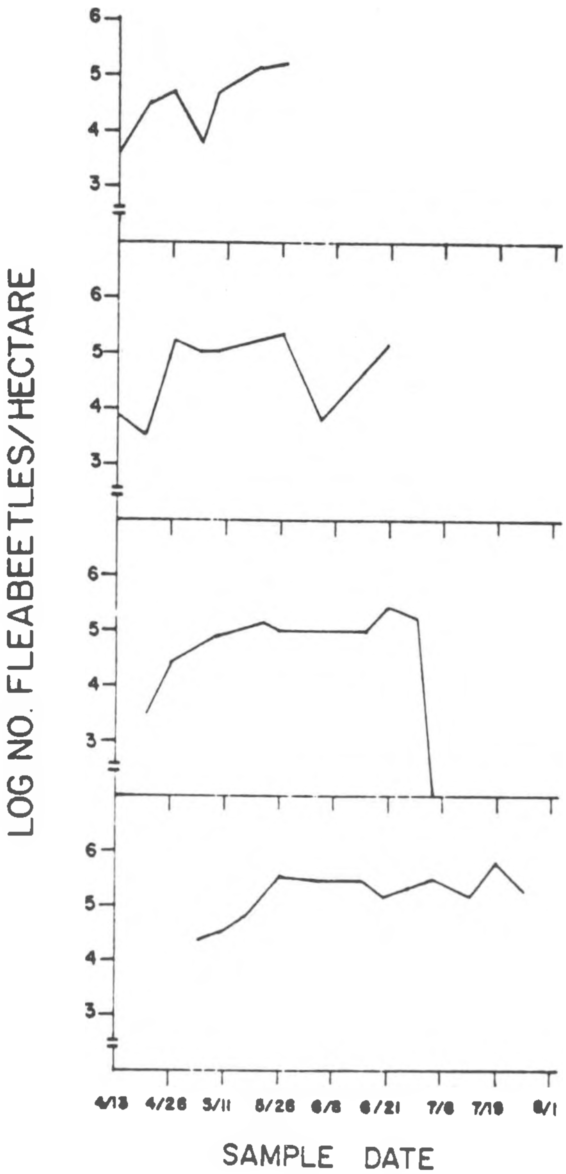


FIGURE 47. SEASONAL ABUNDANCE OF FLEA BEETLES INFESTING SWEET SORGHUM PLANTED ON FEBRUARY 27, MARCH 12, APRIL 2, AND APRIL 16, 1979, WESLACO, TEXAS

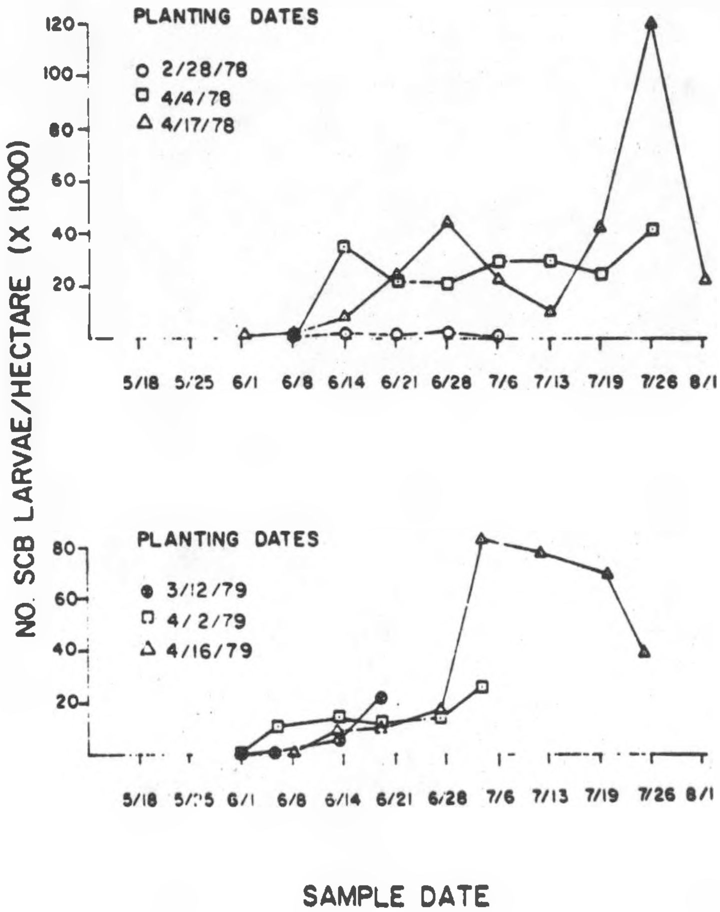


FIGURE 48. SEASONAL ABUNDANCE OF SUGARCANE BORER LARVAE INFESTING SWEET SORGHUM, 1978 AND 1979, WESLACO, TEXAS

Differences in varietal susceptibility to borers have been demonstrated and should be considered in variety selection. The variety Sart is very susceptible to borer damage (Sim A. Reeves, unpublished data).

The sorghum midge, Contarinia sorghicola, and the sorghum webworm damage developing seeds and are important pests of sweet sorghum grown for seed in the Lower Rio Grande Valley. Sorghum websorm, Celama sorghiella, damage was much more severe in the early planted sweet sorghum in 1978 and decreased as planting dates were delayed (Table 35). In 1979, however, no apparent trend was noted.

Sorghum midge damage was severe in all plantings (Table 35). Sweet sorghum planted between the range of dates used in this study will apparently have to be protected with insecticides to make an acceptable yield until or unless new technologies can be developed.

Grain sorghum is normally planted in the Rio Grande Valley from mid-February until mid-March. Since grain sorghum is also an excellent host for sorghum midge, interaction of populations of midge from grain sorghum and sweet sorghum will probably make midge control extremely difficult in sweet sorghum planted from mid-March to at least mid-April.

Other insect pests that will probably sporadically damage sweet sorghum in the Lower Rio Grande Valley include white grubs, chinch bugs and greenbugs.

Date of Planting Trial

The date of planting trials indicate that Rio was very little effected (Table 36). The yield was lower in the second planting but the sugar content was higher in the last three planting dates. The early planting date produced sorghum with a lower sugar content. The sugar values, however, are not replicated data but just observations.

The cultivar MN 1500 (Table 37) produced a greater response to yield from date of planting. The third and fourth planting produced the greatest yield. The sugar samples indicate that at maturity there was no effect of date of planting on sugar concentration in stalks. The longer day lengths produce a greater tonnage of total sugars.

TABLE 35. EFFECT OF PLANTING DATES ON POPULATIONS OF THREE INSECT PESTS OF SWEET SORGHUM, WESLACO, TEXAS 1978-79

Planting Date	% Heads Damaged	% Heads w/75% Seed Damage(a)	% Damaged Heads	Mean No./ Head	% Damaged Internodes
			1978		
Feb. 28	92.3	57.1	93.0	20.5	--(b)
April 4	100.0	98.5	45.5	0.7	11.4
April 17	90.3	17.6	1.5	0.2	14.2
			1979		
Feb. 27	100.0	49.6	11.1	0.2	0.0
March 12	100.0	100.0	17.2	0.7	3.2
April 2	100.0	100.0	7.3	0.1	12.0
April 16	98.1	67.8	17.4	0.3	22.7

(a) Obtained by visual estimate of 80 heads/planting date each year.

(b) Data not collected.

TABLE 36. THE EFFECT OF FOUR PLANTING DATES ON AGRONOMIC CHARACTERISTICS AND YIELDS OF SUGAR AND SORGHUM FOR RIO, WESLACO, TEXAS

	1st	2nd	3rd	4th
Planting Date	2/27/79	3/18/79	4/2/79	4/16/79
Date Started Flagging	5/1/79	5/16/79	6/1/79	6/19/79
50% Bloom	5/11/79	5/21/79	6/8/79	6/25/79
Populations/ha	71,000	55,000	64,000	53,000
Diameter (mm)	13	13	14	16
Height (cm)	182.88	205.74	228.60	238.76
Head Excertion (cm)	16.76	16.43	12.70	16.51
Total Tons per Hectare (mt/ha)	35.7	29.6	36.9	32.8
Percent Trash	30	27	22	29
Stalk Yield (t/ha)	25.0	21.6	28.8	23.3
	[a] Stalk Sugar Content			
[b] Brix	15.5	19.22	19.0	18.1
[c] Pol	10.9	14.4	14.3	13.3
Apparent Purity	70.2	74.9	75.4	73.7

(a) Sugar samples represent only observation samples taken at maturity.

(b) Percent total solids in juice.

(c) Percent sugar in juice.

TABLE 37 . THE EFFECT OF PLANTING DATE OF SEVERAL AGRONOMIC CHARACTERISTICS AND YIELD OF MN 1500, WESLACO, TEXAS

	1st	2nd	3rd	4th
Date of Planting	2/27/79	3/12/79	4/2/79	4/16/79
Date Started Flagging	5/1/79	5/15/79	6/10/79	6/22/79
50% Bloom	5/11/79	5/21/79	6/17/79	6/29/79
Population/ha	42,000	60,000	69,000	68,000
Diameter (mm)	20	16	18	17
Height (cm)	300	302.26	310	289
Head Excertion (cm)	50	14	12	13
Total Tons per Hectare (mT/ha)	35.5	48.9	62.4	58.6
Percent Trash	29	26	27	28
Stalk Yield (t/ha)	25.2	36.2	45.5	42.2
	(a) Stalk Sugar Content			
(b) Brix	17.7	15.7	16.0	15.5
(c) Pol	11.6	9.9	10.3	9.5
Apparent Purity	65.4	62.9	64.0	61.5

(a) Sugar samples represent only observation samples taken at maturity.

(b) Percent total solids in juice.

(c) Percent sucrose in juice.

The cultivar Sart (Table 38) is very day-length sensitive. The first planting was lower in tonnage than the other three. Sart responds to the longer days. The sucrose content was higher at the first planting but the tonnage was low.

It appears that Rio may be planted early while Sart and MN 1500 respond to the later planting dates.

TABLE 38. THE EFFECT OF FOUR PLANTING DATES ON SEVERAL AGRONOMIC CHARACTERISTICS AND YIELD OF SART, WESLACO, TEXAS

	1st	2nd	3rd	4th
Date of Planting	2/27/79	3/18/79	4/2/79	4/16/79
Date Started Flagging	5/16/79	5/21/79	6/1/79	6/21/79
50 Percent Bloom	5/20/79	5/23/79	7/2/79	6/30/79
Population/ha	40,631	59,979	65,000	60,000
Diameter (mm)	18	19	17	18
Height (cm)	286	280	284	280
Head Excertion (cm)	10	12	5.08	10
Total (t/ha)	37.8	55.9	59.4	53.4
Percent Trash	27	26	27	27
Stalk Yield (t/ha)	27.6	41.3	43.4	39.0
Sugar Content of Stalks				
(b) Brix	16.6	15.3	15.8	15.0
(c) Pol	11.9	10.0	10.4	9.9
Apparent Purity	71.9	65.7	65.8	65.8

(a) Sugar samples represent only observation samples taken at maturity.

(b) Percent total solids in juice.

(c) Percent sucrose in juice.

Sugarcane Field Studies

Houma, Louisiana

The 47 early generation Saccharum spontaneum hybrids ranged from 62.5 to 142.5 t/ha of biomass and averaged 103.3 t/ha (Table 39). CP 65-357, Louisiana's best adapted and widest grown cultivar yielded 110.9 t/ha and CP 61-37 yielded 92.8 t/ha. Ten early generation hybrid clones significantly outyielded CP 61-37 and three clones significantly outyielded CP 65-357. (US 74-69, 142.5 t/ha; US 73-79, 140.8 t/ha, and US 72-19, 134.3 t/ha).

Total solids per hectare ranged from 25.1 t/ha to 49.5 t/ha and the 47 early generation S. spontaneum hybrids averaged 37.9 t/ha of total solids (Table 39). The average for the population was higher than the highest commercial check variety CP 65-357 (36.8 t/ha). Eighteen early generation hybrids significantly outyielded CP 61-37 in total solids per hectare and six varieties significantly outyielded CP 65-357. (US 72-19, 49.5 t/ha; US 74-69, 49.5 t/ha; US 72-214, 48.2 t/ha; US 73-43, 47.3 t/ha; US 72-227, 47.1 t/ha; US 73-13, 46.8 t/ha). Two of the three varieties that significantly outyielded CP 65-357 in yield of biomass (US 72-19 and US 74-69) also significantly outyielded it in yield of total solids per hectare.

The 47 hybrid varieties were high in total solids percent cane, ranging from 29.6 percent to 44.1 percent and averaging 36.8 percent, well above the commercial check varieties. Thirty-eight hybrids had significantly higher total solids (percent cane) than CP 61-37 and 27 (57 percent of the population tested) had significantly higher total solids (percent cane) than CP 65-357.

Total solids (percent cane) was higher in these early generation hybrids than in the commercial varieties because of their relatively high fiber content. The 47 hybrids ranged from 14.1 percent fiber to 30.2 percent fiber and averaged 21.9 percent well above the commercial

TABLE 39. BIOMASS, TOTAL SOLIDS, FIBER AND BRIX OF EARLY GENERATION SUGARCANE IN HOUMA, LOUISIANA

	Commercial Checks		S. Spontaneum Hybrids			
					Significantly Higher Than	
Character	61-37	65-357	Range	Mean	CP 61-37	CP 65-357
Biomass (t/ha)	92.8	110.9	62.5-142.5	103.3	10	3
Total Solids (t/ha)	29.1	36.8	25.1-49.5	37.9	18	6
Total Solids (% Cane)	31.4	33.0	29.6-44.1	36.8	38	27
Fiber (% Cane)	14.3	15.4	14.1-30.2	21.9	45	43
Brix (% Juice)	17.1	17.7	11.2-16.4	13.8	0	0

varieties which had 14 to 15 percent fiber. In fact, 45 of the 47 clones had significantly higher fiber than CP 61-37, and 43 of the 47 were significantly higher in fiber than CP 65-357.

On the other hand, all of the early generation hybrids were lower in Brix than either commercial check. They ranged from 11.2 percent to 16.4 percent Brix and averaged 13.8 percent. Both commercial checks were above 17.0 percent Brix.

Discussion

These results suggest that not every early generation *S. spontaneum* hybrids that appears much more vigorous than commercial sugarcane cultivars is necessarily more suitable for biomass production. While most of the hybrids included in this experiment had double the stalk population and far greater vigor than CP 65-357, many did not equal its production of total solids per hectare because of a much smaller stalk weight and much lower Brix. However, the occurrence of 6 clones (12 percent of the population studied) that significantly outyielded CP 65-357 in total solids per hectare, suggests that a breeding and selection program in this type material could quickly isolate varieties superior to commercial sugarcane varieties in production of total solids per hectare. The superiority of these hybrids is likely to become more and more apparent in the first and succeeding ratoon crops.

Obviously, the selection of varieties in early generation *S. spontaneum* progenies with higher total solids percent cane than commercial hybrids would present no problem at all. Note that over half of the population studied significantly exceeded CO 65-357 in total solids percent cane.

However, the total solids in these hybrids are made up largely of fiber. Most would be unsuitable if primary interest lay in fermentable solids for alcohol or sugar production, and fiber was of secondary interest or a by product.

The results suggest, however, that a selection program for high Brix in S. spontaneum progenies might isolate high yielding cultivars with a Brix similar to CP 61-37. In fact, two hybrids (US 74-74 and US 74-40) were not significantly different from CP 61-37 in Brix. This would be particularly true if Brix in these population responded as well to selection pressure as sucrose has responded in Louisiana and other subtropical regions in the breeding program for high sucrose content.

The results also suggest that a level of Brix or fermentable solids equal to that of late maturing commercial clones, like CP 61-37, could be combined with high yield and stubbling vigor, in a breeding program. A limited breeding and selection program is in progress at Houma to accomplish this.

Belle Glade, Florida

First Ratoon Sugarcane on Riviera Sand

Plant populations decreased with time from June through December and as the row spacing was increased (Figure 49). There appeared to be little difference in plant populations for the 100 and 150 cm spacing after October.

Fiber reached 20.7 t/ha for the 50 cm spacing during the December harvest (Figure 49).

Dry biomass reached 44.9 t/ha in December for the 50 cm row spacing (Figure 50). Thirty-six t/ha were accounted for by the stalks. The 50 cm spacing resulted in higher biomass at all harvests in comparison to the 100 and 150 cm spacings.

Total sugar and sucrose production reached 21.0 and 18.2 t/ha, respectively, for the 50 cm spacing in December (Figure 50). Less than 1 mt/ha of total sugar was in the trash regardless of row spacing or harvest date.

Dry biomass, total sugar and fiber yield totals accumulated over 2 years for the plant and first ratoon crops were approximately 100, 49, and 50 mt/ha, respectively.

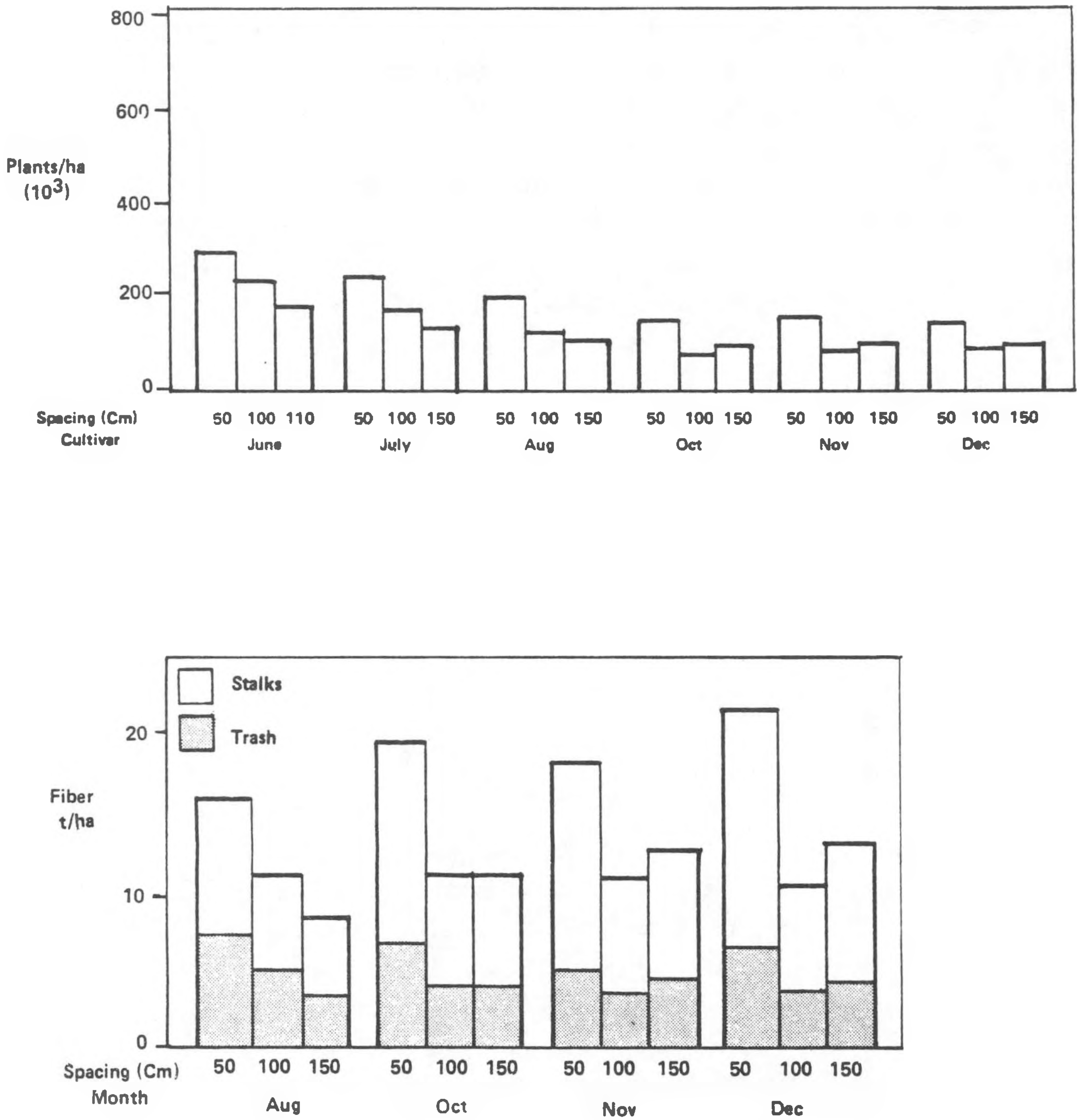


FIGURE 49. PLANT POPULATION AND FIBER OF FIRST RATOON SUGARCANE GROWN ON SAND SOIL, BELLE GLADE, FLORIDA

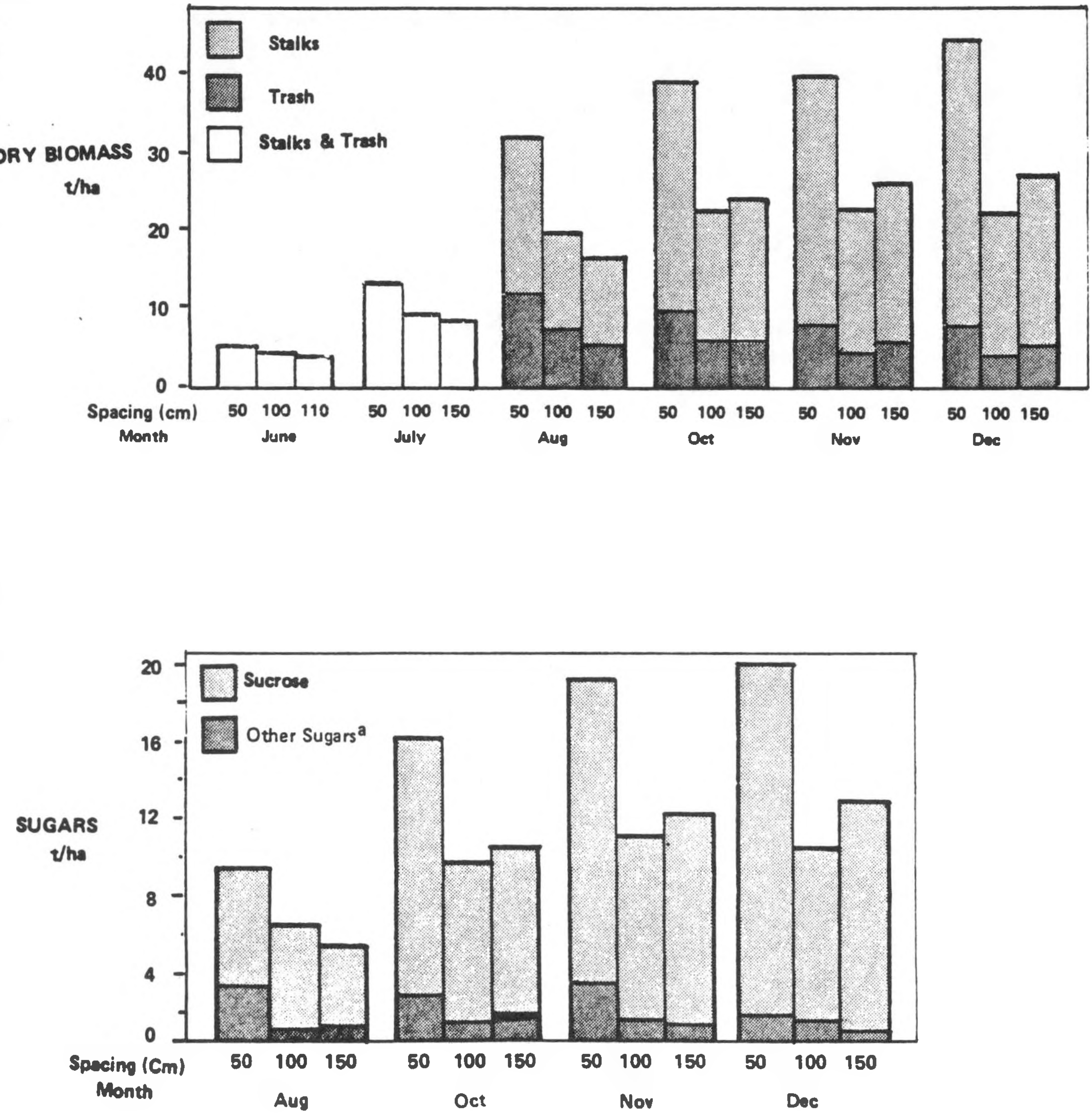


FIGURE 50. DRY BIOMASS AND TOTAL SUGARS OF FIRST RATOON SUGARCANE GROWN ON SAND SOIL, BELLE GLADE, FLORIDA

Nutrient uptake varied during the growing season (Figure 51). Maximum N, P, and K uptake was 200, 50, and 375 Kg/ha, respectively.

Second Ratoon Sugarcane on Pahokee Muck

Plant populations decreased with time, July through December, and as the row spacing was increased (Figure 52).

Fiber reached 22.9 t/ha for the 50 cm spacing during the December harvest (Figure 52).

Dry biomass reached 52.2 t/ha in December and was significantly higher for the 50 than for the 150 cm row spacing in July, August, and December (Figure 53).

Total sugar and sucrose production reached 25.4 and 21.5 t/ha, respectively, for the 50 cm spacing in December (Figure 53). Total sugars in the trash reached 1.21 t/ha for the 50 cm spacing in December.

Total biomass accumulated over 3 years for the plant; first ratoon and second ratoon crops was approximately 145 t/ha.

Nutrient uptake generally reflected biomass yield differences between the two row spacings (Figure 54). Uptake levels of nutrients from the muck soil was similar in most cases to that removed from the sandy soil (Figure 54).

High biomass, sugar and fiber were produced on sand and muck soils in south Florida. Yields were, as in previous years, higher for the narrow row spacing where solar radiation utilization was more efficient than in plant cane. Likewise, it is greater for a second ratoon than for a first ratoon.

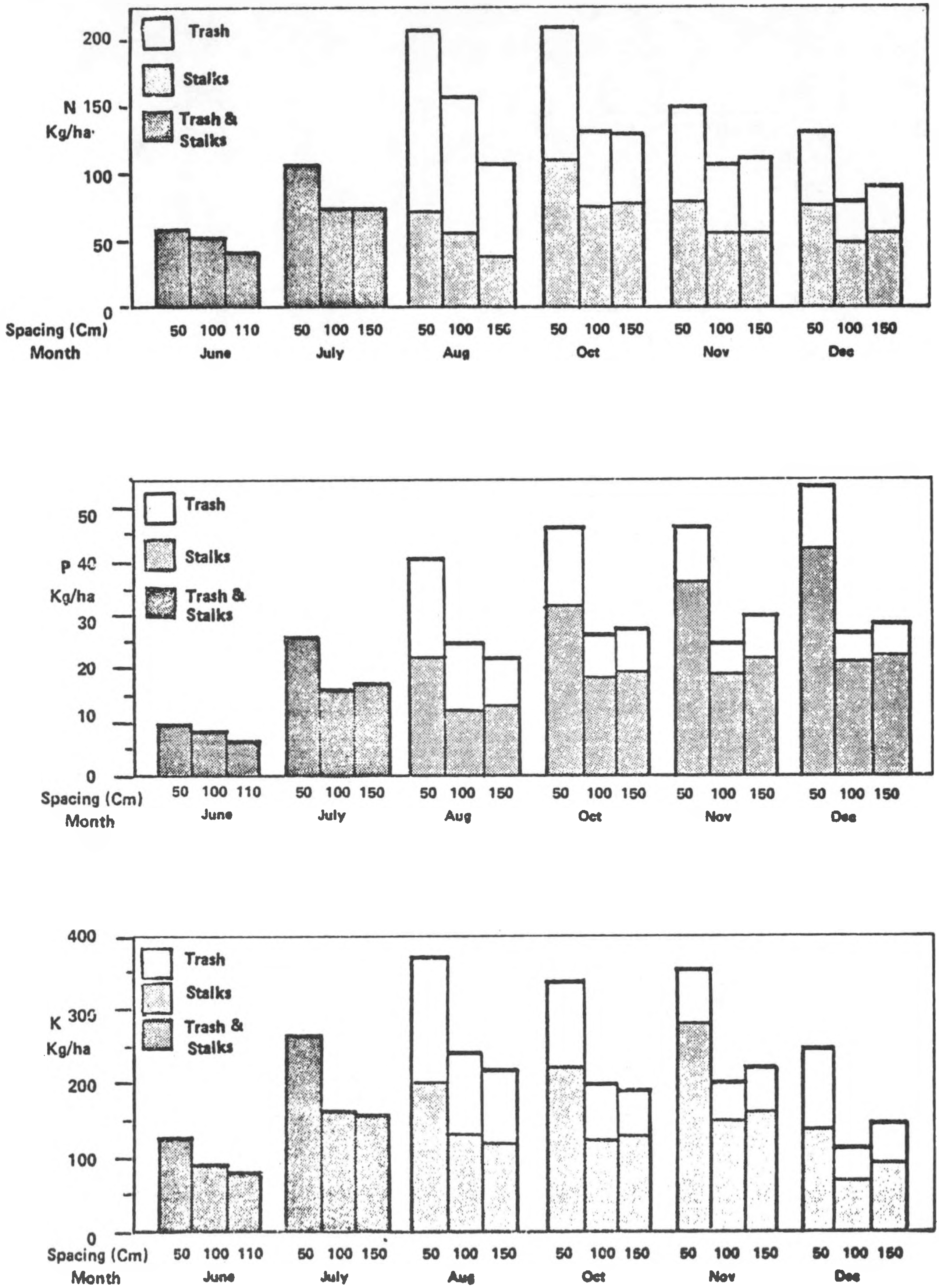
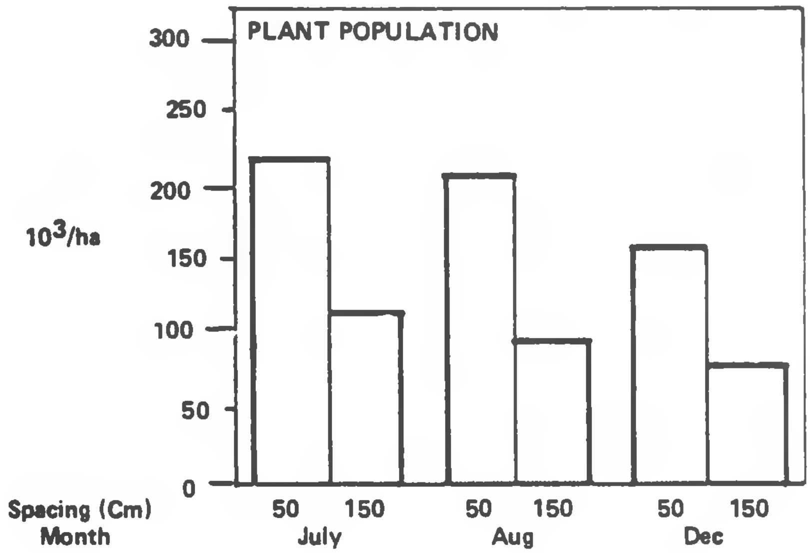


FIGURE 51. NUTRIENT ACCUMULATION OF FIRST RATOON SUGARCANE GROWN ON SAND SOIL, BELLE GLADE, FLORIDA



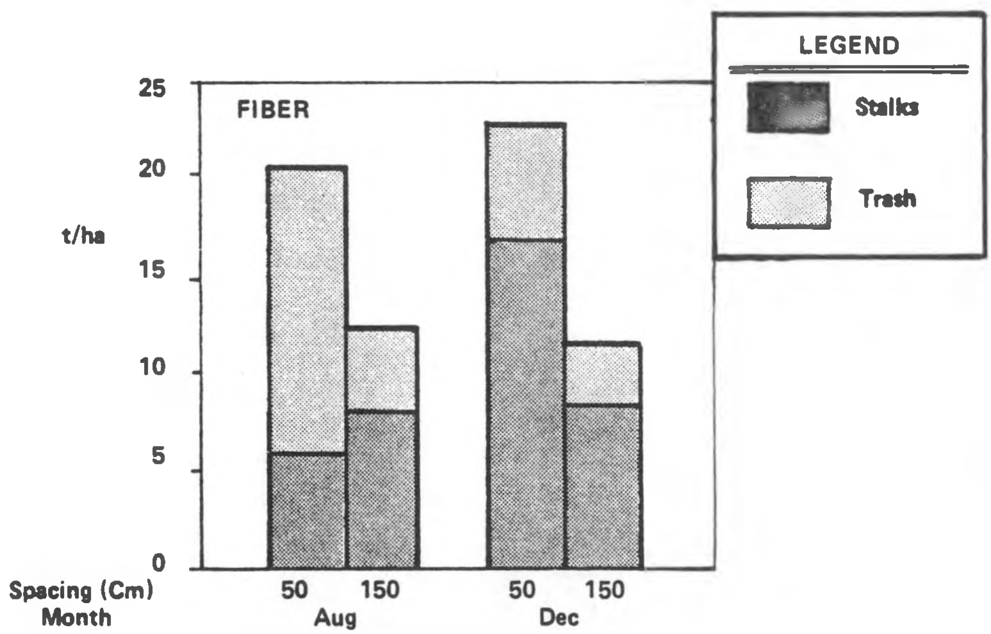
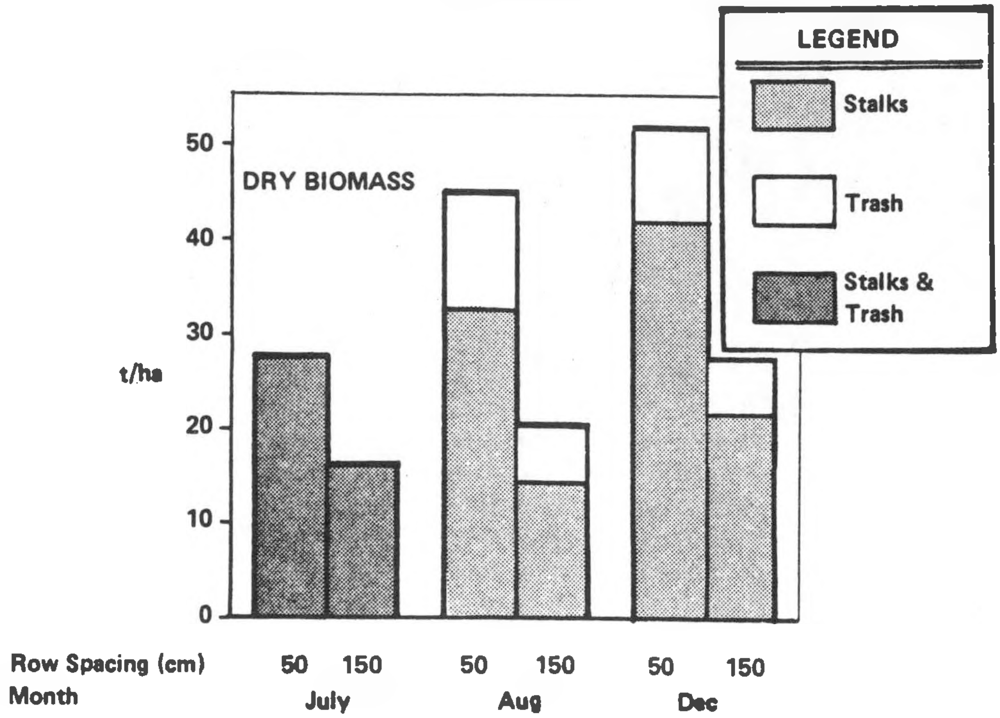


FIGURE 52. PLANT POPULATION AND FIBER OF SECOND RATOON SUGARCANE GROWN ON MUCK SOIL, BELLE GLADE, FLORIDA



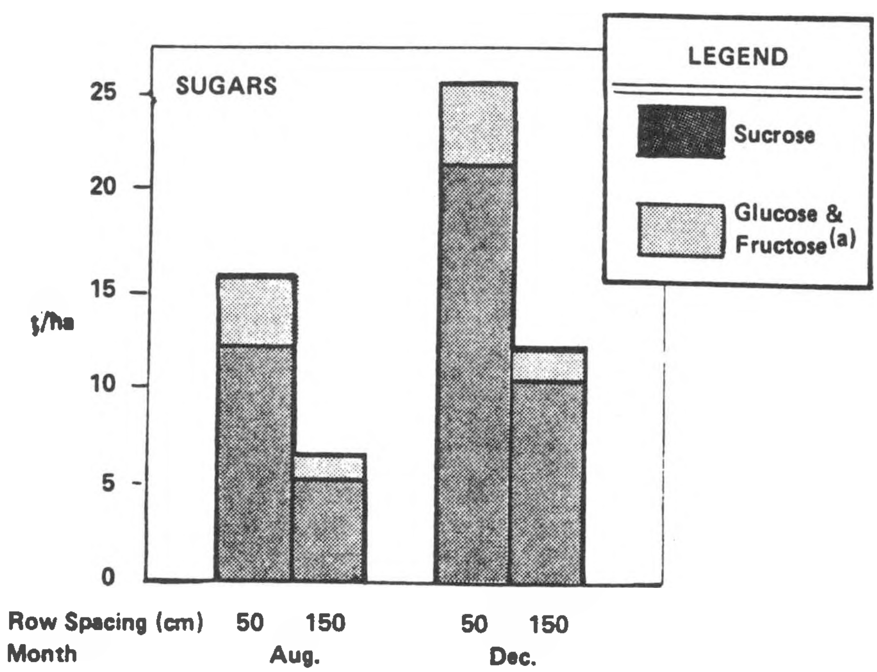


FIGURE 53. DRY BIOMASS AND TOTAL SUGARS OF SECOND RATOON SUGARCANE ON MUCK SOIL, BELLE GLADE, FLORIDA

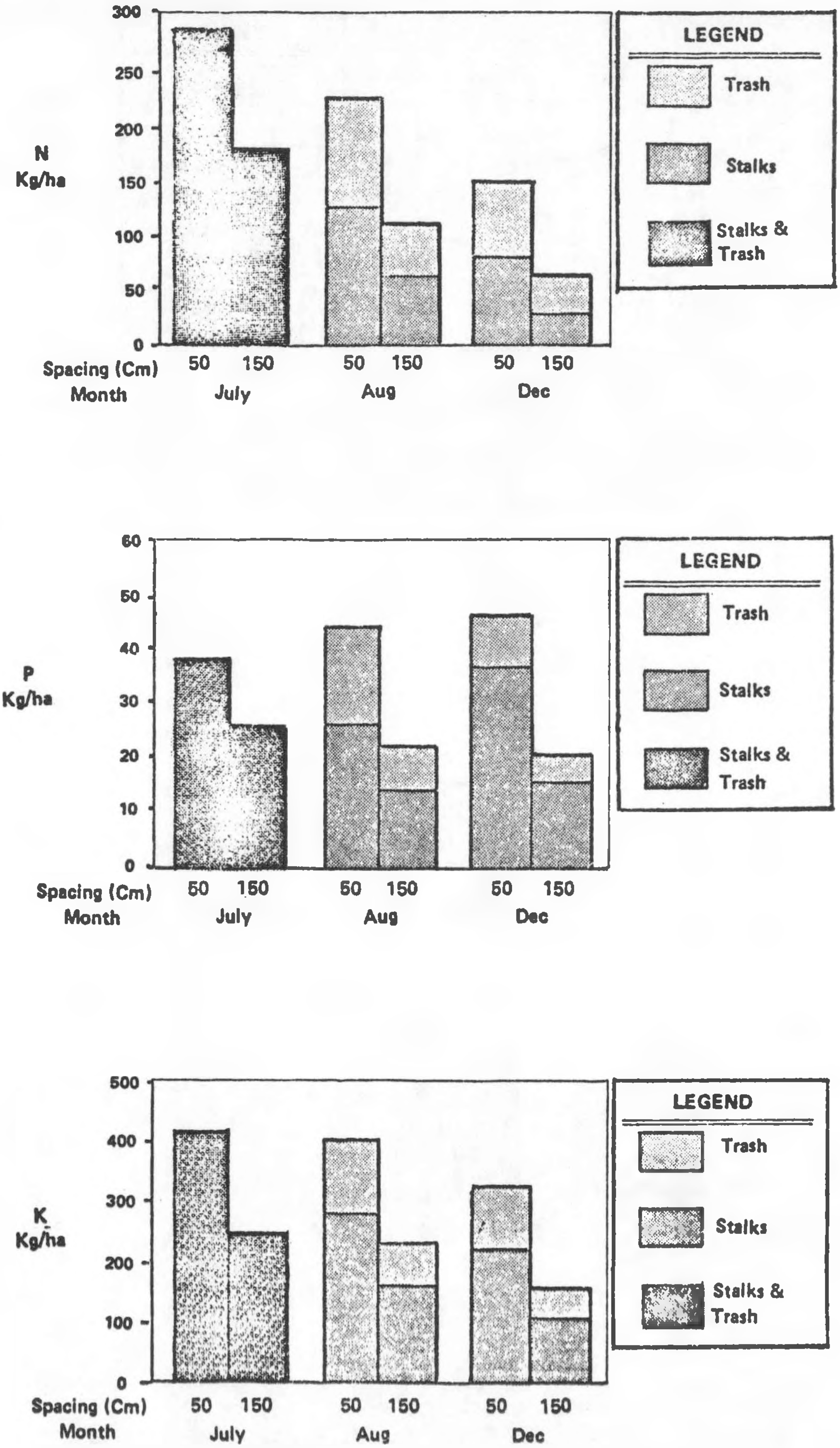


FIGURE 54. PLANT NUTRIENT ACCUMULATION OF SECOND RATOON SUGARCANE GROWN ON MUCK SOIL. DATA ARE PRESENTED BY MONTH. LOCATION IS BELLE GLADE, FLORIDA

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APPENDIX A

EXPERIMENTAL METHODS

Field Procedures

Belle Glade, Florida

Sweet Sorghum Planted on Pahokee Muck. The second sweet sorghum experiment planted on Riviera sand failed due to lack of moisture during the germination and early growth stage.

Calendar of events:

May 15, 1979 - approximately 1 1/2 ha was fertilized with 56 kg/ha of P_2O_5 from triple superphosphate and 56 kg/ha of K_2O by broadcasting.

May 17-18, 1979 - one-half of the area was planted with 71 cm rows - the other one-half with double rows (30 cm apart) centered at a spacing of 142 cm.

Late May 1979 - hoed weeds.

June 15, 1979 - sprayed Lannate L to kill fall armyworms (25 l/ha).

June 19, 1979 - second spraying with Lannate L.

August 21, 1979 - counted stalks and measured heights.

August 22, 1979 - harvested sorghum with sugarcane harvester.

August 31, 1979 - measured heights and took samples.

Stalk heights (to base and flag leaf) and shoot counts at harvest time were determined in 3 rows selected at random in each plot. Shoots were counted in 4 m of each row. Stalk heights were measured at random 30 times in each plot. At harvest 4 m of a row selected at random was cut. One row was harvested in each plot.

First Ratoon Sugarcane on Riviera Sand. The statistical design was a randomized complete block with 5 blocks with a plot size of 13 x 20 m. Three row spacings were used (50, 100, and 150 cm) as indicated in last year's report (Lipinsky et al., 1979).

Calendar of events:

March 6, 1979 - sugarcane was cut and the stalks were removed from the field.

March 10, 1979 - 560 kg/ha of 10-8-32 applied broadcast and applied 2.2 kg/ha Atrazine broadcast.

June, 1979 - 212 kg/ha of 10-0-30 applied.

August, 1979 - 212 kg/ha of 10-0-30 applied.

June 4, 1979 - shoot count and samples.

July 2, 1979 - shoot count and samples.

August 6-9, 1979 - shoot count and height measurement and samples.

September, 1979 - hurricane, no samples taken.

October 15-17, 1979 - shoot count and height measurements.

November 19, 1979 - 15 stalk samples taken.

December 18, 1979 - 15 stalk samples taken.

Shoot counts and height measurements at harvest time were made in three rows selected at random in each plot. Shoot counts were made in 7.6 m of row in each of the three rows. Twenty-five shoot height measurements were made in each row, giving a total of 75 shoot height measurements for each plot. Based on the shoot height measurements, 15 stalk samples were taken from the plot. For example, if 45 percent of the plants were between 230 cm and 241 cm in height, then 7 plants would be harvested having a height between 230 cm and 241 cm. The 15-stalk samples were weighted, dried at 70 C and reweighed.

Second Ratoon Sugarcane on Pahokee Muck. The statistical design was a randomized complete block with 4 blocks with plot size of 24 by 27 meters. The two row spacings were 50 and 150 meters as indicated in the last two years' reports (Lipinsky et al., 1978, 1979).

Calendar of events:

March 15, 1979 - the first ratoon crop was destroyed by a "devil catcher", a large roller with cutting blades. The chopped stalks were not removed from the field.

April 17, 1979 - Fertilized according to soil test with 245 kg/ha of K_2O - spot sprayed weeds with glyphosate.

July 17-18, 1979 - shoot counts, height measurements and samples.

August 27-38, 1979 - shoot counts, height measurements and samples.

December 26-January 2, 1980 - shoot counts and samples.

The harvest methods were the same methods that were used in the sand experiment.

Manhattan, Kansas

Uniform Experimental Design. The plot area was chisel plowed in the fall, partially incorporating the soybean residue of the preceding crop. In the spring, the field was double-disced once. Fertilizer was applied at a rate of 88 kg/ha actual N and 44 kg/ha of P_2O_5 and incorporated with a spring-tooth. Milogard herbicide was applied (3.3 kg a.i./ha) and incorporated with a spring-tooth plus a spike-tooth harrow.

Three cultivars of sweet sorghum, Dale, Rio, and Wray, were planted May 30, 1979. The planter consisted of three John Deere unit planters attached to a Hefty-G plot tractor. The varieties were planted in 50, 75, and 100 cm row widths. Seed was treated with Captan fungicide and a furrow application of Furadan granular insecticide was applied to control chinch bugs. Seeds were planted 7.5 cm apart and thinned to 15 cm spacing within each row. Four replications were included in a split-plot design with row spacings as main plots and varieties as sub-plots. Individual plots were 6 m wide and 9 m long. Borders of hybrid sudangrass were planted surrounding each replication.

Following planting, chinch bug and greenbug infestation occurred. Dry weather rendered the granular insecticide ineffective. The experimental area was sprayed with Sevin (1.66 kg a.i./ha) and Cygon (0.37 kg a.i./ha) on June 11 and again on June 15. Greenbug populations were reduced; however, chinch bugs were less well controlled. The 100 cm plots in replication 1 were badly damaged along with the 100 cm plots of Dale and Wray in replication 2. These plots were replanted with a Planter Jr. wheel planter on June 23. Applications of Furadan 4F flowable insecticide (1.66 kg a.i./ha) were made on June 25, July 9, and July 18. Alleys and grassways surrounding the plots were regularly sprayed to form a "barrier" against further chinch bug movement into the plots.

Stands were thinned on July 3 and counts taken on July 10 except in the replanted rows which were thinned and counted on July 12.

Subplots 4 m x 10 cm (2 rows), 4 m x 15 cm (2 rows), and 4 m x 10 cm (1 row) were harvested from the .5, .75, and 1.0 m row spacings, respectively, at the boot and 50 percent flower stages. Eight m x 20 m (4 rows), 8 x 22.5 m (3 rows), and 8 x 20 m (2 rows) were harvested from the .5, .75, and 1.0 m row plots, respectively, at the soft dough stage.

Plot weights were recorded at all stages of harvest. Ten plants from each plot were hand separated into leaf and stalk components at the boot stage, and into leaf, stalk, and top components at the 50 percent flower and soft dough stages. Stalk diameter was measured in cm at the center internode of each of these 10 plants. Stalk height was measured in cm from the base of the cut stalks to the base of the peduncle at the boot stage and to the top of the panicle at the 50 percent flower and soft dough stages.

Seven of the 100 stalks were chopped in a Smalley stationary forge chopper and 1 kg sample was frozen for sugar analyses at the 50 percent flower and soft dough stages. Subsamples of wet leaf, stalks, and top components were weighed, oven-dried for 5 days at 50 C, and weighed again to determine dry weights. The dried subsamples from the dough stage were ground with a Wiley mill, using a 1 mm mesh screen, for fiber and nutrient analyses.

Cultivar Selection. Adjacent to the main experiment, two rows each of 18 cultivars of sweet sorghum were planted with a Planet Jr. wheel planter.

A .75 m row spacing was used with planting on June 13 and thinning to a .15 m spacing within rows on July 12. Flowering notes were taken at the boot, 50 percent flower, milk, soft dough, and ripe stages. Sugar content was measured with a refractometer at frost (October 20) and again on November 12 prior to fall chiseling.

Baton Rouge, Louisiana

Uniform Experimental Design. The experiment was planted in a split plot design with three cultivars, three plant spacings and four replications. The spacings were main plots and varieties were the subplots. Each plot was three rows wide on rows 180 cm wide and 15 m long. The spacings were one, two, and three drills on 180 cm rows. Each drill had three plants per 30 cm of row. The Wray, MN 1500 and MER 71-1 varieties were planted in each spacing. The spacings were selected to give the range in plant populations desired and to accommodate the use of sugarcane harvesting equipment.

The sorghum was planted on April 17, 1979. It was over-seeded and thinned by hand to the desired plant populations. Milogard was applied as a pre-emergence herbicide for weed control. Ammonium nitrate and muriate of potash fertilizers were applied as a top dress application at a rate of 170 and 90 kg/ha of N and K_2O, respectively. The fertilizer was applied when the plants were 20 cm tall. The sorghum was cultivated twice with a Lilliston rolling cultivator. Seven centimeters of irrigation water were applied in June. Azodrin was applied to control aphids and sugarcane borers.

The sorghum was harvested at the boot, anthesis and and mature stages of maturity on the following dates in 1979:

	Boot	Anthesis	Mature
Wray	July 27	Aug. 21	Sept. 4
MN 1500	July 27	Sept. 19	Oct. 9
MER71-1	July 27	Aug. 28	Sept. 25

On each harvest date, the sorghum on a 4.5 m segment of the center row of each plot was cut and weighed in the field. A 20-stalk sample was used in the laboratory to determine the wet and dry biomass of stalks, leaves, and tops. Samples of stalks were chipped and pressed for juice extraction. The percents sucrose, glucose, and fructose sugars in the juice were determined with a high-pressure liquid chromatograph. The percent fiber was determined in the bagasse sample. The N, P, and K contents of the dry stalks, leaves, and tops were determined at the dough stage using standard methods. The plant population and height were measured at each stage of maturity.

Houma, Louisiana

Sugarcane Studies. Forty-seven *Saccharum spontaneum* hybrids from the basic breeding collection at Houma were planted in a three replicate yield trial in comparison with the commercial varieties CP 65-357 and CP 61-37 in the fall of 1978. Plot size was limited to 1.8 x 4.6 m by a limited seed cane supply.

Twenty-seven of these clones were F_1 hybrids, 15 were BC_1 hybrids, and 5 were BC_2 hybrids.

An accurate stalk count was made in each plot in August and 20 stalk samples were cut at ground level in December and weighed with leaf and trash adhering to provide the estimate of total green weight or biomass produced. Five stalk samples were shredded in the Jeffco cutter grinder and frozen for later fiber determinations. The remaining 15 stalks were milled and the juice analysed for Brix or percent total solids.

Total solids percent cane was calculated by adding Brix percent cane and fiber percent cane. Total solids per hectare was calculated by multiplying total green weight per hectare by total solids percent cane.

An analyses of variance was conducted for each character studied and variety means grouped with Duncans Multiple Range Test.

Meridian, Mississippi

Sweet Sorghum Row Spacing Trial. Rio and Wray cultivars of sweet sorghum were planted April 30, 1978, at Meridian, Mississippi on McLaurin loamy sand. The 12 treatments resulted from combinations of two cultivars (Rio and Wray) and six row spacings (46, 61, 76, 91, 107, and two lines of plants centered on 107-cm rows, respectively). The design was a randomized complete block with split plots. The main plots (row spacing) were three-rows x 12.8 m and were replicated four times. Subplots (cultivars) were three rows and were 6.4 m long. An excess of seed was planted in hills 61 cm apart and the plants were hand-thinned to four per hill two weeks after emergence. At planting, 673 kg of 8-8-8 fertilizer was broadcast per ha. Weeds were controlled by hand hoeing and cultivating with a small motor-powered, single-row plow.

All plants from each plot were harvested and weighed at the hard dough stage of grain development to measure gross plant yield. A 15-stalk sample was selected randomly from each subplot and weighed. The tops (seed heads) were removed and the stalk reweighed to measure fresh top yield. After removing the leaves from the topless stalks, the leaves and stalks were weighed to measure fresh leaf and fresh stalk yield. Five stripped stalks from the 15-stalks sample were chopped in a Wiley mill. A sample from the copped stalks and the fresh leaves and fresh tops were dried at 55 C to measure dry yield of tops, leaves, and stalks. The tops were threshed to obtain dry seed yield.

The remaining 10 stalks from the 15-stalks sample were crushed in a three-roller mill to obtain juice for measuring Brix (soluble solids) and sucrose. Brix was measured with a Brix hydrometer. Sucrose was determined with a saccharimeter. Sucrose per ton of stalks was calculated with the Winter-Carp formula. Fermentable sugar per ton of stalks was calculated by the formula, Brix x normal extraction (0.75) x 100 kg ÷ 100.

Lincoln, Nebraska

Uniform Experimental Design. Rio, Wray, and Dale were planted at the University Field Laboratory, Mead, Nebraska, on May 25 and bordered where appropriate with SF 20 forage sorghum. The plot was uniformily fertilized with 125 kg/ha N and conventionally disked and harrowed, but dry weather did not favor a particularly good seedbed. A preemergent application of 0.9 kg/ha Atrazine plus 2.6 kg/ha propachlor was used for weed control, but was ineffective so hand weeding was performed shortly after sorghum emergence. On May 31, the plots were sprinkle-irrigated with 1.5 cm water because of continued hot, dry weather conditions. The plots were overseeded by 2X and good stands appeared to be assured by thinning to appropriate densities. The cultivars performed in the same manner as their germination percents would indicate with respect to seedling emergence. Wray (80 percent germination) was inferior to both Dale and Rio (94 percent germination) having generally about 15 percent fewer plants emerge from the soil even though adjustments were made to compensate for the germination differences. An early greenbug infestation was controlled with 0.55 l/ha Cygan 267. Plots were thinned to 2 plants per 30 cm row on June 21 and cultivated once July 3. Stand counts were made on the middle two rows (7.5 cm plant ht.) an July 9.

Rio was harvested at boot stage on August 17-18; Wray, August 20-23; and Dale, August 27-28. At flowering stage Rio was harvested on September 3-5, and was followed by Dale on September 7-9, and Wry on September 13-15. Four meters of the appropriate number of rows were harvested for each spacing according to the subcontract description at the boot and 50 percent flowering growth stages. Yield was determined from 6 m of the appropriate number of rows at maturity. Rio was harvested on October 8-9, while Dale was harvested October 11-12. The later maturing Wray was harvested October 11-12. The first killing freeze occurred at the plot area on October 5, but the stalks did not appear to be altered at harvest even though the leaves at the top of the canopy were starting to dry rapidly.

At each harvest, all of the plants were weighed for yield and then ten plants were randomly selected and processed for analyses. These were divided into stalks, sheaths, and leaves (all stages) and inflorescences (last two growth stages). Stalks were chopped into 2 cm sections using a small tractor driven chopper (not commercially available) and thoroughly mixed for sub-sampling. Approximately 500 g of stalk material was frozen for sugar analysis. The remaining portion of stalks as well as the leaves and inflorescences were taken to complete dryness in an oven at 90 C for about 10-12 days. This dry material was ground to pass a 20 mesh screen and analyzed for nutrient elements (all parts), fiber (ADF and NDF), and nonstructural carbohydrates on stalks.

Fargo, North Dakota

Uniform Experimental Design. The uniform experimental design included three sweet sorghums planted at three row spacings (50, 75, and 100 cm rows) in a split plot design. The three row spacings were essentially three plant densities since plant spacing within the row was 22.9 cm for all row spacings. The Fargo experiment deviated from the UED by having only two sweet sorghums, Wray and MER 63-7. The third cultivar was the HS-50 male-sterile corn. In addition, the experiment was planted in a randomized complete block design with a fractorial arrangement of the treatments.

The experiment was seeded on summerfallow June 4 and 5, 1979, utilizing a single-row cone planter. The soil was compacted with a corrugated roller following seeding to obtain seed-soil moisture contact. Ramrod at 4.48 kg/ha was applied June 6 for grassy weed control. The first precipitation following seeding occurred June 19 with several rains following amounting to about 13 cm. A heavy shower June 28 caused standing water on 2 replications for 2 days. The cool, cloudy weather plus water logged soil condition caused the emerged plants to apper N deficient in late June. July 5 112 kg N/ha was applied as a side-dress treatment.

Established stands were thinned July 9 to about 1 plant/22.9 cm of linear row in all row spacings but poor emergence by the sweet sorghum resulted in less than the desired plant density. Wray stands averaged 34.6 plants/9.14 m of row or about 13.5 percent less than desired. MER 63-7 had slightly better stands at 36.0 plants/9.14 m of row. HS-50 stands averaged 39.9 plants/9.14 m of row.

A severe thunderstorm with 110 km/hr winds hit the Fargo area on July 23 resulting in severe lodging to all crops including the corn and sweet sorghum. The lodging was only temporary with most plants completely recovered within a week. A moderate infestation of aphids was controlled by applying 1.75 l/ha of malathion 55 (0,0-dimethyl dithiophosphate of diethyl mercaptosuccinate) on July 23 and August 1.

Dry biomass samples were taken at three growth stage-boot, 50 percent anthesis, and maturity. The boot growth stage in corn was sampled August 6-7, 50 percent anthesis August 30 in Reps 2 and 3, and September 4 for Reps 1 and 4 (water stressed), and the final harvest October 4-5, following a killing frost on October 4. The boot sampling of MER 63-7 was taken September 5, 50 percent anthesis September 11-14, and the final harvest October 5-6. Wray's maturity was too late for the Fargo environment; consequently, only one harvest October 6-9 following the killing frost was taken.

Samples for sugar were obtained on stalks of the anthesis and final harvests following uniform methods. Frozen extracts were analyzed for sugar content using a glucose oxidase method described by Roehrig and Allard (1974). Their method was modified for glucose by changing the enzyme to invertase. Accuracy of this method was compared to the UV-method of Boehringer-Mannheim with results presented in Table 1. The simple correlation coefficient among treatment glucose percentages was 0.985. All sugars were expressed on a dry weight basis. Stalk fiber was determined on all samples using the acid detergent fiber method and is expressed on a dry meter basis.

Cultivar Selection. The 17 genotypic treatments listed in Table A-1 were seeded June 5, 1979. The plots were four rows spaced 75 cm apart and 7.1 m long. A randomized complete block designed with 2 replications was used. The experiment was handled in a manner described in the previous section except the middle two rows were harvested October 10-11, following the October 4 killing frost. All plots were sampled for final wet and dry biomass yield, stalks/ha, plant height, percent acid detergent fiber, and total sugar (glucose, sucrose, and fructose independently) production expressed on a dry weight basis.

TABLE A-1. COMPARISON OF GLUCOSE PERCENTAGES DETERMINED BY THE GLUCOSE OXIDASE OR UV METHODS

Treatments		Method of Determination	
Species	Row Spacing (cm)	Glucose Oxidase	UV
		(% Glucose on Dry Basis)	
Wray	50	13.0	10.4
	75	11.5	10.0
	100	9.5	9.6
MER 63-7	50	15.3	12.9
	75	18.1	14.4
	100	15.6	12.9
HS-50	50	5.7	5.0
	75	5.2	4.1
	100	5.5	4.1

Nitrogen Fertilization Trials. MER 56-12 sweet sorghum was seeded June 5, 1979, at Fargo, North Dakota. Soil analyses prior to seeding indicated an average 92, 51, and 560 kg/ha available N, P, and K, respectively. Four N treatments - 0, 50, 100, and 200 kg/ha - were imposed June 26 before the heavy thunderstorm June 28. A randomized complete block design with 4 replications was used. The experiment was handled in a manner described in the previous section except the harvest data was October 12-15, following the October 4 killing frost. Percents N, P, K, ADF, glucose, sucrose and fructose, and total sugars were determined on 2 replications and expressed on a dry weight basis.

Deferred Processing Experiment. Duplicate samples of a standing Wray and piles MER 63-7 plot were taken on October 4 (killing frost), November 5, and December 6. The piled samples were harvested October 4 and placed in 3 to 4 foot high piles for storage. Water soluble carbohydrates were extracted and determined on as is basis following procedures mentioned in the previous section.

Columbus, Ohio

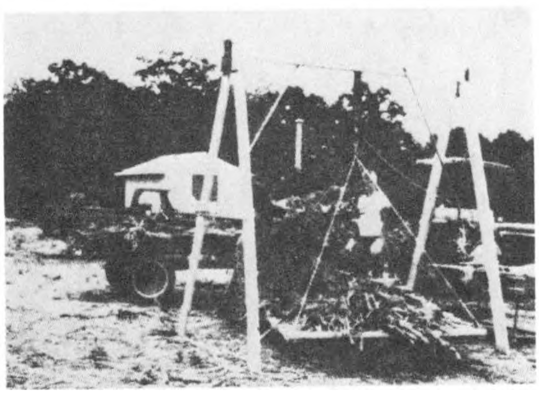
Cultural practices and experimental designs employed were based on the previous 3 years' experience with sweet sorghum cultivation in the Midwest. Photographs of the field procedures are shown in Figure A-1.

Common Procedures. The three field experiments, cultivar selection, plant spatial configuration, and nitrogen fertility studies, employed certain common agronomic and laboratory procedures. The experimental design in all three tasks consisted of a split-plot design of four replicates. A total of 128 plots, each 5 m x 9 m, were employed in the three experiments. The field lay-out encompassed two similar soil types: Brookton and Crosby silt-loam. Atrazine at a rate of 2.24 kg/ha was applied pre-planting for weed control. Two mid-summer applications of Malathion at a rate of 1.3 kg active ingredient/ha were required for aphid control. Planting was performed on May 19-21, 1979; harvesting was performed October 3-18, 1979.

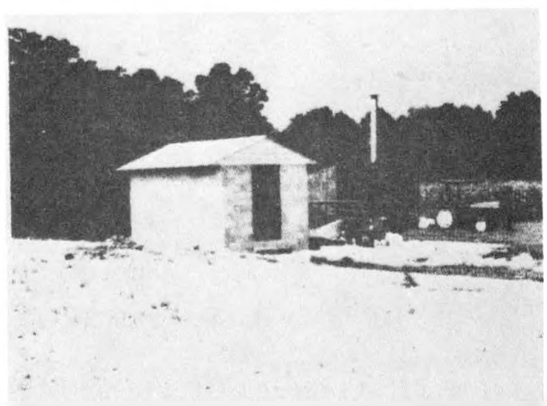
In most cases, the entire length of three rows from the center of each plot was harvested. The only exception to this procedure was in the case of the plant spatial configuration studies, in which four rows were harvested in some plots (see experimental design). All plants from the harvested rows in each plot were weighed on a specially constructed readout. Following the determination of total wet weight, twenty plants were randomly selected from those harvested and re-weighed. The twenty

A. Plot Planter

B. Mature Sorghum



C. Scales



D. Drying Shed

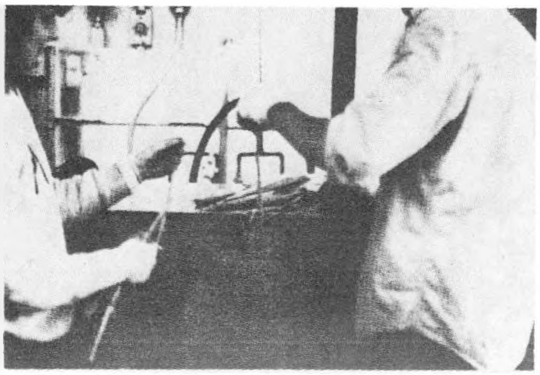
FIGURE A-1. SWEET SORGHUM FIELD PROCEDURES, COLUMBUS, OHIO selected stalks from each plot were then segregated into leaves, tops, and stalks, and placed in tared cloth bags. The stalk portions were cut into lengths of approximately 30 cm and processed through a specially designed de-pithing machine (Intercane Systems, Ltd., Ontario, Canada) resulting in separated wet pith and stalk rind. Five-hundred grams of wet pith were removed for sugar extraction procedures. The remainder of the wet pith and the stalk rind was placed in separate tared cloth bags. The wet weight and the weight after forced-air drying for 5-7 days at 55 C (130 F) was determined for leaves, tops, pith, and rind. Following drying, the grain was separated from the tops and weighed. All weights were converted to metric tons per hectare based on the area harvested from the field plots.

Laboratory procedures common to all three experiments included sugar analyses of pith for glucose, fructose, and sucrose (Figure A-2). Experimental parameters measured in each experiment included biomass, sugar yield, plant population (post-emergence and post-harvest), plant height, and stalk diameter.

Cultivar Selection Studies. The following cultivars were chosen for studies in 1979:

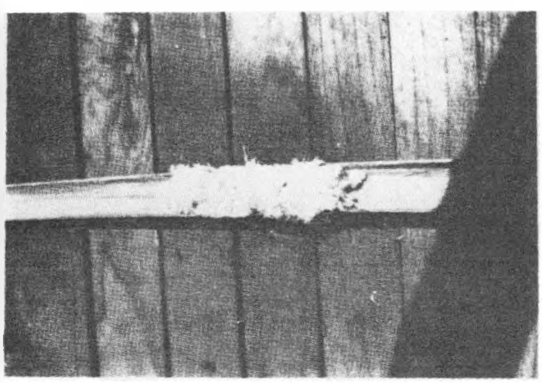
1. Dale	5. MER 61-1
2. Wray	6. MER 63-7
3. Sugar Drop	7. MER 69-5
4. MER 56-12	8. MER 69-7

The first three cultivars, Dale, Wray, and Sugar Drip, are commercially available cultivars. The five MER cultivars are unreleased cultivars developed by researchers at the USDA Sugar Crops Field Station in Meridian, Mississippi. All eight cultivars were chosen for midwestern cultivation based on expected days to maturity of less than 130 days. Since each cultivar was replicated four times, the cultivar selection trial consisted of thirty-two separate plots. Cultivars were planted with an interrow spacing of 46 cm and an intrarow spacing of 15 cm. Fiber content was determined at the time of harvest. All thirty-two plots were fertilized prior to planting with 278 kg/ha N applied as urea and 84 kg/ha each of available phosphorus (P) and potassium (K).



A. Tilby Stalk Splitter

B. Sorghum Pith



C. Sorghum Pith and Stalk

D. Sugar Extraction

FIGURE A-2. SWEET SORGHUM LABORATORY PROCEDURES

Row Spacing/Plant Configuration Studies. Three cultivars, Dale, Wray, and Sugar Drip, were grown in four spatial configurations:

(1) 76 cm interrow; 15 cm intrarow
(2) 46 cm interrow; 15 cm intrarow
(3) 46 cm interrow; 7.5 cm intrarow
(4) 15 cm interrow; 15 cm intrarow
91 cm between groups of four rows

Each treatment was replicated four times, requiring a total of forty-eight plots. Each plot was fertilized prior to planting with 278 kg/ha N applied as urea and 84 kg/ha (75 lbs/acre) each of available P and K.

Nitrogen Fertilization Studies. This experiment was designed to determine growth responses to various levels of nitrogen fertilizer and to evaluate the effect on soil nutrient levels of cultivating sweet sorghum. Dale, Wray, and Sugar Drip were grown with four different levels of N fertilizer applied as urea:

(1) 0 kg/ha
(2) 112 kg/ha
(3) 224 kg/ha
(4) 336 kg/ha

All plots received 84 kg/ha each of available phosphorus and potassium. A total of forty-eight plots was required. Plants were grown in rows 46 cm apart with 15 cm between plants in a row. The plant population was determined post-emergence and post-harvest. Root biomasss was determined at harvest.

Soil samples were removed from each of forty-eight plots to a depth of 15 cm and 30 cm two weeks following fertilization, at mid-summer, and two weeks post-harvest. Additionally, porous cup lysimeters were installed to a depth of 30 cm after fertilization for sampling soil water pre-germination and post-harvest. Soil and water smaples and plant parts, including leaves, tops, stalks, and roots, were analyzed for dissolved carbon, N, P, and K.

Investigation of Mycorrhizal Infections of Sweet Sorghum Roots. Entire sorghum plants were removed from the various plots in October, 1979. Roots were washed to remove soil, were cut into lengths of approximately 3 cm, and were placed in a fixative solution containing 13 ml formalin, 50 ml glacial acetic acid, and 200 ml 50 percent ethanol. Roots were later cleared in 10 percent KOH at room temperature for 2-3 days, rinsed in distilled water, acidified in 3 N HCl, simmered for 5 minutes in a 0.05 percent trypan blue solution in lactophenol, and decolorized in clear lactophenol. Lactophenol consisted of 120 g crystalline phenol dissolved in 120 ml distilled H_2O, 140 ml 86 percent lactic acid, and 200 ml glycerine. Roots were examined microscopically with either a Zeiss ICM 405 inverted photomicroscope or a Zeiss compound light microscope. Sweet sorghum roots obtained from six locations other than Columbus, Ohio were treated and examined in a similar manner.

Mycorrhizae-forming spores in soil were quantitatively determined from the 48 plots of the nitrogen fertility study at Columbus, Ohio and in soils from other locations by modifications of the adhesion-floration method of Smith and Skipper (1979) and the wet sieving method of Gerdemann and Nicholson (1963). Two hundred fifty grams of soil from each plot were suspended in 1.0 l distilled water, allowing to settle for approximately 30 seconds. Suspensions were then passed through a 400 mesh (38 microns) sieve. Supernatant fluid passed through the sieve was allowed to settle for approximately 30 seconds and decanted into a 16 mesh (1.19 microns) washed into nalgene bottles which were then filled with distilled H_2O, tightly capped, and stored at 4 C until spores were counted. For counting purposes, bottles were opened, and using a rubber policeman, spores floating on the surface were washed onto filter papers in plastic Petri dishes. Teh remaining contents of the bottle were agitated, washed into a glass beaker, allowed to settle for approximately 30 seconds, and gently decanted. Spores adhering to the sides of the beaker were washed onto the filter paper in the Petri dish. This process was repeated twice more, after which no spores adhered to the sides of the beaker. After evaporation of the water from each Petri dish, spores were examined and counted under a Wild-Heerbrugg Wild M8 dissecting microscope and recorded as number of spores per kg soil.

<u>Sweet Sorghum Growth Regulator Analysis</u>. Wray seeds were initially germinated in Petri dishes at 12 C in the dark. Following hypocotyl emergence, the seedlings were transferred to 40 pots at the rate of 10 per pot. The pots were 22.9 cm in diameter and 20.3 cm in depth. Vermiculite was used as a soil substitute.

The 40 pots were placed in a Sherer® growth chamber and were exposed to incandescent and fluorescent lighting at quantum flux density of 400 μE m^{-2} sec^{-1} during a 12/12-ha light/dark cycle at 19/12 C. Every other day, each pot received 500 ml of a modified Hoagland's solution ans was thoroughly drained.

Two weeks after emergence, the plants were uniformly thinned to three per pot and treated with the growth regulators (applied as a spray) (Table A-2). The following treatments plus a control were replicated four times.

TABLE A-2. GROWTH REGULATOR APPLICATIONS

Compound	Solution Concentration	Quantity of Compound Applied Per Pot*
	(ppm)	
Gibberellic Acid	2.50	25.0 μg
	25.00	250.0 μg
	250.00	2,500.0 μg
Round-up®	0.04	0.4 mg
	0.40	4.0 mg
	4.00	40.0 mg
Triacontanol	0.01	0.1 μg
	0.10	1.0 μg
	1.00	10.0 μg

The plant material was then grown for a period of six weeks. At that point, the plants were destructively harvested and measurements were recorded on:

(1) Wet biomass per pot
(2) Dry biomass per pot
(3) Percent Dry Weight
(4) Tillering numbers.

Weslaco, Texas

Uniform Experimental Design. The uniform experimental design was conducted with Wray, MN 71-1, and MN 1500, grown in three row spacings (50, 75, 100 cm) at a uniform plant density of one plant every 15 cm on each row. The experimental design was a split-plot arrangement with row spacing as main plots and the cultivars as subplots, replicated four times. The plot size was 6 m wide and 9 m in length. They were separated by a 6 m alley for irrigation and cultivation. Cultural practices chronologically applied throughout the production period are presented in Table A-3. Planting was achieved by hand dropping seed through a Planter Jr. planter.

The plants were hand thinned in May to a plant every 15 cm down each row of all row spacings. At the same time seeds of each variety were planted in the greenhouse in 3 cm peat pots. These plants were transplanted into areas to achieve the 15 cm spacing. After thinning the plant population was determined for each plot.

Fertilizer practices consisted of 225 kg/ha of 24-36-0 applied broadcast before planting and 45.3 kg of N in the irrigation water the first of June.

Insecticide application of Dipel were applied as needed to control insects. Irrigation water was applied as shown in Table A-3.

Plant population, plant height, biomass, dry matter, sugar content, fiber content, and plant nutrients were the parameters measured.

After emergence and thinning, plant counts were made to determine the initial population. Plant counts and plant heights were made twice after emergence and at the final harvest. Biomass harvests were made at three stages of plant growth (boot stage, anthesis and mature stage). Final biomass was determined from plot sizes of 2 rows 6 m long in the 75 cm rows and 4 rows 6 m long in the 50 cm rows.

TABLE A-3. CALENDAR OF EVENTS FOR SWEET SORGHUM BIOMASS RESEARCH, WESLACO, TEXAS, 1979

2/10	Chiseled and dicked soil
2/21	Fertilized broadcast with 24-36-0 @ 224 kg/ha
3/9	Chiseled
3/12	Disced
3/12	Used Howard Rotavator to break up clods
4/3	Bedded 50, 75 and 100 cm rows
4/9	Planted three sweet sorghum varieties which included MER 41-1, MN 1500 and Wray
4/10	Sprayed herbicide 2.24 kg/ha Ingran
4/11	Irrigated 4.0/ha-cm of water
4/17	Had a stand of all varieties
5/4	Cultivated all plots
5/7	Thinned plants to one every 15 cm
5/8	Transplanted skips with greenhouse grown seedlings planted same time as plants in the field
5/10	Irrigated 2.0/ha-cm of water
5/16	Counted plant populations
5/21	Cultivated on 75 and 100 cm rows. Were unable to cultivate 50 cm rows
6/1	Irrigated and fertilized with N-32 @ 112 kg/ha 3.0/ha-cm of water
6/9	Sprayed 1.68 kg/ha Dipel for insect control
6/19	Sampled 50 cm plots of Wray at boot stage
6/20	Irrigated 2.0/ha-cm water
6/22	Sampled 75 cm plots of Wray at boot stage
6/25	Sampled 100 cm plots of Wray at boot stage
6/28	Sampled 50 cm plots of MER 71-1 at boot stage
6/28	Irrigated 2.0/ha-cm of water
7/2	Sampled Wray and MER 71-1
7/5	Sampled Wray cultivar
7/7	Sprayed 1.68 kg/ha Diepel for insect control
7/13	Irrigated 2.0/ha-cm of water
7/18	Sampled Wray and MER 71-1 cultivar
7/19-20	Sampled MER 71-1
7/21	Sprayed 1.68 kg/ha Dipel for insect control
7/25-27	Sampled Wray and MER 71-1
7/31	Sampled MN 1500 cultivar
8/3	Irrigated 2.0/ha-cm of water
8/6-8	Sampled MN 1500 cultivars
8/15-17	Sampled MN 1500 cultivars
8/27-29	Sampled MN 1500 cultivars

Variety vs. Post-Harvest Treatment. Two sweet sorghum cultivars, Rio and SC0599-6 (converted Rio), were established in a completely randomized block design with three replications. Plot size was four x 6.1 m rows with 102 cm row spacings. Plots were thinned to give a plant population of 148,000 plants per hectare. At 150 days after planting 15 plants per plot were harvested by hand at ground level. Plants from each plot were divided into 3 groups of 5 in a split-plot arrangement for treatments (varieties as whole plots and treatments applied as split plots). All plants were topped and stripped of leaves at harvest. The three treatments were milling and extraction of juice after: 1) same day of harvest, 2) two weeks open storage in field, and 3) two weeks storage under enclosed shed. Juice from the stalks of each plot was collected and weighed and a Brix reading of the juice taken with a hand-held refractometer.

Analysis of Insect Pests. One 6.1 m row plot of Rio was planted to stand on February 28, April 4, and April 17, 1978, and February 27, March 12, April 2, and April 16, 1979. Igran at the rate of 2 pounds a.i./ acre was applied as a preemergent herbicide treatment on each planting date. Every plot in each year received approximately equal amounts of fertilizer and irrigation water applied according to plant growth stages. No insecticides were applied to any plots.

Each 6.1 m row plot was artificially divided into four quadrants for insect sampling. A sample unit consisted of sorghum along 5 feet of row. Sample units were selected by randomly selecting a certain row in each quadrant and a certain number of paces down the row with the use of a random numbers table. Whole plant examinations of each plant along the 1.53 m of row were made to determine insect numbers. Samples for sorghum midge, webworms, and sugarcane borer damage were made at harvest time after sorghum seeds had matured. Samples for sugarcane borer larvae were made weekly throughout the season. Data is given in the main report on the following potential pests: Flea beetles (undetermined species), yellow sugarcane aphids, sugarcane borers, sorghum midge, and the sorghum webworm.

Date-of-Planting Trial. Three cultivars were used for biomass evaluation in the date-of-planting study: Rio (high sucrose), Sart (high in yielding syrup), and MN 1500 (a tropical strain). The soil at the experimental site is classified as Willacy fine sandy loam (Order: Millisols, sub-group Udic Arguistolls). Willacy is a major soil type in the area. The soil was fallowed for 6 months during which time the soil was routinely chiseled and maintained free of weeds. The soil was disced, land planed, and bedded into 101.6 cm rows for planting.

The seeds were planted using a Planter Jr. planter, planting one drill per bed and approximately 12 seeds per 30 cm at the March plantings and 8 seeds per 30 cm at the April seedings. Propazine herbicide at the rate of 2.24 kg/ha was applied as a broadcast spray and the plots were furrow irrigated with approximately 4.0 l/ha/cm of water at each planting. 40 kg N/ha as ammonium sulfate was applied broadcast before planting and 60 kg N/ha was applied at the 4-weeks stage. Cultural practices were applied uniformly to each planting date.

Biomass was determined at the hard dough stage of each variety at each planting date by harvesting four plots 2 rows wide x 10 m in length. Data were recorded for date of flagging, 50 percent flower, height diameter, and individual stalk weight.

Laboratory Procedures

Uniform Experimental Design

Juice Extraction and Sugar Analysis. The Boehringer-Mannheim enzyme analysis for foodstuffs was used except as noted below to determine stalk-sugar content (Anonymous, 1976a). Sugars analyzed were glucose, fructose, and sucrose. Enzyme analyses were performed using Boehringer-Mannheim enzyme kits or reagents and a UV-visible spectrophometer.

Juice Extraction. Two hundred fifty g of wet, fresh, or frozen stalk tissue was blended with 1.0 l of distilled water in a Waring blender for 5-10 min. on a low, medium, or high setting. The resulting homogenate was filtered through a Whatman filter paper, the eluate volume measured, and a 25-50 ml sample frozen for later analysis.

Enzymatic Analysis. The principle of the sugar enzyme analyses is as follows:

Glucose and fructose are phosphorylated to glucose-6-phosphate (G-6-P) and fructose-6-phosphate (F-6-P) by the enzyme hexokinase (HK) and adenosine-5-triphosphate (ATP)(1),(2).

1. Glucose + ATP $\xrightarrow{HK}$ G-6-P + ADP
2. Fructose + ATP $\xrightarrow{HK}$ F-6-P + ADP

In the presence of the enzyme glucose-6-phosphate dehydrogenase (G6P-DK), G-6-P is oxidized by nicotinamide-adenine dinucleotide phosphate (NADP) to gluconate-6-phosphate with the formation of reduced nicotinamide-adenine dinucleotide phosphate (NADPH)(3)

3. G-6-P + NADP + G6P-DH gluconate-6-phosphate + NADPH + H^+

The amount of NADPH formed in this reaction is stoichiometric with the amount of glucose. NADPH is determined by means of its absorption at 334, 340, 365 nm.

On completion of reaction (3), F-6-P is converted to G-6-P by phosphoglucose isomerase (PG1)(4)

4. F-6-P $\overset{PG1}{\rightleftarrows}$ G-6-P

G-6-P reacts in turn with NADP forming gluconate-6-phosphate and NADPH. NADPH again is determined. The amount of NADPH obtained in this reaction is stoichiometric with the amount of fructose.

To obtain sucrose values, sucrose is hydrolyzed to glucose and fructose as follows:

At pH 4.6 sucrose is hydrolyzed by the enzyme β-fructosidase (invertase) to glucose and fructose (5).

5. Sucrose + H_2O $\xrightarrow{\beta\text{-fructosidase}}$ glucose + fructose

The determination of glucose after inversion (total glucose) is carried out in the same assay according to the principle outlined above. The sucrose content is calculated from the difference of the above. The sucrose content is calculated from the difference of the glucose concentrations before and after enzymatic inversion.

Solutions required for the enzyme analyses are as follows:

1. Buffer
   (Triethanolamine, 0.75 mol/l, pH 7.6; Mg^{2+}, 10 mmol/l)
2. Nicotinamide-adenine dinucleotide phosphate solution, NADP
   (ca. 11.5 mmol/l):
3. Adenosine-5'-triphosphate solution, ATP
   (ca. 81 mmol/l):
4. Hexokinase/Glucose-6-phosphate dehydrogenase, HK/G6P-DH
   (2 mg HK/ml; 1 mg G6P-DH/ml):
5. Phosphoglucose isomerase, PGI
   (2 mg/ml):
6. Citrate buffer
   (0.32 mol/l; pH 4.6):
7. β-Fructosidase
   (5 mg/ml):

Standard conditions required for the enzyme analyses are as follows:

Wavelength: 340 nm, Hg 365 nm, or Hg 334 nm

Glass cuvette: 1 cm light path

Temperature: 20-25 C

Final volume: 3.22 ml (glucose)
3.24 ml (fructose)

Read against air [(without a cuvette 3.14 ml (sucrose) in the light path)] or against water. Sample solution: 3-100 μg glucose/cuvette, 5-150 μg sucrose and glucose/cuvette.

Detailed procedures for the glucose/fructose test and sucrose test are shown in Tables A-4-5, respectively.

TABLE A-4. GLUCOSE/FRUCTOSE PROCEDURE
(Anonymous, 1976a)

Pipette into cuvettes	Blank	Glucose/ Fructose Sample	Concentration in the assay
Buffer (1)	1.00 ml	1.00 ml	Triethanolamine, 0.23 mol/l Mg^{2+}, 3.1 mmol/l
NADP (2)	0.10 ml	0.10 ml	0.36 mmol/l
ATP (3)	0.10 ml	0.10 ml	2.5 mmol/l
Sample solution	---	0.10 ml	Up to ca. 180µmol/l
Water	2.00 ml	1.90 ml	
Mix, after ca. 3 min read optical densities of the solutions (E_1). Start reaction by addition of:			
HK/G6P-DH (4)	0.02 ml	0.02 ml	1.7 X 10^3 U HK/l 0.9 X 10^3 U G6P-DH/l
Mix, wait until the reaction has stopped (approx. 10-15 min), and read the optical densities of the solutions (E_2). If the reaction has not stopped after 15 min, continue to read the optical densities at 5 min intervals until the optical density increase is constant over 5 min. Addition of:			
PGl (5)	0.02 ml	0.02 ml	4.3 X 10^3 U/l

Mix, read optical densities of the solutions after 10-15 min (E_3).
Determine the optical density differences E_2-E_1 for both blank and sample. Subtract the optical density difference of the blank from the optical density difference of the sample:

$$\Delta E \text{ (glucose)} = \Delta E_s - \Delta E_B$$

Determine the optical density differences E_3-E_2 for both blank and sample. Subtract the optical density difference of the blank from the optical density difference of the sample:

$$\Delta E \text{ (fructose)} = \Delta E_s - \Delta E_B$$

TABLE A-5. SUCROSE PROCEDURE (Anonymous, 1976a)

Pipette into cuvettes	Blank	Sucrose Sample	Concentration in assay
Citrate (6) Buffer	0.20 ml	0.20 ml	0.2 mol/1
Sample	---	0.10 ml	up to ca. 2.6 mmol/1
β-fructosidase (7)	0.02 ml	0.02 ml	4.8 X 10^3 U/1
Mix, keep the solutions at 20-25°C for 15 min. Add:			
Buffer (1)	1.00 ml	1.00 ml	Triethanolamine, 0.24 mol/1 Mg^{2+}, 3.2 mmol/1
Water	1.70 ml	1.60 ml	
NADP (2)	0.10 ml	0.10 ml	0.36 mmol/1
ATP (3)	0.10 ml	0.10 ml	2.58 mmol/1
Mix, read optical densities of the solutions after ca. 3 min (E_1). Start reaction by addition of:			
HK/G6P-DH (4)	0.02 ml	0.02 ml	1.8 X 10^3 U HK/1 0.9 X 10^3 U G6P-DH/1

Mix, wait for the completion of the reaction (ca. 10-15 min), and read optical densities of the solutions (E_2). If the reaction has not stopped after 15 min, continue to read the optical densities at 5 min intervals until the optical density increases constantly.

Subtract the optical density difference of the blank from the optical density differences of the samples, thereby obtaining ΔE [Total glucose (from sucrose sample)] and ΔE [glucose (from glucose sample)]. The difference of these values yields ΔE [sucrose].

$$\Delta E\ (\text{sucrose}) = \Delta E\ (\text{total glucose}) - \Delta E\ (\text{glucose})$$

Sugars in the sample were either determined by the calculations below or extrapolated from a standard curve, prepared by running a number of standards. According to the general formula for calculating the concentration, the equation is:

$$c = \frac{V \times MW}{\varepsilon x d x v x 1000} \times \Delta E \ (g/l)$$

where V = final volume (ml)

v = sample volume (ml)

MW = molecular weight of the substance to be assayed

d = light path (cm)

ε = extinction coefficient of NADPH at

340 nm = 6.3 ($l \times mmol^{-1} \times cm^{-1}$)

Hg 365 nm = 3.5 ($l \times mmol^{-1} \times cm^{-1}$)

Hg 334 nm = 6.18 ($l \times mmol^{-1} \times cm^{-1}$)

it follows for

glucose:

$$c = \frac{3.22 \times 180.16}{\varepsilon \times 1 \times 0.1 \times 1000} \times \Delta E \ (glucose)$$

$$= 5.801 \times \frac{\Delta E \ (glucose)}{\varepsilon} \ (g \ glucose/l \ sample \ solution)$$

for fructose:

$$c = \frac{3.24 \times 180.16}{\varepsilon \times 1 \times 0.1 \times 1000} \times \Delta E \ (fructose)$$

$$= 5.837 \times \frac{\Delta E \ (fructose)}{\varepsilon} \ (g \ fructose/l \ sample \ solution)$$

and sucrose:

$$c = \frac{3.14 \times 342.3}{\varepsilon \times 1 \times 0.1 \times 1000} \times \Delta E \ (sucr)$$

$$c = 10.75 \times \frac{\Delta E \ (sucr)}{\varepsilon} \ (g \ sucrose/l \ sample \ solution)$$

High Pressure Liquid Chromatographic Analysis. The Weslaco group (S. A. Reeves, B. A. Smith) determined sugars on a Bio-Rad HPLC carbohydrate column. Stalk extracts were prepared by the Hawaiian Sugar Planters Association's "Pol-Ratio" procedure.

The Louisiana group (R. Ricaud and B. Cochran) determined percent sucrose, glucose, and fructose with high-pressure liquid chromatography.

The North Dakota group (D. W. Meyer, O. D. Brosz) determined sugars using a glucose oxidase method described by Roehrig and Allred (1974). Their method was modified for glucose by changing the enzyme to invertase. Accuracy of this method was compared to the enzymatic-method of Boehringer-Mannheim with results presented in Table A-1. The simple correlation coefficient among treatment glucose percentages was 0.985. All sugars were expressed on a dry weight basis.

Plant Nutrients.

Digestion Procedure. Dried and ground plant material (tops, leaves, roots, recombined rind and pith) were generally extracted by Kansas State University, Forage Quality Laboratory procedure. This procedure is as follows:

1. Weigh 0.25 gram tissue per sample.
2. Add 3.0 ml hydrogen peroxide under the hood (hydrogen peroxide at room temperature).
3. Heat on hot plates under hood for 20 minutes at 6.25-6.50.
   a. Turn on hot plates 1-2 hours before beginning digestion.
5. Remove from hot plates to cool for 5-10 minutes.
6. Add 1.0 ml hydrogen peroxide (room temperature) and place on hot plates for 15 minutes.
   a. 2.0 ml of hydrogen peroxide may be added after the 20 minute heating only.
   b. After each 15 minute heating add only 1.0 ml of hydrogen peroxide (room temperature)
7. Continue steps 5 and 6 until the samples are clear then let cool.
8. Dilute to 50.00 ml with distilled water, mix and bottle.

Use 30 percent hydrogen peroxide as the catalyst.

Note: May have to use deionized water for the digestion and for N, P, or K determination.

Note: DO NOT run this digestion when running a procedure in which free ammonia is given off, such as acid detergent fiber, or around any chemical or soap in which free ammonia is given off.

Note: Clean equipment thoroughly and rinse four times in distilled water after the 0.1 N HCL bath to remove the chlorine (for this digestion procedure and the N, P, and K determinations).

Chemical Analyses. Nitrogen and orthophosphate were generally analyzed by colorimetric methods. At Battelle-Columbus PO_4-P was performed on a technicon Auto Analyzer II, while NH_3-N was determined using a NH_3 specific ion electrode. Potassium was analyzed using an atomic absorption spectrophotometer.

(NO_2^- + NO_3^-) -N was analyzed by the cadmium reduction method [Method #605 (Rand et al., 1976)]. A filtered sample was passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. The nitrite originally present plus reduced nitrate is determined by diazotizing with sulfanilamide and coupling with N-(1 - naphthyl) ethylenediamine dihydrochloride to form a red color which is measured at 540-nm. Nitrogen can be determined over a range of 0.5 to 10 mg/l nitrogen.

(PO_4^-) -P was analyzed by the ascorbic acid reduction method [Method #606 (Rand et al., 1976)]. Ammonium molybdate and antimony potassium tartrate react with orthophosphate in an acid medium to form an antimony-phosphomolybdate complex, which, on reduction with ascorbic acid, yields an intense blue color which is measured at 650-660 or 880 nm. Orthophosphate can be determined over a range of 0.0001 to 10.0 mg/l P.

Potassium (K) was measured on a Perkin-Elmer flame emission atomic absorption spectrophotometer, Model 303, using standard conditions for potassium including a wavelength of 766.5 nm, a slit setting of 4 (1.4 nm), a hollow cathode lamp light source, and an oxidizing (lean, blue) air-acetylene flame.

Other Methods. Several of the collaborating groups used different methods. The Nebraska group (J. W. Maranville, M. D. Clegg) analyzed nitrogen by the Kjeldahl method on 1 g samples. Phosphorus and potassium were determined on 100 mg (13 mm diameter) by energy dispersive X-ray fluorescence (Knudsen et al., 1980).

The Kansas group (G. L. Posler, N. S. Hill) performed nitrogen determinations using a salicylate and cyanurate colormetric assay as described by Reardon et al. (1966). This was performed by diluting 0.5 ml of sample into 4.5 ml distilled H_2O. The dilution was mixed and 0.5 ml of the dilution diluted a second time with 5.5 ml of distilled H_2O. Two ml of the salicylate solution was added followed by 2 ml of cyanurate solution. The reaction was permitted to continue for 2 hours and the concentration read on a spectrophotometer at 660 nm. Phosphorus was determined using a vanadomolydate colorometric process (Technicon Industrial Method No. 334-74 W/B^+; Anonymous, 1976b). This was performed by diluting 1.0 ml of the digested solution with 5.0 ml of the vanadomolydate reagent. The reaction was permitted to occur for 30 minutes and absorbance read on the spectrophotometer at 390 nm.

Soil Nutrients.

Extractions. Soil extraction procedures are from Allen et al. (1974). For nitrogen determinations, soil samples were extracted with water as follows:

1. Add 50.0 ml distilled water to 3.33 g ground, air-dried soil samples.
2. Shake 10 min on a rotary shaker at 175 ppm.
3. Centrifuge at 10,000 rpm for 10 min.
4. Store samples at 4 C.

For phosphate and dissolved organic carbon (DOC), soil samples were extracted with sodium bicarbonate as follows:

1. Add 50.0 ml 0.5 M $NaHCO_3$ (pH 8.5) to 2.5 g ground, air-dried soil samples.
2. Shake 30 min. on a rotary shaker at 175 rpm.
3. Centrifuge at 10,000 rpm for 10 min.
4. Store at 4 C.

For potassium, soil samples were extracted with ammonium acetate as follows:

1. Add 50.00 ml 1M NH_4CH_3COO to 2.0 g ground, air-dried soil samples.
2. Shake 1 hr. on a rotary shaker at 175 ppm.
3. Centrifuge at 10,000 rpm for 10 min.
4. Store at 4 C.

Analytical Determinations. Analysis of soil extractions was similar to plant extractions for N, P, and K. It was necessary to do the phosphorus analysis manually with a Spectronic 20. Sodium bicarbonate solutions could not be used in the AutoAnalyzer apparatus. Dissolved organic carbon was analyzed by technicon industrial method #451-76W.

The determination of total organic carbon requires the removal of inorganic carbon which is present in samples as carbonate. This automated pretreatment system is designed to remove inorganic carbon by entraining the acidified stream with a high velocity stream of nitrogen or carbon free air. The samples is transformed into a thin turbulent liquid film which is transported rapidly through a large bore coil providing the necessary surface area for efficient CO_2 removal. At a purge rate of 500 ml per minute, up to 500 mg C of inorganic carbon can be removed with minimal loss of volatiles. An aliquot of the carbonate free samples is then segmented and presented for analysis. The aliquot is then mixed with a stream of acid and potassium persulfate and subjected to UV radiation. The resultant CO_2 generated from the organic carbon present in the sample is dialed through a silicone rubber membrane and reacted with a weakly buffered phenolphthalein indicator. The decrease in color of the indicator is proportional to the original carbon concentration. This method measures carbon at a range of 0.2-20.0 mg/l.

Fiber.

Standard Acid Detergent Fiber Procedure. Acid detergent fiber (ADF) was determined according to standard procedure according to standard procedure (Goering and Van Soest, 1975) except as noted below.

The acid-detergent fiber procedure provides a rapid method for lignocellulose determination in feedstuffs. The residue also includes silica. The difference between the cell walls and acid-detergent fiber is an estimate of hemicellulose; however, this difference does include some protein attached to cell walls.

The procedure is as follows:

1. Weight 1-g air-dry sample ground to pass 20- to 30-mesh (1-mm) screen or the approximate equivalent of wet material into a beaker suitable for refluxing.
2. Add 100 ml cold (room temperature) acid-detergent solution (1 N sulfuric acid plus 20 g/1 cetyl trimethylamonium bromide, CTAB) and 2 ml decahydronaphthalene. Heat to boiling in 5 to 10 minutes. Reduce heat as boiling begins, to avoid foaming. Reflux 60 minutes from onset of boiling; adjust boiling to a slow, even level.
3. Filter on a previously tared Gooch crucible or a Whatman filter paper, which is set on the filter manifold; use light suction. Break up the filtered mat with a rod and wash twice with hot water (90-100 C). Rinse sides of the crucible in the same manner.
4. Repeat wash with acetone until it removes no more color; break up all lumps so that the solvent comes into contact with all particles of fiber.
5. Optional wash with hexane. Hexane should be added while crucible still contains some acetone. (Hexane can be omitted if lumping is not a problem in lignin analysis). Such the acid-detergent fiber free of hexane and dry at 100 C for 8 hours or overnight and weigh.
6. Calculate acid-detergent fiber:

   $(W_o - W_t)(100)/S = ADF$

   where: W_o = tared weight of oven-dry crucible;

   S = oven dry sample weight

Modifications or Additional Fiber Procedures. The Weslaco group (S. A. Reeves, B. A. Smith) did not use air-dried stalk samples. Instead, disintegrated green stalk samples were lyophilized. By subliming water vapor from ice, it was possible to retain the juice solids as part of the total plant dry matter; therefore, fiber data from Weslaco may be somewhat higher than that from the other groups.

The Nebraska group (J. W. Maranville, M. D. Clegg) performed two additional analyses. Neutral detergent fiber (NDF) was determined as described in Van Soest (1965) as modified by Robertson and Van Soest (1977). For NDF, 0.5 g dry sample was refluxed for 30 minutes with 50 ml neutral detergent solution. The beaker was removed from the heat and 50 ml additional neutral detergent solution plus 2 ml of 2 percent filtered enzyme solution (Amylase type III A, crude, from Bacillus subtilis) added. The contents were boiled for 60 minutes, cooled, and filtered into tared borosilicate crucibles with fritted glass discs. Keeping the vacuum to a minimum, the material was washed twice with hot water. The crucible was stoppered on the bottom with a rubber stopper, and 2 ml enzyme solution plus enough hot water (80 C) to fill the crucible was added. The contents were then stirred and allowed to stand for 10 minutes. The crucible was again placed on the filter stand and the filtrate removed with gentle suction. The fiber was washed twice with hot water, twice with acetone, and dried overnight at 100 C. Total non-structural carbohydrates (TNC) were analyzed by the procedure of Smith (1969).

Combustible Biomass. The yield per hectare of rind was based on weight after drying in a drying shed. This material was further dried at 105 C to a constant weight and found to contain 10.4 percent water. Two gram samples of the shed-dried material were ashed at 520 C for 16 hours.

The yield of combustible material per hectare was calculated from the per hectare yield of rind by multiplying by 89.6 percent dry weight and subtracting ash weight.

100 g of frozen pith were dried to a constant weight at 105 C. An additional 100 g of pith were extracted in 400 ml of water (the same 4:1 ratio that was used in all the sugar analyses) and the filter cake was dried at 105 C. A sample of dried, extracted pith was ashed at 520 C for 16 hours. Several samples of pith that had been dried in the drying shed were also dried at 105 C so that the yield per hectare data could be correlated with the laboratory data. These averaged 86.5 percent dry matter.

The yield per hectare of combustible material remaining after extraction of the pith was calculated as follows. The yield of pith per acre was multiplied by 86.5 percent to get dry matter yield per acre. This was multiplied by the ratio of the weight of wet to dry unextracted pith in the laboratory study to get the yield of wet pith per hectare. This was multiplied by the ratio of the dry weight of extracted pith to original wet weight of pith that was taken for extraction to get the yield of dry matter after extraction per hectare. This was multiplied by the percent combustible matter obtained from the ashing experiment.

Standardization of Sugar Analyses Between Sites

Each of the collaborating institutions performed its own sugar analyses. Not only were the laboratories and personnel different but the assay methods in some cases differed between laboratories. This difference in the choice of assay methods was due in part to differences in experience and preference and to differences in available instrumentation.

In order to have maximum confidence in comparisons of sugar data between the various sites, it was necessary to take measures designed to assure the quality of the data. This was accomplished by having each laboratory analyze certain common samples. Five standard solutions, each containing glucose, fructose, and sucrose, were prepared, subdivided into plastic bottles suitable for shipping, and frozen. Five sugarcane juice extracts were similarly subdivided and frozen. The ten frozen sample solutions, identified only by a number, were then sent to each laboratory, packed in dry ice. The results of the analyses were sent to Battelle and are presented in Table A-6.

An examination of Table A-6 suggests that the results from the various laboratories are reasonably comparable. There are a few numbers that are incomparable which have been indicated. Some samples may have thawed during shipment, which could have led to some sugar loss. Although the correlation is not as high as might be desired, sugar yields based on averages of several determinations should be acceptably close to the actual values for any of the laboratories.

TABLE A-6. ANALYSIS OF TEN SUGAR SAMPLES AT SIX LABORATORIES

Sample	Actual Composition	Battelle[a]	Kansas State[a]	Louisiana State[b]	Nebraska[a]	Texas A&M[a]	Florida[c]
Sucrose							
1	40.0	35.4	37.0	40.7	36.3	22.8[d]	21.1[d]
2	17.6	19.5	16.2	18.0	16.1	21.0	15.2
3	10.0	11.0	9.3	10.3	9.7	11.0	8.1
4	22.5	21.0	20.0	23.1	22.2	19.7	18.2
5	4.0	4.2	3.6	3.8	4.1	5.2	3.4
6	--	69.6		73.3	60.5	66.3	68.6
7	--	22.1	27.1	98.2[d]	18.3	29.0	27.9
8	--	109.4	120.3	109.7	102.0	130.0	107.0
9	--	134.3	162.9	150.4	132.0	170.0	146.1
10	--	80.3	100.7	90.3	71.0	88.6	82.4
Glucose							
2	12.0	12.6	10.8	12.1	11.7	6.8[d]	
3	7.5	7.4	6.9	7.0	7.1	7.8	
4	6.0	5.9	5.5	5.8	5.8	6.2	
5	11.0	11.3	10.1	10.6	10.7	10.8	
	2.0	1.9	1.8	2.0	2.0	3.0	
6	--	22.3	--	26.9	24.0	27.2	
7	--	10.8	16.0	12.5	12.3	19.5	
8	--	5.4	7.3	6.0	6.9	7.4	
9	--	5.6	8.3	5.9	8.2	8.4	
11	--	11.3	15.3	14.4	12.8	13.0	
Fructose							
1	20.0	20.3	16.7	17.8	19.4	10.1[d]	
2	6.0	5.9	5.5	5.8	5.6	6.8	
3	5.0	4.9	4.2	4.8	4.8	5.2	
4	9.0	9.3	7.5	8.9	8.9	8.8	
5	2.0	1.9	2.0	2.0	2.1	3.4	
6	--	12.1	--	13.7	16.5	15.2	
7	--	6.5	9.2	6.0	7.6	11.5	
8	--	5.2	7.2	5.0	6.8	7.4	
9	--	4.7	6.3	2.4	6.4	6.7	
10	--	6.9	8.8	7.0	9.2	7.4	

(a) Enzymatic method.

(b) High pressure liquid chromatography method.

(c) Polmethod.

(d) Outlying data.

One of the laboratories submitted earlier results (not shown) which were low for the more concentrated solutions. This pointed out the danger of running out of NAD substrate if the samples were not sufficiently diluted, which leads to an underestimation of sugars. The laboratory was notified of this problem and did the analyses of field and quality control samples a second time after correcting for this problem. Investigators at North Dakota had a similar problem and repeated the analyses of the field samples. However, the quality control samples had been discarded. For that reason their data do not appear in the Table A-6.

Analysis of the Blender Method for Extracting Sugar from Sweet Sorghum Pith

A key limiting factor in any analytical method is the efficacy of the extraction procedure. We can know with precision how much was extracted but there always remains the question of how much may remain that for one reason or another was not extracted.

The extraction procedure used at Battelle and several other sites was to blend 250 g of fresh pith in 1 liter of water followed by vacuum filtration (see appropriate experimental sections). At the same time at Battelle, a sample of the pith was frozen. Eight of these frozen samples from the variety trials were later used in an experiment to determine how much additional sugar could be obtained by a second extraction.

After the frozen pith had thawed, 250 g were blended in 1 liter of water. The water and juice were filtered off and the filter cake was re-extracted by blending in an additional liter of water. The two extracts were analyzed separately and the results were compared to the data from the fresh extract. The filter cakes from the original fresh pith extraction had been frozen. These were also thawed and re-extracted with 1 liter of water. The results of the sugar analyses are shown in Table A-7.

TABLE A-7. SUGAR REMOVED FROM SWEET SORGHUM BY A SECOND EXTRACTION

	Sugars from original pith (t/ha)			Sugars from frozen pith (t/ha)		
	A	B	C	D	E	F
Sample	Pith[a]	Frozen Filtercake[a]	Total[d]	Pith[b,c]	Filtercake[b]	Total[d]
1	2.0	0.4	2.4	3.1	0.9	4.0
2	3.7	0.3	4.0	3.6	0.4	4.0
3	1.7	0.1	1.8	2.5	0.3	2.8
4	0.4	0.1	0.5	0.5	0.05	0.6
5	1.2	0.1	1.3	1.2	0.1	1.3
6	0.8	0.2	0.9	1.3	0.1	1.4
7	1.4	0.2	1.6	2.2	0.2	2.4
8	0.5	0.1	0.6	0.8	0.1	0.9
Mean	1.5		1.6	1.9		2.2

(a) Mean of the percents of sugar in column B compared to column A is 14.3 $\pm$ 4.6 percent.

(b) Mean of the percents of sugar in column E compared to column D is 12.5 $\pm$ 4.7 percent.

(c) Column D is significantly higher than column A ($P \leq 0.05$).

(d) Column F is significantly higher than column C ($P \leq 0.05$).

The results of this experiment suggest that a more exhaustive extraction procedure would have removed approximately 12-14 percent more sugars. The sugars measured from a single extraction could be more or less than would be available for fermentation in a commercial operation, depending upon the design of that operation.

More surprising were the larger amounts of sugars obtained from the frozen pith compared to the fresh pith. The means for the first extractions averaged 27 percent higher for frozen than for fresh pith. The two extractions made on the frozen pith, added together, contained 34 percent more sugar than the extraction of fresh pith and the resulting frozen filtercake.

One possible explanation for this observation is that freezing disrupts some plant structure, accompanied by release of sugar. If this were so, however, the unreleased sugar should still be in the filtercakes. Re-extraction of those filtercakes, which had by then been frozen for some time, should have recovered all the sugar, making the frozen and fresh pith results comparable. This did not occur, so the hypothesis is questionable.

The effect of freezing on sweet sorghum pith needs to be more fully investigated.

APPENDIX B

SWEET SORGHUM PITH AND SUGAR EXTRACTION ANALYSIS, WESLACO, TEXAS

The Texas Agricultural Experiment Station at Weslaco received a laboratory scale Tilby for sugar extraction. This device, manufactured by Intercane Systems, Inc. of Windsor, Ontario, is two separate units, a stalk splitter unit and stalk depither unit.

Through testing it was found that the splitter unit did not split small stalks or would split stalks off center. Three modificiations were made: (1) the splitter blade was moved closer to the counter rotating wheels so small stalks would not be missed, (2) stalks were cut into short billets to keep the stalk from drifting to one side, and (3) a plexiglass funnel was placed behind the blade to channel stalk material into small collection bags (Figure B-1).

The depither unit worked very well as it came from the manufacturer. One modification was made to allow for sample collection. A funnel device was made from plexiglass that is easily removed for washing and that would direct the pith into sample collection bags (Figure B-2).

In testing the Tilby unit, billets were weighed before splitting and pith was weighed after extraction from the stalk. Figure B-3 shows the relationship between stalk diameter and percent pith. As is shown there is increasing pith percentages with increasing stalk diamter. This seems to be due to more favorable rind to pith rations with increasing stalk diameter and not due to increased extraction efficiency.

Once the sample had been collected, the juice was extracted using a hydraulic jack that functions in the horizontal position within a frame capable of withstanding load stresses of 3600 kg. Pressure was applied to samples that had been placed in a 11 cm i.d. by 8 cm deep metal cup that has 1 cm walls. A piston is placed over the samples and pressure is applied, forcing the liquid from the sample.

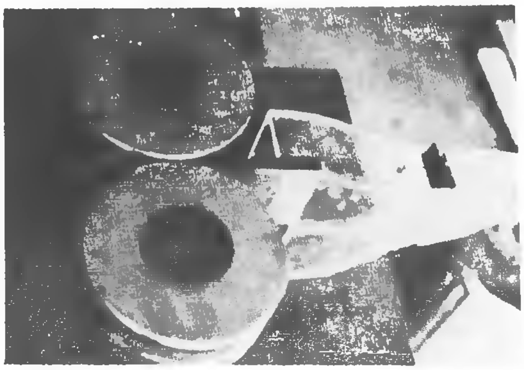


FIGURE B-1. THE STALK SPLITTER COMPONENT OF A TILBY EXTRACTION SYSTEM WITH THE PLEXIBLASS FUNNEL THAT CHANNELS SPLIT STALKS INTO SAMPLE BAGS

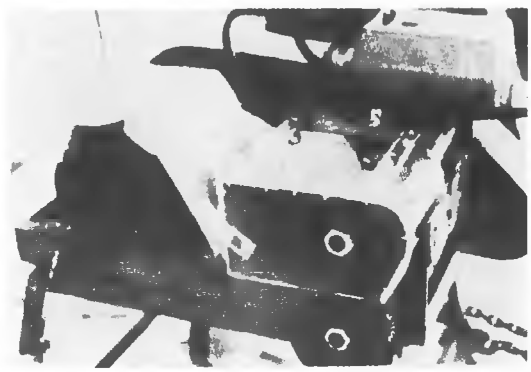


FIGURE B-2. THE PITH EXTRACTOR COMPONENT OF A TILBY EXTRACTION SYSTEM WITH THE PLEXIGLASS FUNNEL THAT CHANNELS EXTRACTED PITH INTO SAMPLE BAGS

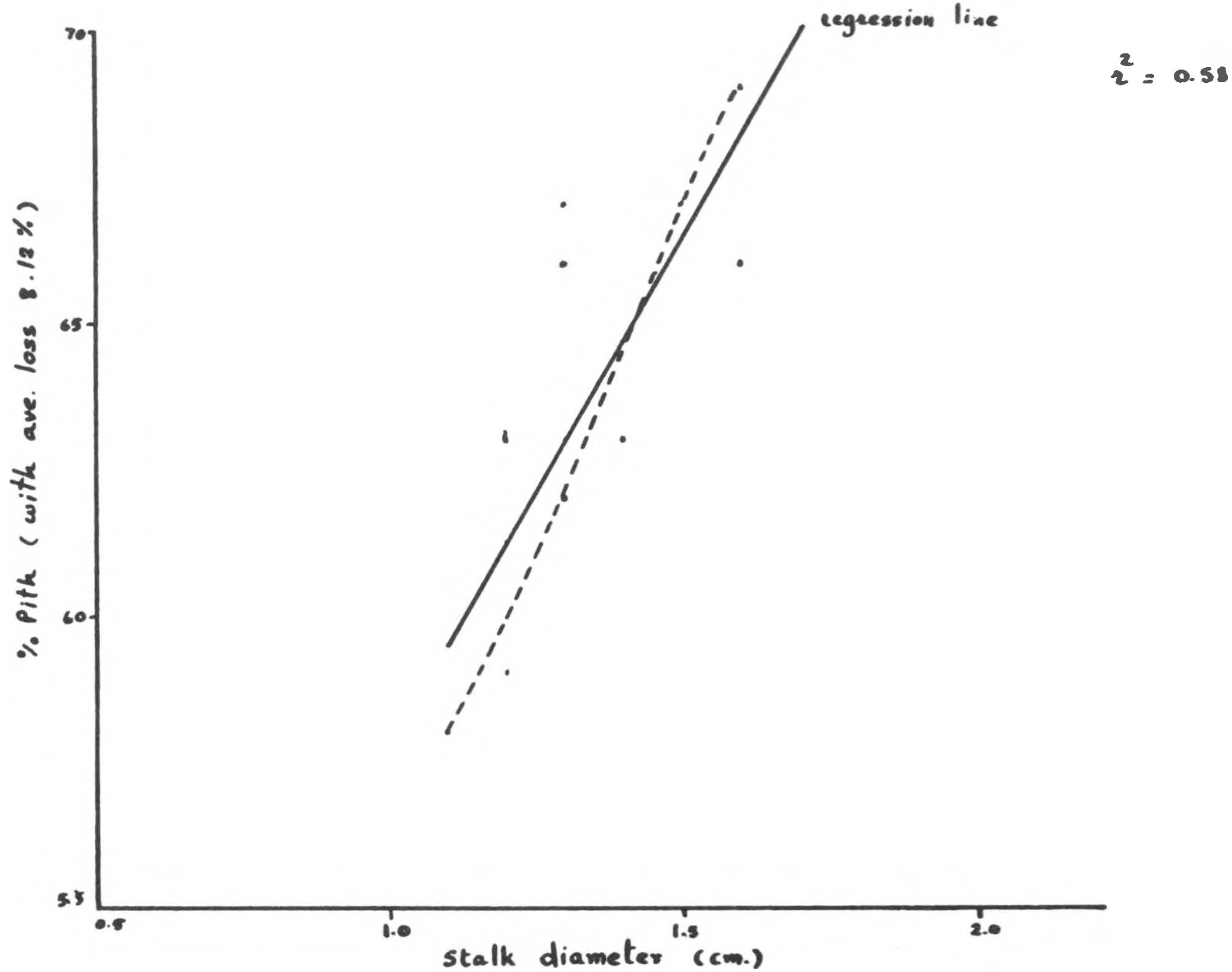


FIGURE B-3. REGRESSION LINE DESCRIBING RELATIONSHIP OF PERCENT STALK PITH TO STALK DIAMETER

The fibrous residue was washed with distilled water and re-extracted in an effort to determine sugar extraction efficiency (Figure 3-4). Up to 5 extractions were necessary to remove all of the sugars present in the pith samples.

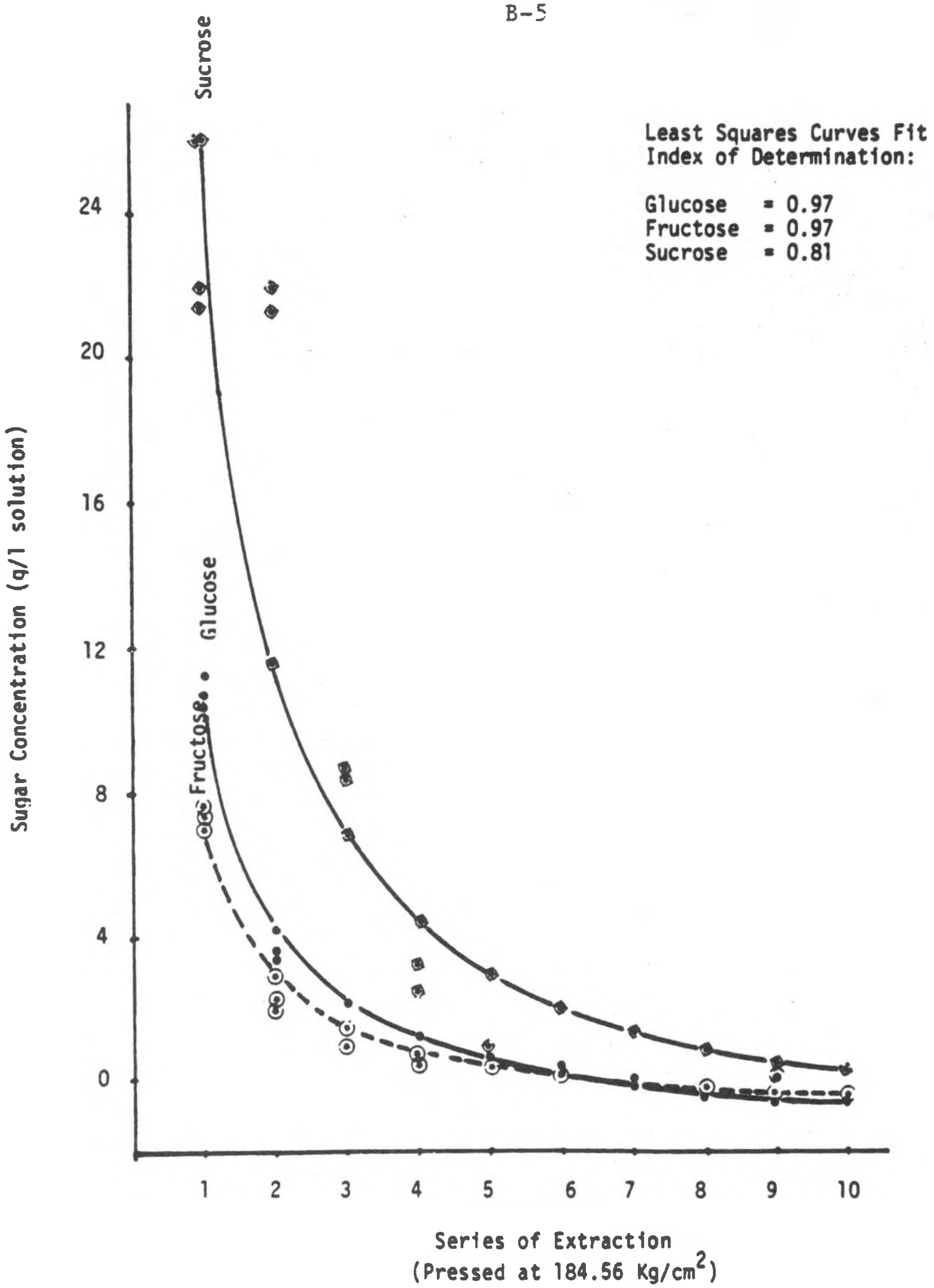


FIGURE B-4. RELATIONSHIP OF SUGAR CONCENTRATION IN THE EXTRACT IN A SERIES OF EXTRACTIONS BY PRESSING

APPENDIX C

ADDITIONAL EXPERIMENTAL RESULTS

Male-Sterile Corn Trials at Columbus, Ohio

Background

Male-sterile corn, developed primarily as a breeding tool, has been evaluated for producing stalk sugars for the corn syrup industry (Schou, 1970). Thus, male-sterile corn hybrids were considered prime candidated for producing stalk sugars for fermentation to ethanol. Four lines of male-sterile corn hybrids were obtained from Cargill, Inc. to investigate their potential for producing biomass and sugars at West Jefferson, Ohio (Table C-1). The HS-50 cultivar is available commercially, the other cultivars are experimental hybrids.

Procedure

A completely randomized design incorporating 3 replicate plots of each cultivar was used in the experiment. Plots were seeded on June 5, 1979, on a plot 3.1 m in length by 1.8 m in width. Paper bags were placed on ears of the male-sterile cultivars as they emerged. However, many bags were blown off during the growing season, resulting in considerable fertilization. At the time of harvest (October 18, 1979), total wet biomass was determined as well as total sugars, according to procedures used in the West Jefferson sweet sorghum field trials.

Results and Discussion

Total sugars produced by the male-sterile corn hybrids ranged from 0.15 to 0.61 t/ha, considerably below values of approximately 2.7 t/ha reported for sweet sorghum at this same location. However, the fact that fertilization and grain-filling occurred, most likely inhibited photosynthate

TABLE C-1. WET BIOMASS AND TOTAL SUGAR YIELDS FOR 4 CULTIVARS OF MALE-STERILE CORN GROWN AT COLUMBUS, OHIO

Cultivar	Total Sugars	Wet Biomass
	t/ha	
3902 X 7311 H	0.32 (0.18)[a]	43.0 (6.2)
C3714 X 1067	0.61 (0.34)	56.9 (9.8)
HS-50	0.54 (0.21)	51.3 (7.4)
C7311 X 2608	0.15 (0.02)	29.1 (1.5)

(a) Standard deviation

storage as sugar in the stalk. Thus, yields from these hybrids would be expected to be higher had sterility been maintained. However, biomass for sweet sorghum may be expected to be 20 to 40 percent higher than the reported values for male-sterile corn.

Further investigation will be required to fully evaluate male-sterile corn hybrids as a sugar-stalk crop for alcohol production in the midwest.

Sorghum Germplasm Nursery

Background

Because of a number of distinctively advantageous characteristics such as high productivity, drought tolerance, and low nutrient requirements, sorghum [*Sorghum bicolor* (L.) Moench] has become a prime candidate as a feedstock for the production of energy from an agricultural system. Over 17,000 lines of sorghum have been identified in the world collection.

For the past three years, researchers at Battelle Columbus Laboratories and several coinvestigators have explored a potential of sweet sorghum for energy. However, the sweet sorghum is only part of a species of sorghum.

Further testing of the germplasm, which included grain sorghum, grain-sweet sorghum crosses, sudangrass, and brown midrib mutants, was necessary. This effort was an initial step to select additional genetic material of sorghum for energy.

Procedure

A completely randomized design incorporating two 6.1 m row plot replicates of each of the twenty-five lines was used in the experiment. The individual plots were fertilized at the rate of 280, 84, and 84 kg/ha^{-1} of nitrogen, phosphorus, and potassium, respectively. The planting arrangement included 76 cm interrow and 15 cm intrarow spacing. Assuming no tillering, this planting arrangement is equivalent to a plant population of 85,800 per hectare. All yield calculations are based on that extrapolation. Planting operations were performed on May 30, 1979.

Harvesting was conducted on October 1 and 2. At that time, total sugars of the stalk were determined, according to procedures used in the West Jefferson sweet sorghum field trials.

Results and Discussion

Total stalk sugars in the study ranged from 0.04 t/ha for AT x 399 x T x 430 (a dry-stemmed sorghum) to 3.33 t/ha for the male-sterile Brandes sweet sorghum. The value for Brandes may have been even higher had not some of it been cross-fertilized. The next two highest yielding lines were also sweet sorghums, Sart and Rio. The highest yielding grain sorghums were AT x 378 x 78CS954 and AT x 622 x 78CS954 at 1.87 t/ha, respectively. Biomass yields followed the same trends as the sugar yields (Table C-2).*

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*More specific information is available on request from Battelle.

TABLE C-2. WET AND DRY BIOMASS YIELDS OF THE THREE MOST PRODUCTIVE LINES OF SORGHUM

Cultivar	Wet Biomass	Dry Biomass
	t/ha	
Male-sterile Brandes	60.9	11.1
Sart	56.8	9.2
AT x 378 x 78CS954	48.0	11.9

Results indicate that the sorghum germplasm exhibits a tremendous amount of variability in Ohio. Yield data appear low because a plant density of only 86,000/ha was utilized (this is much below that of 130,000 for the sweet sorghum field studies). Furthermore, this nursery trial was designed to yield only relative information between the lines for selection purposes. With this point in mind, it is obvious that the male-sterile Brandes, AT x 378 x 78CS954, and AT x 622 x 78CS954, require more testing and analyses on a larger scale.

APPENDIX D

GLOSSARY

Abbreviations

ADF - acid detergent fiber. It is a chemical fiber determination. The ADF residues consist of cellulose, lignin, cutin and acid-insoluble ash (mainly silica).

BC_1 - first back cross hybrid.

BC_2 - second back cross hybrid, crossing the hybrid with one of its parents or parental type.

C_4 - character of a plant that fixes CO_2 first into four-carbon oxaloacelate and then into 3-phosphoglycerate, yielding a high concentration of CO_2, and synthesizing hexose much faster per unit leaf area, growing much faster, and functioning better at higher light intensities.

F_1 - first generation hybrid.

LSD - least significant difference.

NDF - neutral detergent fiber. NDF is a chemical fiber determination of the total fiber in vegetable feedstuffs. It divides dry plant material very near the point that separates the nutritively available (98 percent) and soluble constituents from those that are incompletely available and dependent on microbial fermentation. The difference between NDF and ADF (see above) is hemi-cellulose and some protein attached to cell walls.

$P \leq 0.05$ - a statistical symbol. When the treatment (i.e. of a cultivar, row spacing) means are significantly different $P \leq 0.05$), this means that the probability (p) is less than or equal to 0.05 that the differences could be a result of pure chance alone. Therefore, the probability is 0.95 or greater that the differences in the means are the result of some actual systematic differences among the groups (treatments). This indicates there may be some underlying causal mechanism producing these differences.

TNC - total nonstructural carbohydrates. This is a chemical determination. It consists of all carbohydrates, simple sugars and starches, which are not used as structural components in the plant.

Definitions

Anthesis- see sorghum growth stages.

Bagasse - the residue of sugar cane after crushing in one mill or a train of mills.

Boot Stage- see sorghum growth stages.

Brix - concentration in percent of sugar by weight according to the Brix Scale.

Clone - a group of genetically identical organisms which reproduce vegetatively.

Cultivar a particular genotype in cultivation, recognized and perpetuated by man as a distinct element of a species.

Duncan's multiple range test- used after analyses of variance to rank and make statistical comparisons of treatment menas.

Lodging- stocks of large grasses bending over in angular fashion after a severe wind and rain storm. The degree of lodging depends on the severity of the storm.

Pol - a method of sugar cane analysis of sucrose. Pol is the weight in sugarcane of the sum of the weights of its juice and bagasse.

Ratoon cropping - produced from the tiller or basal shoot arising from the crown or root of the plant.

Shorgum growth stages- Anthesis time of flowering.

Hard Core Boot- the sheath near the upper most leaves on the stems of grasses that enclose the inflorescence which swells within it.

Soft dough- maturity.

Tiller - in grasses, a basal shoot, arising from the crown or root.

Conversions

C to F, centegrade to Fahrenheit, use formula $\frac{C}{100} = \frac{F - 32}{180}$

cm to in, centemeter to inch, multiply by 0.3937

gal/a to l/ha, gallons per acre to liters /hectare, multiply by 9.35

ha to a, hectares to acres, multiply by 2.471

kg/ha to lb/a, kilograms/hectare to pounds/acre, multiply by 1.12

kg/h to mi/h, kilometers/hour to miles/hour, multiply by 0.6214

kg to lb, kilograms to pounds, multiply by 2.205

l to gal, liters to gallons, multiply by 0.264]

l/t to gal/t, liters/metric ton to gallons/ton, multiply by

t to lb, metric tons to pounds, multiply by 2,205

t/ha to t/a, metric tons/hectare to tons/acre, multiply by 2.25

m to ft, meters to feet, multiply by 3.281

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