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SUGAR CROPS AS A SOURCE OF FUELS

Volume I: Agricultural Research

Final Report

By
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D. R. Jackson
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July 31, 1978

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Battelle
Columbus Division
Columbus, Ohio

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VOLUME I: AGRICULTURAL RESEARCH

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in cooperation with

Louisiana State University, Texas A&M University, University of Florida, F. C. Schaffer & Associates, U.S. Department of Agriculture, and Joseph E. Atchison Consultants, Inc.

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ABSTRACT

This report by Battelle Columbus Division presents the results of a study of the feasibility of using sugar crops as a source of fuels. The program is a cooperative effort, including universities, USDA field experiment stations, research organizations, and engineering companies. Narrow-row spacing experiments were conducted at Houma, Louisiana; Baton Rouge, Louisiana; and Belle Glade, Florida. Narrow-row spacing promotes more rapid canopy closure which helps a short season location more than a long season location.

Sweet sorghum experiments in Texas, Louisiana, Mississippi, and Ohio indicate favorable yields compared with sugarcane, and yield increases with close spacing in all areas. The project team concludes that sweet sorghum has considerable fuel potential, based on its ability to grow wherever corn or soybeans grow.

Initial evaluation of the Tilby cane separator process, which separates the pith from the rind fiber without crushing and grinding, indicates that the process is promising as a means of obtaining fermentable sugars at low cost. The advantages of the Tilby process (yet to be demonstrated on a commercial scale) are low energy consumption, high value for the rind fiber coproducts in products that perform like plywood, pulp or paper making, and ability to use high fiber sugarcane or sweet sorghum.

Ethanol from sugarcane or sweet sorghum is unlikely to be available in large quantities for less than $1.00 per gallon because improvements in sugar crop production and processing are needed to hold the raw material costs for ethanol to $0.70 per gallon. When reasonable provisions are made for fermentation, distillation and return on investments, the target of $1.00 per gallon appears appropriate. There are opportunities to manufacture liquid motor fuels other than ethanol from sugar crop juice and/or associated lignocellulosic fractions. Typical alternatives are 2,3-butanediol, ketones derived from short-chain fatty acids, and microbial oils.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

I. INTRODUCTION

The world faces an energy crisis which arises because of the limited quantities and geographical distribution of fossil fuel resources and the growing aspirations for material goods and transportation in both the developed and developing nations. The United States consumes a significant percentage of world energy production and also is an important fossil fuel producer. For reasons of economy and national security, the United States needs to develop domestic resources to assure supplies of fuels to serve especially transportation, heating of buildings, and cooking.

The United States has many fossil and non-fossil resources that it might develop to maintain its level of energy consumption without importing inordinate quantities of petroleum. This OPEC petroleum is needed by others who do not have coal, shale, or large land areas. The choice of resources to develop, estimation of the cost of development, and estimation of lead times to commercialization are some of the most difficult decisions to be made in the near future by both the public and private sectors. The Department of Energy has been organized in part to solve problems associated with these resource management decisions. The The land area of the United States includes hundreds of millions of acres of unharvested terrain that potentially could be the source of fuels. Can some of the land and water resources of the United States be harnessed to supply a significant quantity of fuels?

The Fuels from Biomass Branch of the Division of Solar Technology of the Department of Energy (DOE) is charged with the responsibility for identifying, developing, and demonstrating systems for using biological resources (biomass) as sources of fuels and major chemical feedstocks now derived from nonrenewable energy resources (DOE, 1978). Front-running candidates are trees, sugar crops, and major grains, such as corn. Each biomass source has some outstanding advantages as a source of fuels and some drawbacks that need to be overcome prior to commercialization.

Since mid-1975, Battelle Columbus Division (BCD) has investigated opportunities for fuels from sugar crops under contract with DOE. Results of the initial sugar crop systems study have been presented in a three-volume report (Lipinsky, et al, 1976)*, and at a tutorial conference held in Columbus, October 13-15, 1976. The tutorial conference acted as a catalyst to bring together many interested groups, including the sugar industry, U.S. Department of Agriculture (USDA), universities and experiment stations, and others who perceived fuels-from-biomass opportunities as means to revitalize the U.S. sugar industry.

The major DOE goals are low cost fuels that are available in sufficient quantities to make a significant impact. The systems analyses showed that the cost of fermentable sugars is the primary factor (60%-70%) in the cost of ethanol and other fuels derived by fermentation. Distillation costs and stillage by-product credits also are significant. The high moisture level, mediocre energy content and relatively small quantity of bagasse at a given site led to estimates of methanol costs that exceed those calculated by others for tree biomass (Inman et al, 1977) or for coal (Sherwin and Frank, 1975). The limited land area in the United States that is suitable for conventional sugarcane production was also recognized as a constraint, as were the seasonality of sugar crops on the mainland and the perishability of raw sugar crop juices.

Despite the problems and apparent constraints, the sugar crops emerged as a biomass resource worthy of further investigation. The energy self-sufficiency of ethanol production when bagasse is used as fuel for the conversion facility and the opportunities for extending the geographical range of the sugar crops are significant positive factors.

On April 1, 1977, a broadly based research program spearheaded and coordinated by BCD, was initiated to explore sugar crops as a source of fuels and chemical feedstocks from sugar crops. The level of cooperation by industrial organizations, USDA and universities has been outstanding, in part because the industry's intense need for new products and cost reduction.

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* Names and dates in parenthesis refer to literature citations at the end of each chapter.

This Final Report summarizes the results of this program between April 1, 1977 and March 31, 1978.

Objectives and Scope

This research program has agricultural and process development activities. The primary objectives of the agricultural aspects pertain to evaluation of the feasibility of reducing the costs of fermentable sugars derived from sugar crops and increasing their availability by the following methods:

(1) Close spacing of sugar crops

(2) Production of sweet sorghum varieties with wide geographical ranges that are high in fermentable sugars, regardless of table sugar prospects

(3) Harvesting and processing of the entire aerial part of sugarcane and/or sweet sorghum.

The process development activities include a search for separation processes that are useful for preparing sugar crop biomass for conversion to low cost fuels. Specifically, means to reduce the moisture content of bagasse and to obtain fermentable sugars at little energy expenditures are sought.

The scope of this research program is shown generally in Figure I-1. The scope has been limited as follows:

(1) Sugar beets were not included because the systems study showed serious energy balance and economic problems in making fuels on a large scale from this source.

(2) No thermochemical or microbiological conversion development was undertaken because these conversion activities are handled by DOE for multiple biomass sources. However, inputs were made to those engaged in the development of conversion processes.

(3) Processing of sugar crops to obtain a solution of fermentable sugars or a gasifiable fiber fraction is within the scope of this program.

(4) An economic evaluation of ethanol production from sugarcane and molasses, using conventional technology, was undertaken to provide a baseline for those developing new conversion technologies.

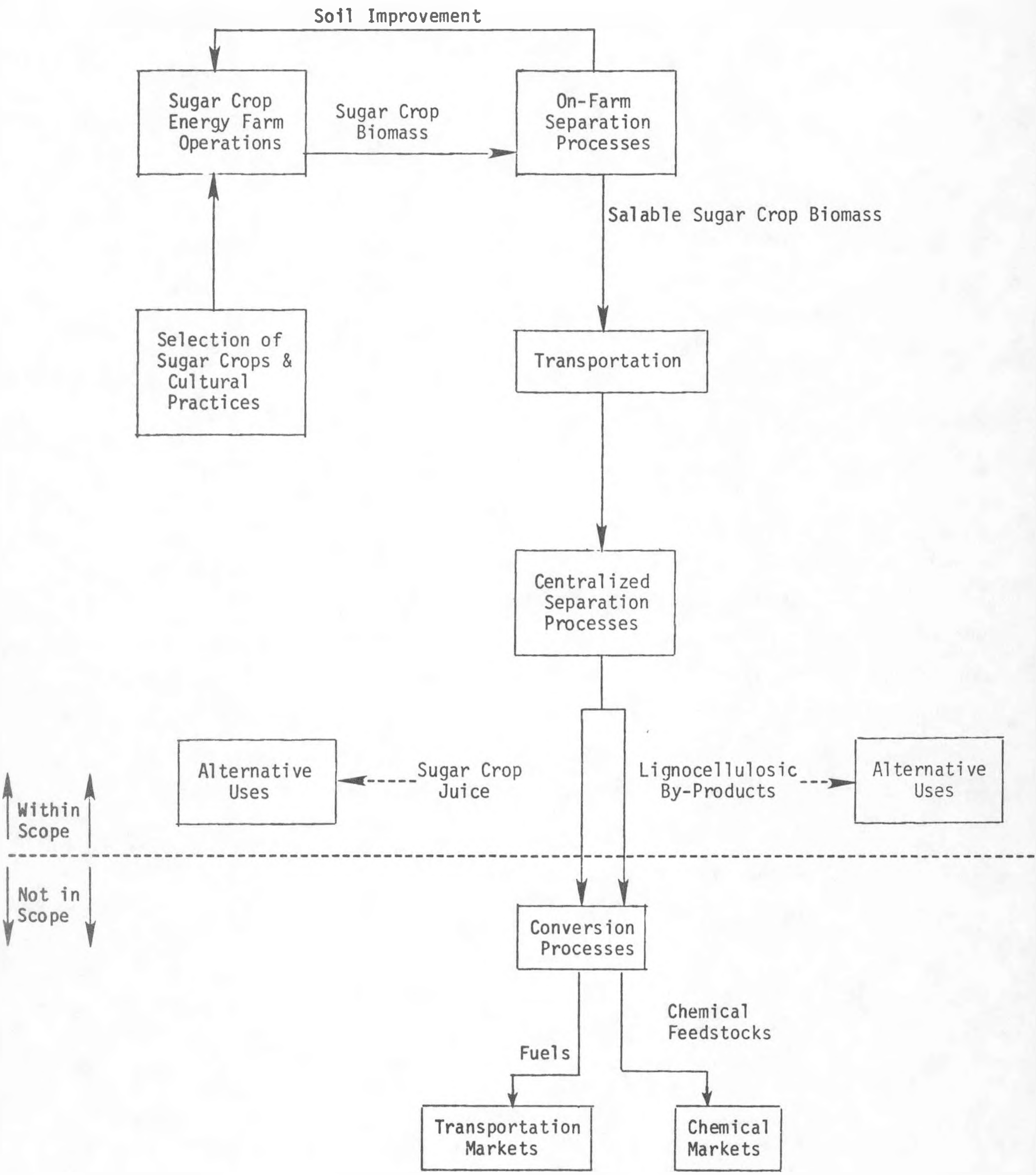

FIGURE I-1. SCOPE OF RESEARCH PROGRAM

Agricultural Research

Close-spaced sugarcane was planted at Florida Agricultural Research and Education Center, Belle Glade, at the Louisiana State University's St. Gabriel Sugar Experiment Station, and at the U. S. Department of Agriculture's Houma, Louisiana, Sugarcane Field Laboratory. Sweet Sorghum field trails have been initiated at Texas A&M's Weslaco Experiment Station and at LSU's St. Garbiel Experiment Station*. Periodic measurements were made of conditions at these sites and performance of the crops yields obtained with close-spaced practices were compared with yields obtained with conventional cultural practices. Sugar crop composition was measured.

Agricultural Economics Research

Development of cost information on sugarcane and sweet sorghum when they are grown under conditions that are appropriate for emphasis on fuels and chemical feedstocks was the major agricultural economics activity in this year's program. The activities and costs entailed in developing new sugarcane cropland were identified and analyzed. Field interviews and interpretation of data developed in this and other research programs were the primary sources of information for the agricultural economics research.

Sugar Crops Processing Research

The extent to which a sugar crop processing facility directed at production of ethanol can be energy self-sufficient was investigated. The impact of total plant harvesting (with its opportunities to provide significantly more biomass at the processing facility) on the materials balance, energy balance, and mode of factory operation is under investigation. The economics of conversion of sugarcane into ethanol was

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*In addition, Battelle is making available the results of internally funded sweet sorghum field trials at West Jefferson, Ohio.

studied by conceptualization of a complete facility that employs conventional technology and itemization of the capital and operating costs. Reuse of hot flue gases to upgrade bagasse fuel quality or to increase steam and electricity production by combustion air preheating was evaluated at LSU.

A radically different means of juice extraction from sugar stalk crops was identified and is being evaluated by a co-contractor (Joseph E. Atchison Consultants, Inc.), and BCD. This Tilby Separator Process could generate a different product mix and has the potential for consumption of much less energy in the production of sugarcane juice. A German process for extraction of juice at elevated temperature also has been identified and investigated briefly by Battelle.

Organization of the Research Team

The organization of the research team is summarized in Figure I-2. BCD had overall project management and coordination responsibilities. Also, certain agronomic, agricultural economics, and processing economic studies were conducted by BCD. The University of Florida, LSU, and the USDA Houma Laboratories investigated closely spaced sugarcane as a means of yield improvement. Texas A&M and LSU investigated sweet sorghum yields and composition. The USDA Weslaco Research Center is playing a major role in development and implementation of analytical chemical procedures. The University of Puerto Rico is investigating tropical grasses other than sugarcane and sweet sorghum and is reporting separately to DOE. The Audubon Sugar Institute at LSU and F. C. Schaffer & Associates researched total-plant processing and the energy requirements for conversion to ethanol. Joseph E. Atchison Consultants, Inc. completed an objective evaluation of the Tilby Separator Process, a new means to obtain sugar and fiber from cane. A topical report was submitted separately by Joseph E. Atchison Consultants, Inc. Although DOE is providing the baseload funding, many of these organizations are supplementing this seed money with their own funds.

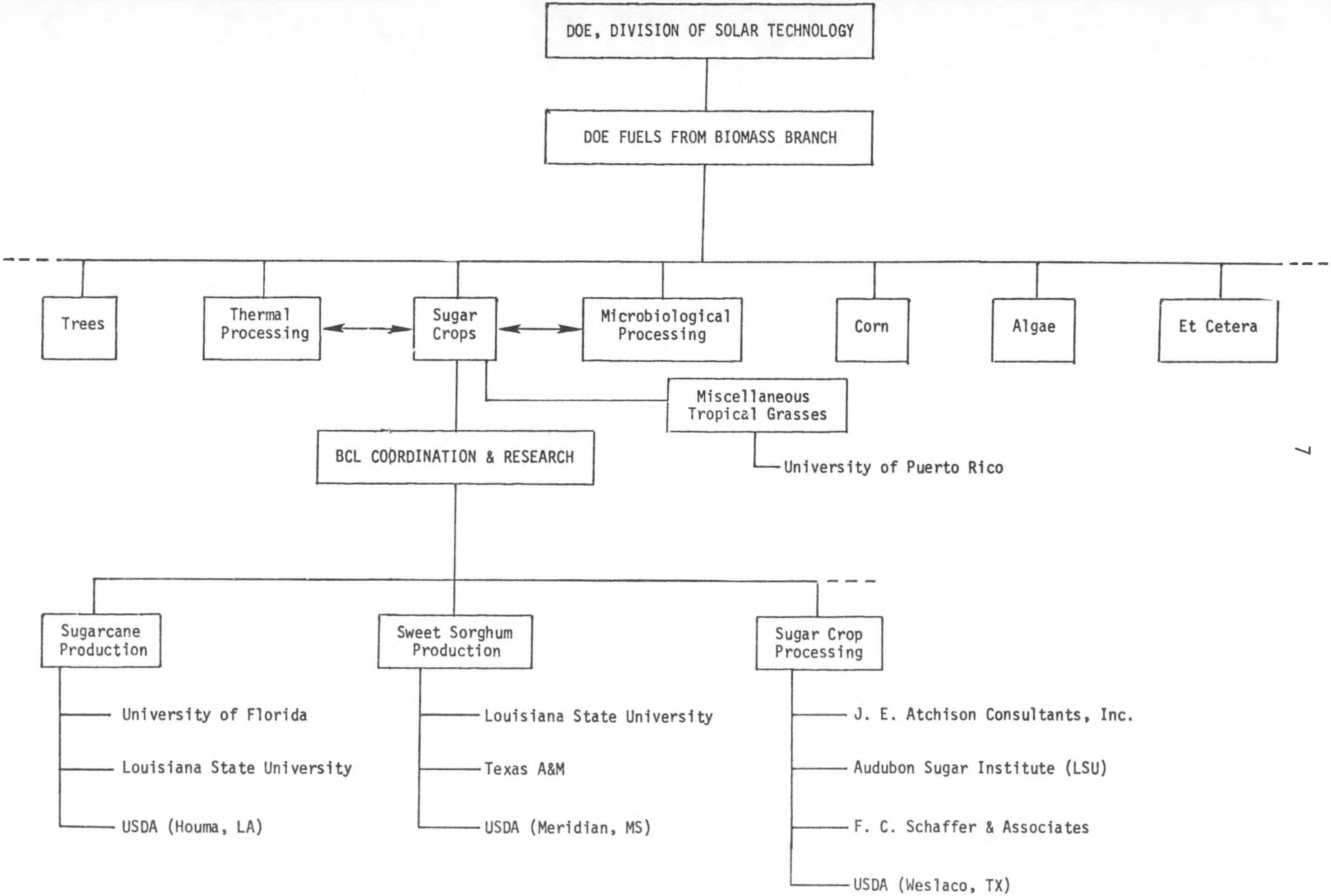

FIGURE I-2. STRUCTURE OF DOE SUGAR CROPS PROGRAM

Key investigators at each research organization are given recognition in Table I-1. Battelle also wishes to recognize the graduate students and other unnamed investigators who are performing much of the hard manual labor in this extensive research program.

Early in the research program, representatives of the entire project team met in Baton Rouge, Louisiana, to discuss materials and methods to be used in the research program. Formats for presenting data, systems of units to be employed, deadlines, and divisions of responsibility were discussed. The outcome of this 1.5 day workshop was summarized in a letter to the project monitor dated May 6, 1977.

The 1976 sugar crops systems study had a large advisory panel which represented diverse viewpoints. In this program, Dr. William Duncan of the Universities of Kentucky and Florida, and Mr. Dwight Miller of the USDA represent the agronomic and processing areas, respectively.

Organization of This Report

Following this Introduction, the Principal Findings for the entire 1977/78 sugar crops research program* are summarized for use by those that do not require detailed information. The Principal Findings section covers both Volumes I and II of the study.

Volume I continues with a more detailed presentation of the agricultural research on sugarcane and sweet sorghum (Chapter III). Crop development activities and costs are discussed in Chapter IV. Raw material cost and availability information as it pertains to sugarcane and sweet sorghum as renewable resources for the manufacture of fuels are derived in Chapter V. Volume I concludes with Chapter VI, which is a discussion of the agricultural research and development implications generated by the 1977/78 research. Appendices on resource regions for sugarcane production and land development activities also are included in Volume I.

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* The University of Puerto Rico is reporting its results separately.

TABLE I-1. KEY INVESTIGATORS IN DOE FUELS FROM SUGAR CROPS PROGRAM[a]

Organization	Investigator	Role
Battelle Columbus Division	E. Lipinsky	Agricultural evaluation
	S. Kresovich	Agronomics evaluation
	T. McClure	Agricultural economics studies
	W. Lawhon	Agricultural task leader
	D. R. Jackson	Agricultural evaluation
Louisiana State University, Audubon Sugar Institute	J. Polack J. Carvajal	Bagasse & juice & juice extraction studies
College of Agriculture	R. Ricaud B. Cochran M. Giamalva	Sugarcane and sweet sorghum studies
Texas A&M University	C. Connolly S. Reeves	Sweet sorghum studies
University of Florida	D. Myhre G. Gascho T. Shih	Sugarcane studies
F. C. Schaffer & Associates	F. Schaffer H. Birkett	Juice extraction & ethanol engineering
USDA Houma Sugarcane Field Laboratory	J. Irvine R. Matherne	Sugarcane Studies
USDA Food Crops Utilization Research Laboratory at Weslaco, Texas	A. Smith B. Lime	Sweet sorghum processing & sugar crop analyses
Joseph Atchison Consultants, Inc.	J. Atchison	Canadian separator equipment process
USDA Sugar Crops Field Station, Meridan, Mississippi	K. Freeman D. Broadhead N. Zummo	Sweet sorghum studies
University of Puerto Rico	A. Alexander	Tropical grasses studies

(a) USDA, University of Puerto Rico, and Atchison Consultants, Inc. received funding directly from DOE. F. C. Schaffer & Associates subcontracts from Louisiana State University. Battelle Columbus Division is the prime contractor for the other participants.

Volume II opens with the same Introduction and Principal Findings sections presented in Volume I, for the benefit of those reading only the Volume II report. The processing of sugar crops for the manufacture of fermentable sugars is discussed in Chapter VII. The conversion of fermentable sugars into ethanol is discussed from both a technical and an economic viewpoint in Chapter VIII. The research and development implications of the technical and economic results obtained in the entire study are presented in Chapter IX, entitled "Research and Development Implications". The appendices in Volume II provide detailed equipment lists, materials and energy balances, and costs for the manufacture of ethanol from sugarcane and from molasses, using state-of-the-art technology.

References

(1) Bliss, C., and D. O. Blake, "Silvicultural Biomass Farms, Volume V: Conversion Processes and Costs", MITRE Technical Report No. 7347, NTIS MITRE-TR-7347 - V5/LL (1977).

(2) Lipinsky, E. S., et al, "Systems Study for Fuels from Sugarcane, Sweet Sorghum, Sugar Beets, and Corn, Vols. I-III," Battelle - Columbus Laboratories for DOE under Contract No. W-7405-Eng-92, NTIS Report Nos. BMI-1957-V1,V2,V3/LL (1976).

(3) Sherwin, M. B., and M. E. Frank, "Chemicals from Coal and Shale: an R & D Analysis for the National Science Foundation", prepared by Chem. Systems, NTIS No. PB-243-393 (July, 1975).

II. PRINCIPAL FINDINGS

This section of the report is an extended summary that provides an overview of the substance of the result of a year's investigation by eight organizations. More detailed information is provided in subsequent chapters of this report and the appendices.

Sugarcane Production

The previous systems study of sugar crops (Lipinsky, et al, 1976) noted the practice of planting sugarcane in rows 1.5 to 1.83 m apart and suspected that much less sugarcane was being grown per unit land area than was possible, due to inefficient capture of solar energy early in the season. The goal of narrow-row spacings is to develop a full canopy sooner, thereby capturing more solar energy early in the season. The increase in capture of solar energy leads to a corresponding increase in biomass production. This increase in biomass production is highly dependent on the length of the growing season of the crop.

It is realized that row width used for cultivating crops is, after all, a compromise between yield and practical considerations. However, in the initial production phase of research, emphasis is placed on yield per unit area. These results will, in turn, be tempered by economic and equipment constraints which are addressed in their respective sections.

Comparison plots of conventionally spaced and narrow-row spaced sugarcane were established in Louisiana and Florida. Two sites were chosen in Louisiana, Baton Rouge and Houma. The Florida site was on muck soil at Belle Glade (near Lake Okeechobee). Specific cultural practices adopted at Baton Rouge differed from those at Houma in that the Baton Rouge system would be more immediately usable by farmers with conventional equipment, whereas the more radical Houma planting arrangement had prospects for high yields but required design of new equipment. The experimental prediction was that Houma and Baton Rouge sugarcane yields would increase by a much larger percentage than would the Florida sugarcane yields because early canopy closure would help a short season crop more than it would a long season crop.

The data from this series of experiments supported the experimental hypothesis. The narrow-row spaced sugarcane yields showed significant gains over conventional plantings at both Louisiana sites. In Florida, however, yield increases by the use of narrow-row spacings were less. The increases in total biomass, fermentable sugars, and sucrose per unit area can be related to the increased number of millable stalks present at harvest, due to the use of narrow-row spacings.

Belle Glade, Florida

As expected, the advantage of narrow-row spacing was experienced early in the growing season but disappeared by the harvest period. Total biomass production reached 40 metric tons of dry matter per hectare at the 0.5 m row spacing and 36 metric tons of dry matter per hectare at the 1.5 m spacing; however, the difference is not statistically significant. Narrow-row spacing did have a statistically significant effect on total sugar and sucrose production per hectare, due to a combination of a higher level of total sugar per stalk and a greater stalk number per hectare. These results were enhanced by the use of the sugarcane "ripener" Polaris® later in the season.

The data indicate that the effect of narrow-row spacing remained high through July (approximately 21 metric tons of dry matter per hectare at the 0.5 m spacing compared to 12 metric tons at the 1.5 m row spacing) although the total fermentable sugar content of the stalks was only about 6 percent. This leads to the question of whether the combination of the use of a growth regulator and a July harvest would appreciably increase yield. Many varied opinions have been expressed on the question of multiple harvests of sugarcane in one growing season, but to our knowledge no experimental work has been conducted. With the recent introduction of an assortment of sugarcane growth regulators, it seems logical to attempt to analyze this aspect of production more closely in the future.

Another question raised is the effect of muck soil on sugarcane planted at narrow-row spacings. Do the effects of high nitrogen and water contents of the muck soil offset the advantages of narrow-row spacings? Perhaps under more stressful conditions, such as sugarcane production on sandy soil, narrow-row spacing may show a marked advantage.

The goal of narrow-row spacing is to produce more millable stalks per unit area at harvest without causing a reduction in the levels of total fermentable sugar or sucrose per stalk. This now has been accomplished in Florida on muck soil with a 0.5 m row spacing. The level of yield improvement caused by row spacing alone on muck soil is not great enough to make these planting arrangements and techniques economically attractive; however, narrow-row spacing may become a simple way to economically increase yields under more demanding conditions.

Baton Rouge, Louisiana

The hypothesis that narrow-row spacings cause a greater yield increase in areas where the sugarcane growing season is short (approximately 270 days) rather than where the season is longer was successfully tested in Baton Rouge. This production demonstration yielded data that indicated all narrow row planting arrangements significantly out-yielded the conventional "V" single-drill*, raised-bed treatment on 1.83 m rows. The conventional treatment yielded approximately 21 metric tons of dry matter per hectare, whereas the 2 through 5 drills per 1.83 m row yielded approximately 28, 30, 31, and 30 metric tons of dry matter per hectare, respectively. This result can be attributed to an increase in stalk number per unit area.

There was no significant difference in dry matter yield between multiple-drill treatments. Possibly this finding was due to inadequate covering of the seed cane in the 4- and 5-drill treatments. Because material was mechanically covered, problems were created when covering greater amounts of planted cane per row. A poor covering causes poor stand

*A drill is a shallow furrow into which seed is deposited.

development and, in turn, results in a less than maximum production level. Total sugar production per unit area was significantly higher in the multiple-drill treatments than in the conventional-row spacing. Conventional-row spacing yielded 7.6 metric tons of total sugar per hectare with the multiple drill treatments yielding from 10.6 to 14.0 metric tons per hectare. Sucrose yield followed the same trend. Conventional-row spacing yielded 6.3 metric tons of sucrose per hectare. The total sugar and sucrose yields were significantly higher with the 3 and 4 drills per 1.83 m row than with the 2-and 5-drill treatments. These differences are due to a greater stalk number per hectare rather than a higher level of total sugar or sucrose per stalk.

These planting arrangements increased yields from 30 to 60 percent. In days when yield increases of 10 percent are of agronomic importance, these results add emphasis to the use of narrow-row spacings on a commercial level. The demonstration used commercial equipment for planting and harvesting with only minor modifications, thereby accelerating the possible commercialization of narrow-row sugarcane. These equipment modifications can be completed for a minor cost and will not significantly increase the economic burden encountered by the sugarcane producers.

Houma, Louisiana

Similar to the data from Baton Rouge, the results of the narrow-row spacing trials at Houma document the advantages of high density plantings in a marginal climate. The narrow-row spacings caused the canopy to develop more quickly and to make a more efficient capture of the early season solar radiation.

A significant increase in yield is attributed to the implementation of the narrow-row spacings. The conventional single-drill sugarcane on 1.83 m rows yielded 31 metric tons of dry matter per hectare. The double-drill treatment on 1.83 m rows yielded 34.6 metric tons of dry biomass per hectare (not statistically significant). However, total dry matter yields per hectare with the 0.6 m and 0.9 m treatments were significantly higher than the yield from the conventional treatment. Dry matter yield per hectare was approximately 40 metric tons with the 0.9 m rows and 50 metric tons with the 0.6 m row spacing. These yields correspond to a 30 to 60 percent increase in biomass production per unit area. Total fermentable sugar yield was 14.4 metric tons per hectare with the conventional planting, with the 0.9 row yielding 17.6 metric tons, and the 0.6 m rows yielding 23.7 metric tons. Similarly, sucrose yields per hectare were significantly higher in the 0.6 m and 0.9 m row spacings when compared to the conventional control plot. More millable stalks present at harvest was the major reason for the yield increase.

Comparisons of nutrient applications through irrigation water versus direct use of solid material showed no difference in yield results or nutrient utilization efficiency at any row-spacing treatment.

The potential of narrow-spacing looms large in areas with a marginal climate. The direct use or modification of narrow-row planting arrangements must be addressed before commercialization can occur. For example, the double-drill planting on 1.83 m rows requires the same amount of sugarcane to be planted as the 0.9 m rows. However, the yield of sugarcane was significantly greater at the 0.9 m row spacing. This may be offset due to the fact that the 1.83 m double-drill planting arrangement can be mechanically harvested with current commercial equipment while the 0.9 m row cannot. More efficient capture of solar radiation is accomplished with the more equidistant row spacings. Should planting arrangements and yields be limited by current harvesting constraints? Should agricultural engineering gear up and redesign equipment to fit biological potential? These questions appear next on the road to commercial use of narrow-row spacings.

Conclusions

Yields of sugarcane in Louisiana were significantly improved by the use of narrow-row spacings. Production levels reached 50 metric tons of dry matter per hectare. As hypothesized, the advantages of these high density plantings are greater in the marginal sugarcane production regions.

Yield improvement in Florida was only 10 percent. Production levels reached 40 metric tons of dry matter per hectare. There is no obvious reason why yields of sugarcane were higher in Louisiana than in Florida. Possibly the variety of sugarcane, CP65-357, is more adapted to the Louisiana growing conditions or perhaps the muck soil of Florida had an inverse or offsetting effect to that of the narrow-row spacings. The results indicate a need for an integrated program to improve yields. This program should include both improvement in cultural practices along with emphasis on breeding and selecting varieties for energy production.

Sweet Sorghum Production

The systems study of sugar crops (Lipinsky et al., 1977) noted two points regarding sweet sorghum production and processing. These were: (1) Despite the dedicated research of several teams on sweet sorghum, this crop remains essentially unexplored territory. (2) The determination of the potential merits and drawbacks of sweet sorghum needs to be made by generating and analyzing data on sweet sorghum nutrient requirements, yields, and composition. This work is of the highest priority for the Department of Energy. The field experiments carried out during this year's study magnified the importance of these findings. Without sweet sorghum, the prospects for fuels from biomass from sugar crops would be relatively dim, except in crisis circumstances. With sweet sorghum as the central sugar crop for biomass fuels purpose, sugar crops may have a three-quad potential (Lipinsky, et al, 1978).

Although sweet sorghum has an enormous potential, development of the appropriate agricultural technologies to facilitate the achievement of the potential is a major undertaking. Specifically: (1) Sweet sorghum varieties that are appropriate in the various geographical areas in the United States need to be selected and/or bred. (2) The cultural practices that will make sweet sorghum available at high yield at low cost over a maximum harvest season in the Corn Belt and other major potential sweet sorghum growing regions need to be developed.

This year's study collected information from Texas, Louisiana, Mississippi, and Ohio. Results and trends indicate that the use of narrow-row spacings can significantly increase yields of sweet sorghum.

Weslaco, Texas

Due to destruction of the Sart variety plantings by the sugarcane borer (Diatraea saccharalis) and the corn earworm (Heliothis zea), data were collected on the variety MN 1500 at 0.7 m row spacings. MN 1500 matured in approximately 180 days compared to the usual 120-140 days. It yielded approximately 44 metric tons of dry biomass per hectare. Total fermentable sugar yield of MN 1500 was 8.3 metric tons per hectare with a sucrose yield of 7.0 metric tons per hectare. These yields are approximately double those of the sweet sorghum grown with commerical varieties and conventional cultural practices.

With the commercial variety, Rio, yields were significantly higher with the 0.7 m row spacing than with the 1.0 m row spacing. Due to the implementation of the narrow-row spacing, the sweet sorghum canopy closed approximately 20 days sooner at the 0.7 m row spacing. This led to a greater production of millable stalks at harvest with the 0.7 m row spacing. Rio total dry biomass yields per hectare were 21.7 metric tons at the 0.7 m spacing and 13.6 metric tons at the 1.0 m row spacing. This result corresponds with a 60 percent increase in dry matter production per unit area. Total fermentable sugar yield was 5.0 metric tons per hectare and the sucrose yield was 4.2 metric tons per hectare at the 0.7 m row spacing. Both of these values are greater than average yields with conventional-row spacings.

Meridian, Mississippi

Row-spacing trials of the Rio variety were conducted at the USDA Sugar Crops Field Station at Meridian, Mississippi. These results have been provided to Battelle by the USDA to present a more complete picture on the effects of narrow-row spacings on sweet sorghum production levels.

The effect of a decrease in row spacing led to a significant increase in total dry biomass, total fermentable sugars, and sucrose production per hectare in the Rio variety. For example, total dry biomass yield per hectare reached 20.3 metric tons with a 1.1 m row spacing and

25.4 metric tons with the 0.6 m row spacing. Fermentable sugar production was 4.4 metric tons per hectare with the 1.1 m row spacing and 5.5 metric tons with the 0.6 m row spacing. Finally, sucrose yield reached 3.7 metric tons per hectare with the 1.1 m row spacing, while the 0.6 m rows yielded 4.6 metric tons of sucrose per hectare.

This study clearly demonstrated the advantage of narrow-row spacing with a commercially released variety. It is Battelle's belief that improvements in cultural practices, like narrow-row spacing, when coupled with varietal improvements through breeding and selection will significantly affect the potential of sweet sorghum as feedstock for energy production.

Baton Rouge, Louisiana

Data regarding sweet sorghum yields as affected by row spacing also were collected in Baton Rouge. The two varieties and planting arrangements demonstrated an outstanding potential for sweet sorghum production in Louisiana. The total dry matter production of the Rio variety was high at both row spacings. A yield of 19.6 metric tons per hectare was achieved with broadcast planting, and the double-drill planting on 1.83 m rows yielded 19.5 metric tons per hectare of dry biomass. The variety Meridian 69-13 (now known as Wray) yielded 19.8 metric tons per hectare when broadcast and 18.4 metric tons when double-drilled on a 1.83 m row.

The weather during the growing season was dry in July and August, possibly preventing yields from achieving their full potential. However, the yields from this study approximately double current yield values of conventionally spaced sweet sorghum in Louisiana.

One drawback encountered with the broadcast planting was that due to the high plant population, interplant competition was increased and thin stalks were produced with both the Meridian 69-13 and Rio varieties.

West Jefferson, Ohio

The sweet sorghum biomass demonstration carried out by Battelle Columbus Division indicates sweet sorghum can be grown in the Midwest with yields comparable to the rest of the United States. Total dry biomass production at a 0.5 m row spacing was 25.6 metric tons per hectare by the Sart variety, 18.1 metric tons per hectare by the Ramada variety, 15.4 metric tons per hectare with the Rio variety, and 9.4 metric tons per hectare by the MN 1202 variety. These yields were achieved in spite of late planting, poor weather, no fertilization, and little seedbed preparation. The yield of the Sart variety is comparable to commercial sugarcane production in Louisiana; however, sweet sorghum is only a 4-month crop, whereas the sugarcane growing season in Louisiana is 9 months.

Conclusions

The destruction of the Sart variety in Texas and high yield of the narrow-spaced MN 1500 variety demonstrate the integral importance of variety breeding and selection of sweet sorghum. These coupled with the use of narrow-row spacings offer a crop with a great potential for energy production. When compared with sugarcane, sweet sorghum requires less fertilizer and is an easier crop to plant. In addition, in areas with a longer growing season, sweet sorghum gives the producer flexibility in his crop production system. A short season sweet sorghum can be double-cropped for energy production, or it can be double-cropped with a food crop for food and energy production, or the producer may just wish to grow a long season variety specifically for energy production.

Sweet sorghum is also relatively drought and cold tolerant. It is a very adaptable crop from an agronomic viewpoint, whether the end-product is food or energy.

Sweet sorghum has been known in the United States since 1853, but has not become a major crop because attempts to make crystalline table sugar from it have been frustrated by the presence of starch and aconitic acid until very recently. In addition to the absence of a market, plant diseases and insects have attacked some of the more popular varieties of this crop. Casual use of herbicides that are acceptable for similar crops causes damage with many sweet sorghum varieties which are more sensitive than are commercial varieties of corn and sugarcane.

Sugarcane and Sweet Sorghum Economics

In considering the agricultural economic aspects of utilizing sugarcane and sweet sorghum as renewable resources for fuels or chemicals production, four factors are especially significant. These include:

(1) Availability of land and water for production

(2) Crop production and harvesting costs

(3) Grower "opportunity costs" associated with producing sugar crops for biomass

(4) Energy inputs associated with sugar crops production, harvesting, and transportation.

Availability of Land and Water

Currently, there is approximately 250,000 hectares of sugarcane produced in the mainland United States. Based on temperature, potential water availability, and proximity to existing sugarcane production regions, the potential land area in the regions capable of growing sugarcane includes about 3.2 million hectares of cropland that is either harvested or used for pasture, 1.0 million hectares of woodland, and about 5.9 million hectares of other land in farms. If, for example, the current area devoted to sugarcane production were to be doubled, it would take approximately 6 percent of the total cropland and woodland area of 4.2 million hectares capable of producing sugarcane.

The largest quantity of relevant agricultural land is contained in the Rio Grande Plain (Texas), the Gulf Coast prairies (primarily Texas, with a small quantity in Louisiana), and the southern Florida flatwoods area. Combined, these three areas encompass about 2.4 million hectares of cropland, pasture, and woodland. Irrigation would be necessary in the Rio Grande Plain and part of the Gulf Coast prairie regions. Availability and cost of this water for irrigation is one impediment to developing large volumes of additional sugarcane area. Water availability also is questionable in Florida, due to heavy demand by urban areas.

The productivity of new potential sugarcane regions will vary, according to climatic and soil factors. For example, in Florida, additional sugarcane would be produced on sandy soils, which would require more fertilizer to maintain productivity comparable with that currently obtained on muck soils.

To initiate sugarcane production, some land development activities must be undertaken, including land clearing and leveling, and installation of drainage systems. Installation of an irrigation system may be necessary. Cropland development activities vary from approximately $500 per hectare in some parts of Florida up to over $1,400 per hectare in heavily wooded areas of Louisiana. On an annualized basis, the cost of land development as a percentage of total sugarcane production costs is approximately 2-3 percent in Florida and 5-7 percent in Texas and Louisiana. Overall, if land acquisition charges are included with land development costs, the annual land costs for sugarcane production are estimated to comprise approximately 10-13 percent of the total costs of sugarcane delivered to a mill.

Land develcpment costs should not be a major impediment to increased production of sugarcane for energy purposes.

Sweet sorghum, unlike sugarcane, can be grown over a much wider geographic region. Sweet sorghum may be grown in almost any region where corn can be cultivated. This crop is being grown in small amounts for syrup by commercial operators in several midwestern and southern states. With favorable production economics, development of harvesting and processing technologies and development of markets, sweet sorghum production potentially could reach 5 million hectares within the next two decades.

Production and Harvesting Costs

A summary comparison of the yield and cost goals for close-spaced sugarcane and sweet sorghum in the southern United States is shown in Table II-1. Some noteworthy items include:

- Dry weight of total biomass from sugarcane and sweet sorghum each could approach 40 metric tons per hectare by the year 2000, compared to 23-30 metric tons per hectare in 1980. However, the dry matter content of sweet sorghum is approximately 35 percent versus 25-30 percent for sugarcane. Therefore, the fresh weight yields of sugarcane are considerably greater than sweet sorghum.

- Sugarcane has a higher percentage of fermentable sugars than does sweet sorghum, based on 1977 experimental data. However, the relatively high fiber content of sweet sorghum offers more potential for by-product credits, if its fibrous portion can be upgraded into marketable by-products through new processing techniques, such as the Tilby process.

- The net cost of fermentable sugars (after deduction of by-product credit and fuel values) is anticipated at $0.055 to $0.069 per pound for sugarcane by 1980, and $0.054 to $0.066 per pound for sweet sorghum. However, by the year 2000, sweet sorghum is expected to have a greater cost advantage resulting from increased research and development emphasis on this crop. By the year 2000, the goal for fermentable sugars from sweet sorghum is $0.035-$0.043 per pound, versus $0.043-$0.052 per pound for fermentable sugars from sugarcane. The above data assume that only the stalk portion of the plant would be utilized.

- The cost advantage for sweet sorghum becomes greater if the entire plant biomass is utilized. Under this alternative, the cost goals for sweet sorghum fermentable sugars are $0.023-$0.028 per pound, versus $0.041-$0.049 per pound for fermentable sugars from sugarcane. In order to realize these costs, it is important that the assumed by-product credits can be realized.

- If higher fiber sugarcane could be produced, without any loss in fermentable sugars, the by-product credits for sugarcane would be increased. For example, if sugarcane stalks averaged 35 percent dry matter content (versus 25-30 percent) with the extra dry matter assumed to be

TABLE II-1. COMPARISON OF YIELD AND COST GOALS FOR CLOSE-SPACED SUGARCANE AND SWEET SORGHUM IN THE SOUTHERN UNITED STATES, 1980 AND 2000[a]

	1980		2000	
	Sugarcane	Sweet Sorghum	Sugarcane	Sweet Sorghum
Yield (Metric tons per hectare)				
Fresh weight				
Stalks	83-92	47-57	112-124	70-85
Total biomass	98-117	64-78	132-158	95-117
Dry weight				
Stalks	23-24	16-20	31-32	24-30
Total biomass	30-31	23-28	40-41	33-41
Fermentable sugars (stalks only)	13-14	6.0-7.5	18-19	9-11
Combustible organic material				
Stalks	7-8	9-11	10-11	13-16
Total biomass	12-13	15-19	16-17	23-28
Costs Utilizing Stalks Only ($ per hectare, unless otherwise noted)				
Total costs per hectare	1865-2400	1070-1310	2035-2615	1175-1435
Credit for fibrous byproducts	150-165	180-220	200-224	265-320
Fuel value of residual combustible organic material	74-83	99-110	100-112	130-160
Net cost of fermentable sugars				
Dollars per hectare	1645-2155	805-985	1735-2280	780-950
Dollars per metric ton	121-152	118-144	95-119	78-96
Cents per pound	5.5-6.9	5.4-6.6	4.3-5.2	3.5-4.3
Costs Utilizing Entire Plant				
Total costs per hectare	1930-2330	1025-1255	2090-2510	1080-1320
Credit for fibrous byproducts	148-166	180-220	200-224	265-320
Fuel value of residual combustible organic material	167-178	220-270	224-240	330-400
Net cost of fermentable sugars				
Dollars per hectare	1604-1997	630-770	1650-2060	490-600
Dollars per metric ton	118-141	93-113	90-108	50-60
Cents per pound	5.4-6.4	4.2-5.2	4.1-4.9	2.3-2.8

(a) Without drip irrigation

Source: Battelle Columbus Division

combustible organic material with an average value of $30 per ton, the net cost of fermentable sugars from sugarcane would be reduced by about 5 percent from the levels shown in Table II-1.

In Table II-2,

- The cost of ethanol from sweet sorghum in the year 2000 is estimated at $0.90-$1.20 per gallon ($0.24-$0.32 per liter) compared to $1.15-$1.30 per gallon ($0.30-$0.34 per liter) from sugarcane.

- Due to the higher content of fermentable sugars, the potential ethanol production per hectare is about 10,000-11,000 liters for sugarcane by the year 2000, versus 5,000-6,000 liters per hectare from sweet sorghum.

- The higher productivity in terms of ethanol per hectare from sugarcane is offset by the narrow geographic range over which this crop can be grown in the United States. If similar yields and costs for sweet sorghum can be obtained in the midwestern United States, sweet sorghum could become a major contributor to that region's liquid fuels needs by the year 2000. Total ethanol production from all sweet sorghum could conceivably reach 25-30 billion liters by the year 2000. It is recognized that attainment of such a level depends on other contingencies and priorities, such as availability of resources for ethanol plant construction, rate of acceptance for ethanol, developing technologies in alternative fuels, etc.

Grower Income Comparisons

Comparisons were made between sugarcane and sweet sorghum as "energy crops" with conventional sugarcane for sucrose production and other crops that might be grown in the same region. Based on average prices, costs, and yields from 1975-1977, it does not appear that either sweet sorghum or sugarcane could effectively compete with alternative crops in the southern or midwestern United States if by-product credits are not obtained for the fiber and combustible organic material in the plant. With by-product credits, sweet sorghum compares favorably with other crops, particularly under the concept of whole-plant utilization. From the grower-income viewpoint, sugarcane for ethanol production appears to be more favorable for growers in Louisiana than in Florida, if the 1977

TABLE II-2. GOALS FOR YEAR 2000, ASSUMING ETHANOL PRODUCTION FROM SUGAR CROPS

	Goals, Year 2000
Sugarcane	
Yield	10,200-10,800 liters per hectare
Area under cultivation	650,000 hectares
Total production	6.4-6.8 billion liters
Cost[b]	$0.30-$0.34 per liter
Sweet Sorghum	
Yield	5,100-6,200 liters per hectare
Area under cultivation[a]	5,000,000 hectares
Total production	25-30 billion liters
Cost[b]	$0.24-$0.32 per liter

Source: Battelle Columbus Division estimates.

(a) Includes midwestern United States.

(b) In 1980 dollars.

experimental results are indicative. This is due to the much higher yield increases obtained with close-spacing in Louisiana than were obtained in Florida. Sweet sorghum for ethanol production in the Midwest, including by-product credits, would appear to lie somewhere between corn and soybeans in terms of grower income. In evaluating grower income effects, it is important to note that in growing millions of acres of sweet sorghum, some corn and soybean land would be taken out of production, which would place upward pressure on prices of these commodities. This study does not include an evaluation of these possible effects upon grower income.

Seasonality factors for the processor and converter also play a major role in commercialization decisions.

Energy Inputs

Total energy usage in producing, harvesting, and transporting sugarcane ranges from approximately 1.0 to 1.9 gigajoules per metric ton of dry material, depending upon the need for fertilizer and irrigation. Sweet sorghum requires approximately 0.8 to 1.1 gigajoules of energy equivalent per dry metric ton of material, assuming that only 10 percent of the total area under production would be irrigated. In comparable environments, it appears that the energy usage per dry ton of crop yield for sweet sorghum would be approximately 65-75 percent of the energy necessary to grow and harvest sugarcane.

Sugar Crop Processing

In this report, a distinction is made between the primarily physical treatments applied to sugar crops to prepare them for the manufacture of fuels and the primarily chemical processes to make the fuels. The former, primarily physical, operations are called "sugar crop processing"; the latter, primarily chemical treatments, are called "conversion to fuels". Two major sugar crop processing concepts were investigated in the 1977-78 research program--whole-cane processing and the Tilby cane separator process.

Whole-Cane Processing

Limited tests were conducted at the Audubon Sugar Factory (a small-scale experimental sugar factory located on the campus of Louisiana State University [LSU]) to determine the processibility of the whole sugarcane plant (tops and leaves included). The effect of including tops and leaves was proportional to their quantity and quality. Compared with clean stalks, whole cane produced more bagasse and less juice per ton of material, with some drop in mixed juice purity. The tops and leaves contribute mainly fiber because their content of sucrose and invert sugars is quite low. There seems to be no incentive for including this nonproductive fraction directly in the mill feed. Instead of seeking to process the whole aerial portion of the plant at once, this research and other considerations indicate that better initial separation is required so that more homogeneous fractions can be processed (see Research and Development Implications).

Tilby Cane Separation Process

Conventional sugarcane juice extraction processes use energy-intensive and capital-intensive equipment to obtain a solution suitable for crystallization. A sugarcane stalk consists of zones of different composition (central pith, which is the soft material containing most of the sucrose and other sugars, surrounded by rind that has much tougher fibers that contribute to structural strength, and an outer, waxy epidermis with its adhering dirt). The conventional process scrambles these zones, thereby adding impurities to the sugar solution and degrading the fiber quality of the lignocellulosic residue (bagasse).

S. E. Tilby, a Canadian architect and inventor, invented a process to separate the sugarcane stalk into its primary constituents (pith, rind fiber segments, and epidermis) by means of a series of slicing and scraping operations. An initial evaluation of this process by Joseph E. Atchison Consultants, Inc., and BCD indicate that the new process has the following potential advantages over conventional sugarcane milling and juice extraction:

(1) The rind fiber segments are low in pith and appear much superior to conventional bagasse as a raw material for pulp and paper making.

(2) The rind fiber segments appear to be a promising raw material for plywood and lumber substitutes to be made by resin-bonding rind fiber strands together.

(3) The sugar-containing pith should yield a juice that needs little clarification or other processing prior to use in fermentation.

(4) Extraction of sugarcane juice from pith should require little capital equipment or energy compared with conventional sugarcane operations.

(5) De-sugared pith is a potential source of fermentable sugars by hydrolysis of the lignocellulose. Alternatively, it might be used as a cattle feed or fuel.

(6) Whereas conventional milling equipment makes it desirable to have the minimum quantity of fiber in sugarcane or sweet sorghum, the Tilby device appears capable of handling high fiber cane as well or better than low fiber cane and without apparent need for additional power consumption.

Although the listing of potential advantages appears impressive, this concept needs extensive testing under field conditions (see Research and Development Implications).

Conversion to Fuels

Capital investment requirements and operating costs for facilities to manufacture anhydrous ethanol from molasses and from sugarcane juice were undertaken by F. C. Schaffer & Associates, Inc., in cooperation with BCD. The studies were intended to provide an equipment listing and current cost calculations to serve as a baseline with which to compare new processes. The most sensitive aspects of ethanol from sugar crops also were identified in this exercise. Using conventional sugarcane technology and sugarcane raw material costs consistent with conventional growing of sugarcane leads to anhydrous ethanol costs between approximately $1.00 and $1.25 per gallon at best. The longer the harvesting and processing season in which sugarcane is available for use both as raw material and fuel source, the lower the cost of anhydrous ethanol. The long processing season also means that more complete utilization is made of the processing and conversion facilities. For a grassroots ethanol-from-sugarcane facility, the capital investment in cane handling, milling, and steam generation are about 75 percent of the capital investment, while the fermentation and distillation facilities constitute only 25 percent of the investment. For this reason, improvements in sugarcane processing (e.g., the Tilby cane separation process) would have a more important impact on capital charges than would comparable improvements in fermentation and distillation.

Sweet sorghum can play an important role in keeping down the cost of anhydrous ethanol from sugarcane by lengthening the processing and conversion season. The processing and conversion season also may be extended by allowing cane to stand in the field past the conventional date for termination of the harvest season. One of the major reasons for cessation of the harvesting is that sucrose tends to turn to invert sugar after a freeze. This is an economic disaster for table sugar manufacture, but not for fermentation. There appear to be additional means to preserve sugar crop juice which are under investigation for DOE. Details of these investigations cannot be presented until the patent applications have reached the appropriate stage.

Although sweet sorghum has great agronomic potential for producing fermentable sugars over a wide geographic range, the harvesting, processing, and conversion season for this crop is likely to be quite short in many areas. As noted above, sweet sorghum can be used to extend the sugarcane processing season in southern states. In the north, sweet sorghum might be used to extend the sugar beet processing season. There may be ways to combine sweet sorghum conversion with conversion of grain to ethanol.

Ethanol from molasses has the potential to be substantially cheaper than ethanol from sugar crop juice. Availability of steam and other utilities at a sugar crop processing facility contributes greatly to these low costs, which can be less than $1.00 per gallon. However, molasses from conventional sugarcane crystallization operations contains contaminants that are removed by acid pretreatment. These operations increase capital and operating costs. In any event, the quantity of ethanol that can be made available from molasses is so small from a fuels point of view that it can only have fuel impact on some Hawaiian Islands where there is considerable molasses capacity and relatively few automobiles. Ethanol from molasses also can play a role on the U.S. mainland by replacing ethylene as a source of some U.S. industrial ethanol.

Research and Development Implications

This evaluation of alternative means to use sugar crops as an economical source of fuels has led to many research and development opportunities. The most significant opportunities are discussed briefly here.

Sweet Sorghum

The emergence of sweet sorghum as a major potential source of fuels results in many research and development problems, such as

(1) Sweet sorghum varieties rich in sugars and which have large-diameter stalks suitable for Tilby processing need to be identified, developed, and matched with appropriate climate and soil conditions throughout the United States.

(2) Cultural practices need to be developed to optimize sweet sorghum yields, bearing in mind the processing season dates, weather, fertilizer requirements, and pests.

(3) Economical means to plant, harvest, and transport sweet sorghum are needed, with special attention to leaf stripping.

(4) Beneficiation of sweet sorghum to deliver processible stalks and some of the trash for fuel use, leaving enough nitrogen and mineral-rich residues on the field to prevent soil erosion needs to be developed.

(5) The agricultural economics of sweet sorghum is in an embryonic stage compared with the economics of major U.S. crops, and this area merits prompt attention. This includes not only production costs, but evaluation of the impacts of sweet sorghum production upon production and prices of other crops.

Some of these issues are being addressed in the DOE 1978/79 study that is underway, but it is evident that there are many issues involving sweet sorghum that need regional attention.

Sugarcane

Research and development in sugarcane needs to be focused both on new varieties and on cultural practices. The development of processes that permit the use of high fiber sugarcane varieties have implications regarding the geographical range of this crop, which may thereby be increased, its ability to withstand lodging in narrow-row spacing, the yield per acre, and the markets for the sugarcane products. The high fiber canes have been the rejects of sugarcane breeding programs, and there is need for planning and execution of multi-year programs to realize the potential that ultimately is available in this crop.

The initial success of narrow-row spacings in Louisiana need to be verified through several ratoon crops and cultural practices developed for commercial production. There is need for improved harvesting of the high yields of unburned sugarcane in narrow-row spacing. The narrow-row spacing work needs to be integrated into the high fiber variety improvement program.

The favorable effects of narrow-row spacing were barely perceptible in Florida using sugarcane variety CP 65-357 on muck soil. Prospects for growing enough sugarcane to be significant from a fuels point of view involves use of Florida sandy soil, which therefore has high research and development priority. Both the cultural practices and the desirable varieties for Florida conditions need to be developed. A start already has been made during the 1978/79 program on some aspects of this problem. Effective irrigation and fertilization systems also need to be developed for Florida conditions.

Sugar Crop Processing

Sugar crop biomass needs to be used optimally to achieve low fuels costs and to maintain land quality. Methods for in-field beneficiation to leave on the soil those plant parts that are highest in soil nutrients also need to be developed. The sugarcane stalk needs to be separated by processes that yield homogeneous products with low energy consumption. The Tilby cane separation process exemplifies what may be the beginning of a new family of biomass processes that separate constituents in a more effective and useful fashion. However, the Tilby process needs much development before it can be considered a full-scale replacement for conventional facilities. For example, preliminary experiments have shown that the sugarcane or sweet sorghum billets must be quite clean of trash, roots, metal, and stones, which implies extensive cleaning facilities. Although selected sweet sorghum stalks performed well, the processibility of sweet sorghum needs verification. The development of construction materials to compete in plywood markets and of chipped rind fiber to compete in the pulpwood market is at an early stage and needs to be pursued vigorously. Materials balances and energy balances need to be obtained for sugarcane and sweet sorghum varieties and compared objectively with sugar mill esperience. Scale-up of the capacity of key equipment needs to be undertaken.

Beyond Gasohol

Gasohol advocates generally have taken the position that ethanol is a technically effective motor fuel and that all that is needed is subsidies or other incentives to proceed with commercial fuel production. However, it appears appropriate to improve upon the gasohol concept while the United States is not in a crisis situation. The calculations in this report indicate that ethanol has both cost and energy balance problems that arise from the need to distill ethanol to free it from the water and impurities contained in the fermentation broth. Both the cost and the energy balance could be improved substantially by fermenting ethanol to higher concentrations in the broth prior to distillation and/or substituting solvent extraction for distillation at appropriate stages of the product isolation operations. Development of inexpensive fermenters (Dr. H. Bungay's idea) that are capable of slowly manufacturing ethanol derived from the large output that occurs in a short time with short season crops merits investigation.

The value of the stillage that is obtained from fermentation of sugar crops remains a major uncertainty in determining the net cost of ethanol made by this route. Upgrading and disposal of this stillage which would otherwise be an environmental pollution problem might be accomplished by combustion to recover salts with fertilizer value, anaerobic digestion to manufacture methane, or evaporation to produce an animal feed ingredient.

Development of solvent extraction processes for such hydrophilic materials as ethanol is likely to be extremely difficult. Therefore, it becomes desirable to look beyond gasohol to fermentation of sugar solutions to make more hydrophobic fuels. Examples include 2,3-butanediol, which can be used as a high boiling fuel or converted to methyl ethyl ketone which would be in the volatile gasoline range. Fermentation of sugars to butyric or caproic acids can facilitate product recovery because these short chain fatty acids form insoluble salts with calcium ions. The calcium salts can be pyrolyzed to yield ketones suitable for fuel use, with recovery of the calcium oxide for precipitation of more fatty acid.

Many microorganisms will produce microbial lipids when the fermentation conditions are adjusted appropriately. These microbial lipids are very high in energy content and might be used as such in diesel fuel or cracked to obtain gasoline or jet fuel ingredients. The hydrophobic nature of the lipids makes them extremely easy to isolate so that the distillation problem is avoided. The proteinaceous by-products can be used as cattle feed, if the appropriate FDA-approvable microorganisms were selected. This concept merits exploration to determine its technical and economic merits and drawbacks.

Progress in the development of pretreatment processes to separate lignocellulose into its constituents has been rapid in the last few years. The fibrous parts of the sugar crops are especially desirable for this separation because the lignin content is low, the lignin of pith especially is not highly cross-linked, and the products are routinely taken to central locations for processing. Therefore, the evaluation of processes to separate the pith and rind fiber fractions of sugarcane and sweet sorghum in the Purdue solvent processes and other lignocellulose separation processes merits quite high priority.

The Mobil process for conversion of methanol, ethanol, or other low molecular weight oxygenated chemicals into high octane gasoline has been demonstrated. A companion process that begins with synthesis gas made from coal is under investigation. Adaptation of this process for use with gasified biomass should have high priority because it converts the least valuable part of sugar crop biomass into the type of fuel that is most needed. Investigation of the application of the Mobil process to biomass should include not only sugar crop biomass, but also forest products and carbohydrate crop stalks.

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(2) Lipinsky, E. S., Kresovich, S., McClure, T. A., and Lawhon, W. T., "Potential Benefits and Technology Development Costs for Sugar Crops as an Energy Resource: Topical Report", prepared by Battelle-Columbus Laboratories for DOE under Contract No. W-7405-Eng-92 (1978).

(3) Smith, B. A., et al, Sugar Journal 35(12), pp. 22-27.

III. AGRICULTURAL PRODUCTION OF SUGAR CROPS

The specific agricultural production goal is to develop cultural practices that will make sugar crops available in high yield and at low cost over a maximum harvest season throughout the United States. Initial attempts to achieve this goal are centered around the use of narrow-row spacings with both sugarcane and sweet sorghum. This approach is based on the work of the Battelle core team in conjunction with sugar crop researchers who are familiar with the idiosyncrasies of these crops.

Site Selection

An integral part of any thorough agricultural investigation is the site selection. Many future activities are largely dependent on the location and environment of the test.

Sugarcane

Selection of sites for the sugarcane study was primarily based on two criteria: (1) the plant environment should be conducive to good cane growth (i.e., warm soil temperatures, ample rainfall, and high solar radiation levels), and (2) the economic feasibility of producing sugarcane for fuel in a given area and the ability of a research group in that area to perform competent research on sugarcane production.

Florida. Sugarcane currently is growing on approximately 112,000 hectares around the periphery of Lake Okeechobee in southern Florida (Figures III-1 and III-2). Yields of cane, with the ratoon system, (5 years - 4 harvests), average approximately 105 metric tons per hectare wet weight per year (Todd, 1975). The environment for cane growth in the southern Florida region fits well with sugarcane growth requirements. A frost-free period of 300 days, approximately 1,473 mm of rainfall per

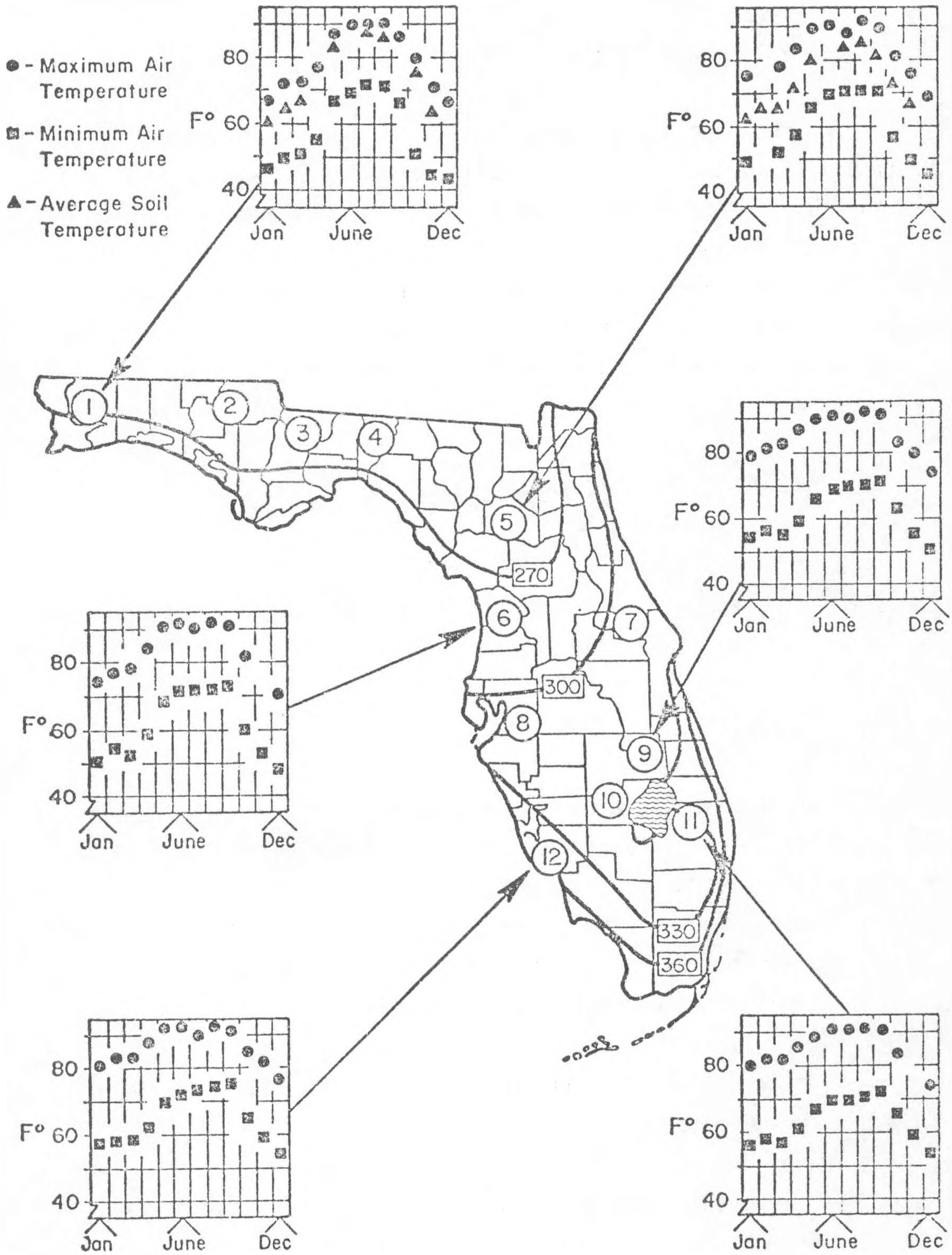

FIGURE III-1. GEOGRAPHICAL DISTRIBUTION OF MEAN ANNUAL FREEZE-FREE PERIODS (IN DAYS) FOR FLORIDA. ANNUAL TEMPERATURE PLOTS ARE SHOWN FOR SIX SELECTED LOCATIONS WITHIN REGIONS.

Source: Battelle's Columbus Division.

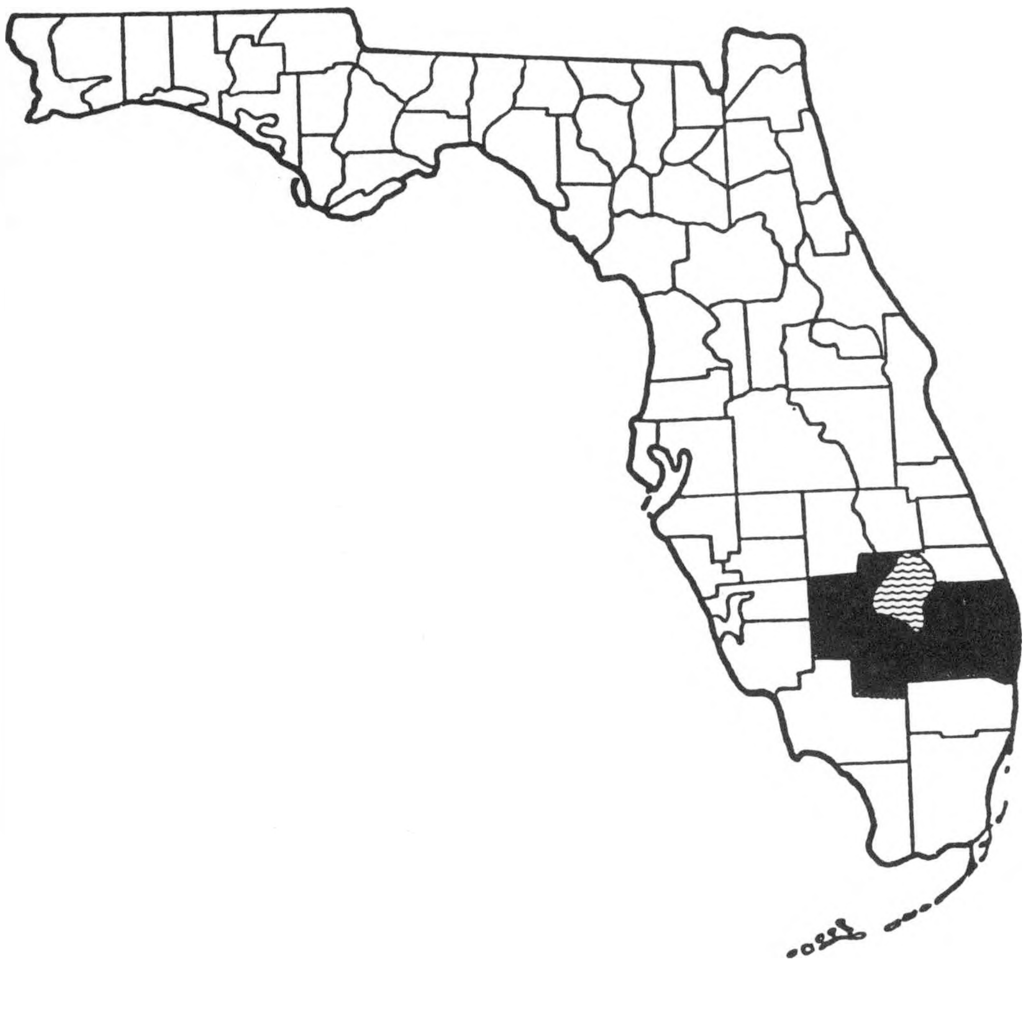

FIGURE III-2. COUNTIES IN FLORIDA IN WHICH SUGARCANE IS CURRENTLY GROWN.

Source: Battelle's Columbus Division.

year (the majority falling during the summer months), and the unique advantage of growing cane on a muck soil (i.e., good water holding capacity and high natural fertility) made the southern Florida region an important site in this year's study. The University of Florida was selected as the research site in Southern Florida. If additional sugarcane is planted in the United States for fuels, the Florida group will spearhead (by virtue of location and experience) the research and development for such an effort.

Louisiana. Sugarcane currently is being grown on approximately 136,000 hectares (Agricultural Stabilization and Conservation Service, 1974) in central and south central Louisiana (Figures III-3 and III-4). The frost-free period in this area is only 270 days, which creates problems when attempting to maximize cane yields. Therefore, by incorporating the practice of narrow-row spacings in Louisiana, the crop can take more advantage of early season solar radiation and water by closing the canopy more rapidly. Narrow-row spacing should cause higher final yields and greater incremental gains than those areas with longer growing seasons.

The research sites chosen in Louisiana were Louisiana State University in Baton Rouge and the USDA Sugarcane Field Laboratory at Houma. The Louisiana State University's Audubon Sugar Institute is uniquely equipped and staffed to conduct juice extraction experiments on a scale that permits extrapolation of results to full-scale operations. The Houma Research Station was chosen because it is further along in close-spaced cane research than any other organization in the United States.

Sweet Sorghum

Many of the criteria used in choosing sites for sugarcane research (i.e., long growing season, warm soil temperatures, high solar radiation levels, and ample water supply) also were applicable to sweet sorghum research. It also was important to find a research group that had previous experience in sweet sorghum research.

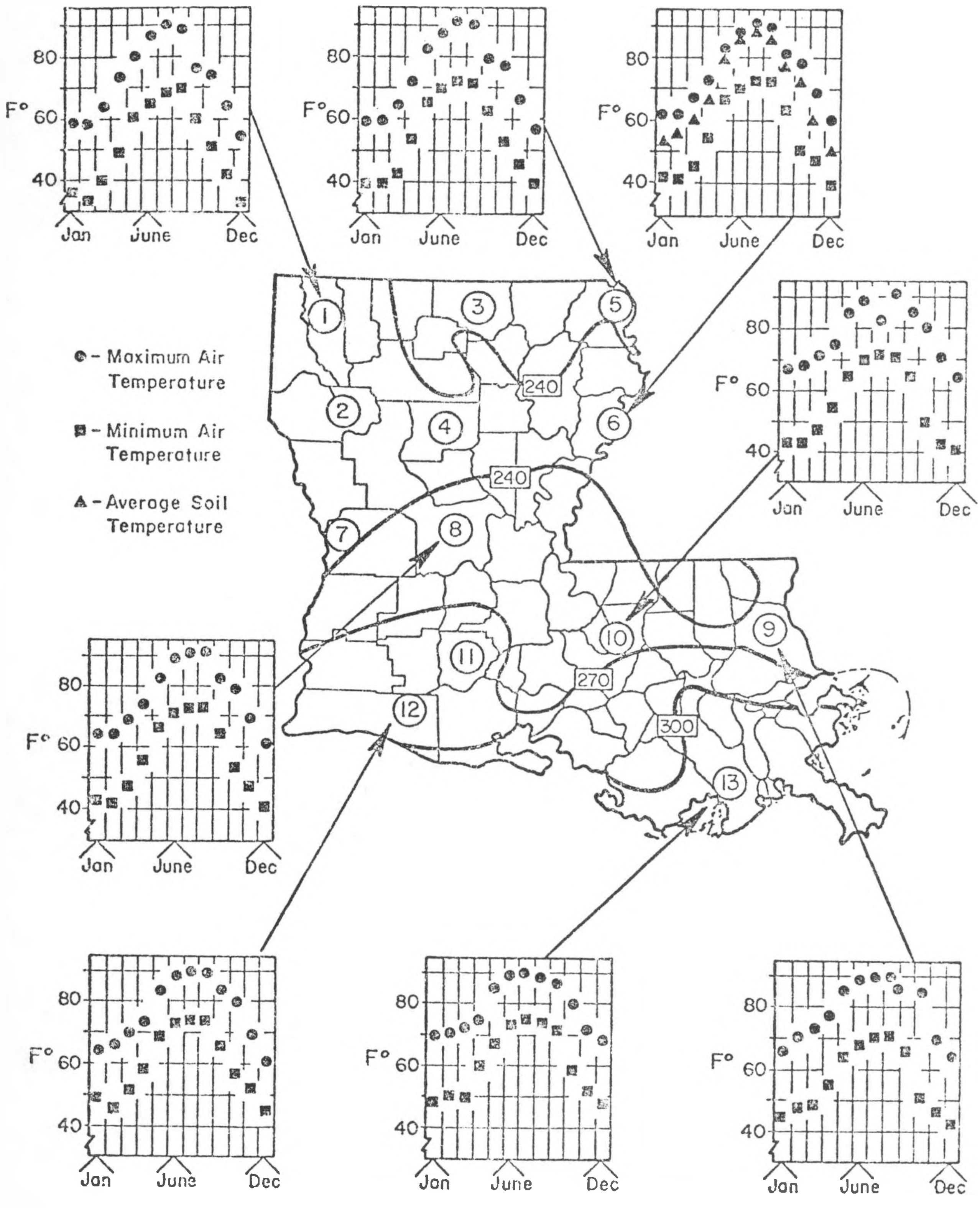

FIGURE III-3. GEOGRAPHICAL DISTRIBUTION OF MEAN ANNUAL FREEZE-FREE PERIODS (IN DAYS) FOR LOUISIANA. ANNUAL TEMPERATURE PLOTS ARE SHOWN FOR EIGHT SELECTED LOCATIONS WITHIN REGIONS.

Source: Battelle's Columbus Division.

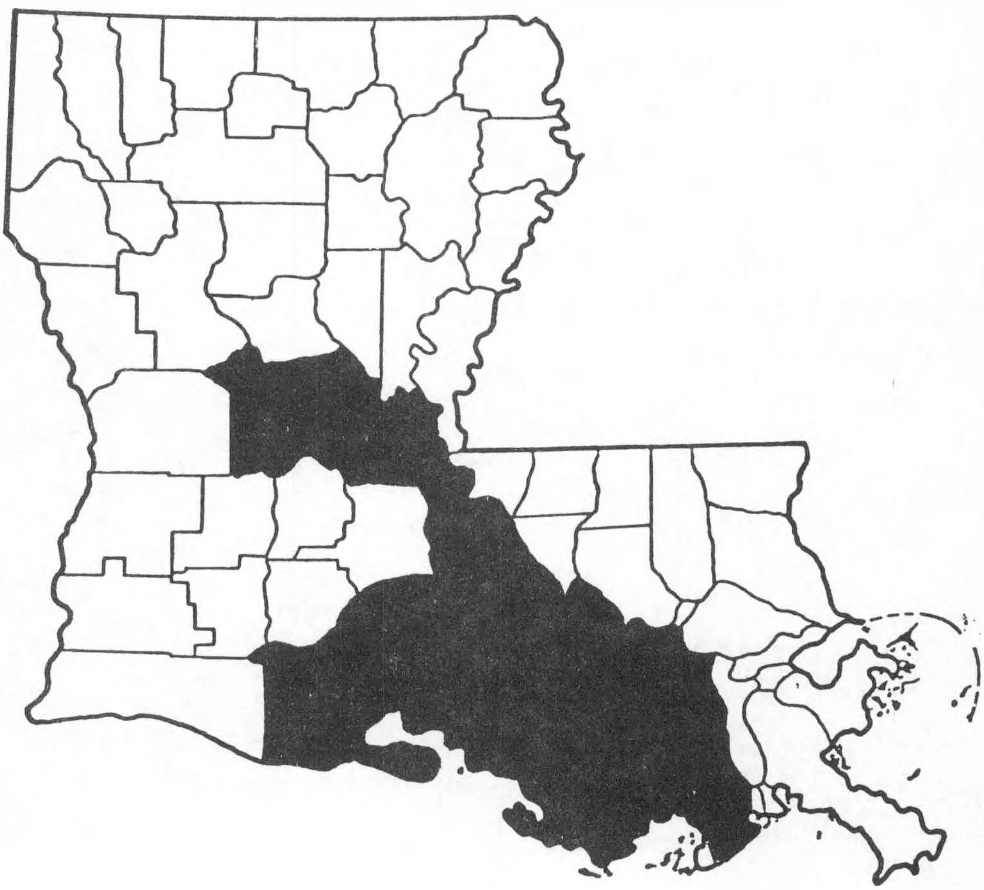

FIGURE III-4. COUNTIES WHICH PRODUCE SUGARCANE IN LOUISIANA.

Source: Battelle's Columbus Division.

Texas. When water is supplied by irrigation, the Lower Rio Grande Valley is a prime area for maximizing sweet sorghum yields because of its 330-day frost-free period (Figures III-5 and III-6). In addition, this long frost-free period permits the possibility of multiple cropping in this area (Crowley and Smith, 1972). Unlike much of the United States, an adequate supply of water is available in the Rio Grande Valley and high yields for many other crops have been realized because of this factor. The Texas A&M Agricultural Experiment Station at Weslaco, Texas, was selected because of its experience in growing and processing sweet sorghum. The Texas A&M group is located close to the sugar mill in its producing region.

Louisiana. Sweet sorghum has great potential in producing biomass for energy production in Louisiana. High yields can be produced at a relatively low cost during a short growing season. Sweet sorghum can be grown on fallow land in cane production, totaling about 30,000 hectares each year. Also, sweet sorghum grows well in the low fertility soils located north of the Louisiana cane area that are not suited for sugarcane (Figures III-3 and III-4). The Baton Rouge site was chosen because the Louisiana State University researchers have begun studies of growing sweet sorghum in conjunction with sugarcane to keep the sugar mills in operation a greater part of the year. An added advantage of the Louisiana State University site is that by working in Baton Rouge, we are able to use the Audubon Sugar Institute for conducting the juice extraction experiments.

Narrow-Row Spacing

Narrow-row spacing is a cultural practice that has been used successfully in a number of crops. Theoretically, it also should produce higher yields with sugarcane and sweet sorghum. The advantages and disadvantages can be summarized as follows:

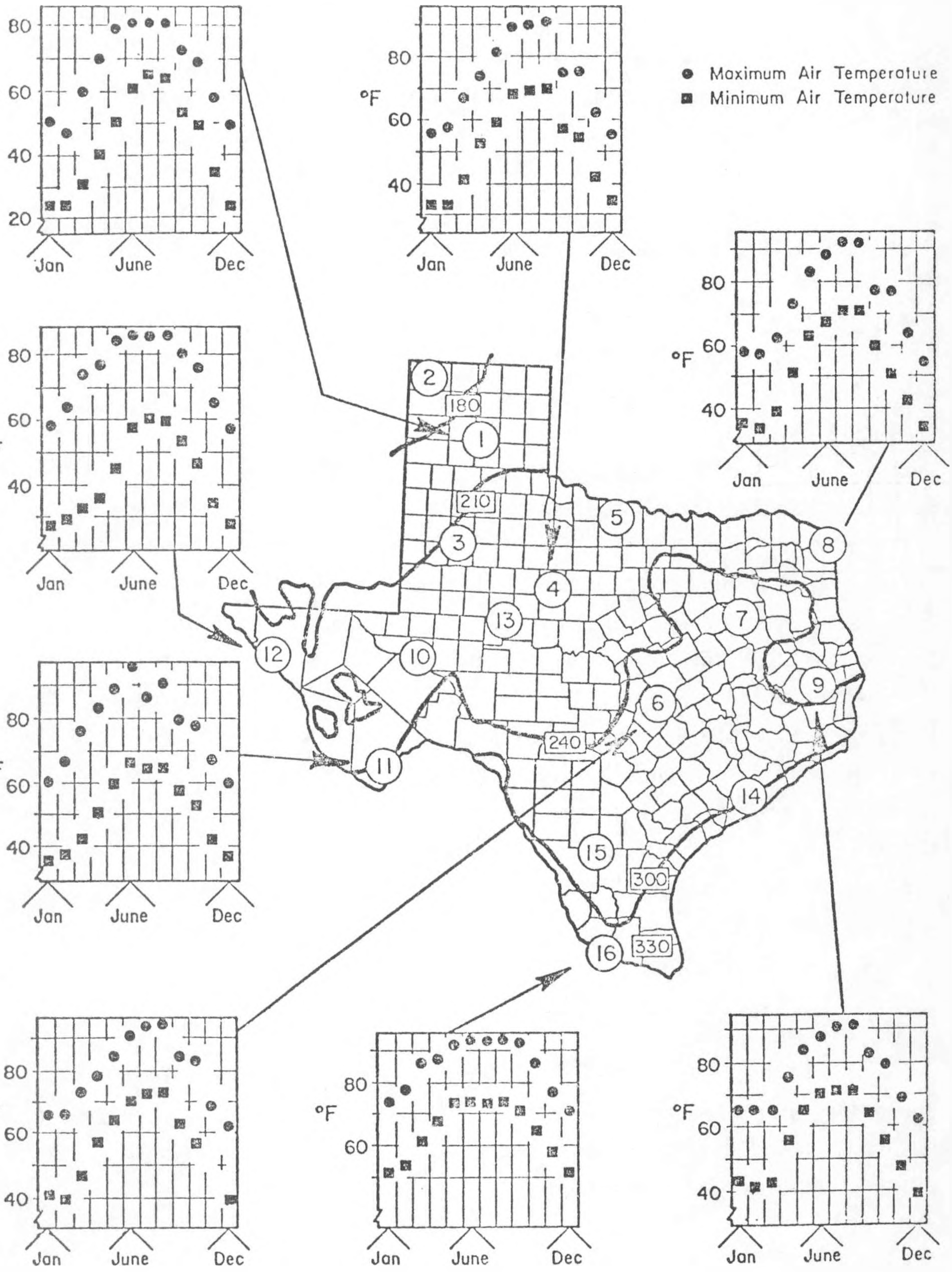

FIGURE III-5. GEOGRAPHICAL DISTRIBUTION OF MEAN ANNUAL FREEZE-FREE PERIODS (IN DAYS) FOR TEXAS. ANNUAL TEMPERATURE PLOTS ARE SHOWN FOR EIGHT SELECTED LOCATIONS WITHIN REGIONS.

Source: Battelle's Columbus Division.

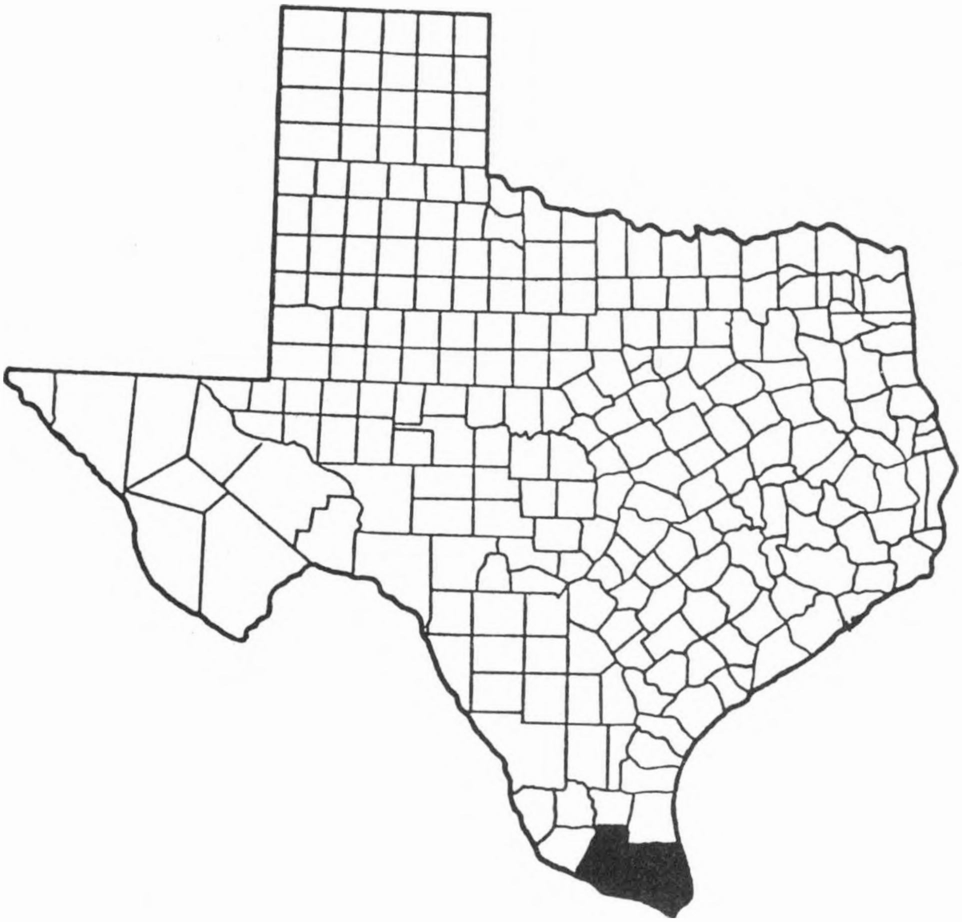

FIGURE III-6. COUNTIES IN WHICH SUGARCANE IN TEXAS IS CURRENTLY BEING GROWN.

Source: Battelle's Columbus Division.

Advantage 1: More Efficient Use of Solar Energy

Temperate-zone sugarcane is characterized by slow early growth and a crop life of 8-10 months. Added to conventional wide-row spacings (1.2 - 1.8 m), slow early growth and a short growing season promote inefficient use of solar energy (Matherne and Irvine, 1977). Data from the Annual Report of the South African Sugar Association Experiment Station (1964) show that full ground cover was attained in 14 weeks on 0.45 m row spacing but had not been attained at 24 weeks with the more usual 1.4 m row spacings. Bull (unpublished data) obtained full ground cover in 12 weeks or less with 0.45 m row spacings of three varieties, but full cover was delayed by 4 weeks or more with 1.4 m row spacings. If water supply is not limited during the early weeks of growth, there appears to be a gain to be made by attempting to get a full lead canopy as early as possible in the crop cycle, particularly for short-term crops (Bull and Glasziou, 1975). This earlier development of the full canopy results in a more efficient use of the sun's energy and, in turn, results in higher yields (see Figure III-7). Experiments have been conducted in Australia (Bull, 1975), Hawaii (Case, 1975), Florida (James, 1975), and Louisiana (Irvine, 1975; Matherne and Irvine, 1977) that demonstrate that significantly more biomass per unit area can be grown through reducing row spacings from between 1.2 and 1.8 meters to 0.3-0.6 meters. Also, these studies indicate that along with greater yields of biomass, there was not found to be a significant reduction in the concentration of sugar per stalk. From these studies, it appears that yield per hectare can be increased considerably without proportionate increases of many of the cultural inputs.

Most sweet sorghum crops in the United States are seeded using row spacing intervals of 1.1 m. Row spacings of this magnitude result in inefficient use of solar radiation, especially during the early growth stage of the crop. Narrow-row spacing may be particularly important in the midwestern states where optimum solar radiation levels occur only a brief time during the growing season.

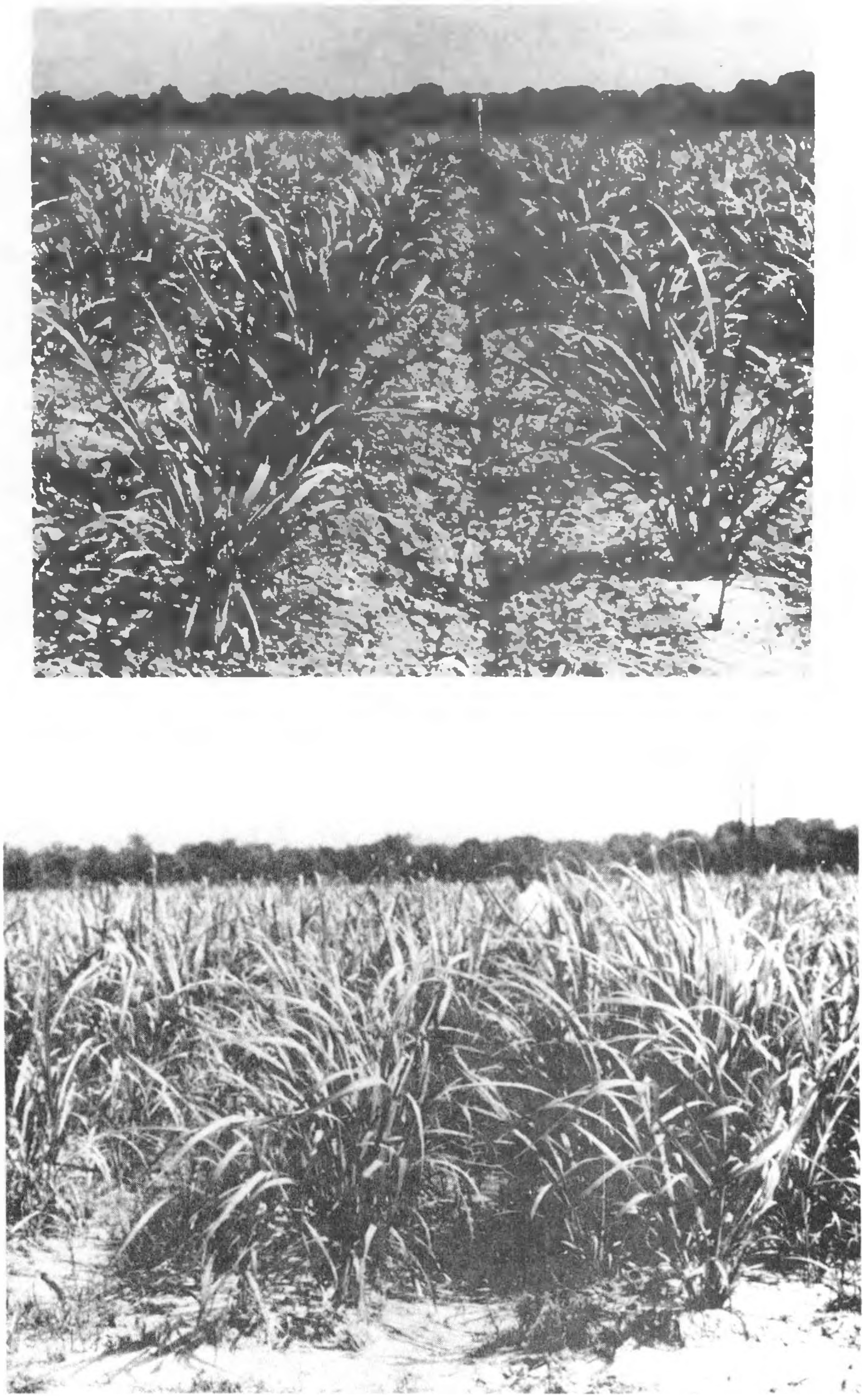

FIGURE III-7. NARROW-ROW SPACINGS MAKE MORE EFFICIENT USE OF THE SUN'S ENERGY. THIS FIGURE CONTRASTS THE DIFFERENCE IN CANOPY DEVELOPMENT BETWEEN A CONVENTIONAL 1.8 M AND A 0.6 M ROW SPACING (PHOTOGRAPHED AT THE USDA SUGARCANE FIELD LABORATORY, HOUMA, LOUISIANA).

Advantage 2: Weed Control

Because of early shading, chemical weed control of narrow-spaced sugarcane and sweet sorghum may be reduced. By rapid development of a full canopy, solar energy and water are used more efficiently; thus the crop is better able to compete against weeds. Thus, the number of cultivations required during the season should decrease. Preliminary studies (Matherne, 1977) indicate the cost of weed control decreases 6 percent when comparing sugarcane grown at 0.6 m row spacings to cane grown at the conventional-row spacings of 1.8 m. Bull (1975) reports similar results with his experiment. In this case, weed control was required in the conventional-spaced (1.4 m) plots but not with the close-spaced (0.5 m) plots. Decreased use of herbicides will result in less environmental pollution, as well as help lower crop production expenses.

Disadvantage 1: Lodging

With the introduction of narrow-row planting, the tendency for the sugarcane and sweet sorghum to lodge increases. This problem is created by an increase in interplant competition causing the production of taller and thinner stalks. Sugarcane data collected at Houma this year indicate that a smaller barrel size was produced at the narrower row spacings. However, this result has never previously occurred at Houma (Irvine, personal communication) in the 10 years of study of row spacings for sugarcane production. Results of other sugarcane sites showed greater numbers of lodged stalks in the narrower row spacings, although the percentage of lodged stalks per treatment appeared about equal. Unlike sugarcane, sweet sorghum produces a seed head and the barrel size of the stalks is usually thinner than sugarcane stalks. These two morphological traits, along with the production of taller and thinner stalks, created by an increase in interplant competition, cause a definite lodging potential. Results at all of the sweet sorghum research sites indicate more lodged stalks with the narrow-row spacings; however, the percentage of lodged stalks per plot appeared about equal.

A logical inference from these studies is that the potential of late season lodging also will increase as tonnage of fresh biomass increases, due to the use of narrow-row spacing. To overcome this problem, breeders of sugarcane will need to select for more erect varieties. Agronomists will need to develop planting techniques and seedbed preparations which will lend physical support to growing stalks, and agricultural engineers will need to develop equipment for harvesting recumbent sugarcane.

Disadvantage 2: Diseases and Insects

From this year's study, it appears that diseases and insects may be a greater problem to control with the introduction of narrow-row spacing. Due to the closer proximity of plant stalks, diseases and insects may spread more easily through a crop. This problem will require further investigation as commercial-level crop production for energy is approached.

Disadvantage 3: Lack of Equipment

This year's report will document the potential increase in production of sugarcane and sweet sorghum by the implementation of narrow-row spacing. Before considering production of narrow-spaced sugarcane for commercial energy production, some of the applied problems must be approached. One area of research is the design of new equipemnt for planting, cultivating, and harvesting of sugarcane on narrow rows. Alternatively, current equipment could be modified to handle the increased biomass production. Harvesting equipment must be designed so that plant parts can be selectively separated in the field. Field separation would facilitate easier processing at the mill since fewer problems would occur in the disposal of "trash". Also, covering equipment should cover narrow rows of sugarcane with enough soil to prevent freezing during winter.

The lack of equipment causes two problems in the production of narrow-row sweet sorghum. First, like sugarcane, equipment has not been designed for harvesting the amounts of biomass produced by use of narrow-row spacing. Secondly, no equipment has been designed specifically for sweet sorghum, because very little research has been carried out on sweet sorghum and there is very little commercial production. Currently, commercial producers of sweet sorghum use modified equipment for field work. Planting equipment must use a special seed drum to accommodate the small size of the sweet sorghum seed. Also, harvesting is done by a modified ensilage cutter with a number of cutting blades removed and the chopping speed slowed.

Equipment must be designed to selectively separate plant parts in the field during harvesting operations. It may turn out that the seedhead of sweet sorghum, which is currently discarded, may be processed in some other manner.

Weather During the Growing Season

Weather always greatly influences the results of agricultural experiments. A brief description of weather conditions at the specific sites give a better perspective of the yields and their implications.

Belle Glade, Florida

The winter of 1977 was unusually harsh in the Belle Glade area. Freezing temperatures were recorded during 4 consecutive days in January (18-21). Sugarcane was replanted in plots where poor stands occurred as a result of the cold temperatures. Less than adequate rainfall was received in the spring, with 7.6 and 14 mm of precipitation in March and April, respectively. The plots were flooded for a few days in May due to heavy precipitation totaling 130 mm; rainfall of short duration was received in June. Sugarcane growth was accelerated during June as a result of warm, sunny days with daytime temperatures ranging between 25° to 27°C. Weather at Belle Glade was conducive for good sugarcane growth with hot day temperatures (daily maximum approximately 32°C) and warm night temperatures (approximately 21°C). Rainfall was adequate with monthly totals exceeding mean pan evaporation. September weather created problems for the maturing crop. Over a 3-day period, 175 mm of rain fell and caused the cane to lodge in both narrow- and wide-spaced rows.

Baton Rouge, Louisiana

As with Florida, the winter weather in the Baton Rouge area could be described as harsh. Cold temperatures with scattered, light rainfall were common throughout February and March. During April, over 256 mm of rain fell; however, 236 mm of the total fell in a 3-day period between April 18 and 20, causing flooding and much runoff.

The weather has created numerous problems with both the sweet sorghum and sugarcane crops at Baton Rouge. Through July, rainfall was at a minimum putting the sweet sorghum crop under water stress and causing it to set seed early. Temperatures were conducive to growth, but due to lack of rainfall, growth may have been limited.

The weather changed completely from July to August. From August 19 to September 15, over 600 mm of rain fell, flooding fields and, along with high winds, causing lodging in the sugarcane plots. This heavy period of rainfall set back planting dates of sugarcane for 1978 by preventing use of heavy equipment in the fields.

Weslaco, Texas

The weather was not a major problem in Texas, as with the other experimental sites. This is due primarily to the fact that in Weslaco, irrigation, rather than rainfall, is the major source of water for the crops. Therefore a potential limiting factor in crop production was eliminated. Hot temperatures (35°C) along with high radiation levels were common throughout the summer. Coupled with irrigation treatments, the the sweet sorghum grew and matured normally. High winds due to a hurricane south of Weslaco, along with 76 mm rainfall early in September, caused the mature sweet sorghum crop to lodge, creating a minor problem for harvesting.

Houma, Louisiana

Houma, more than any other research site, felt the grips of a cold winter. Freezing temperatures were recorded 13 days in January, 1977, plus 2 days in February. Spring temperatures remained cool and not conducive to rapid cane growth.

Houma, like Baton Rouge, experienced dry weather early in the summer. Rainfall was low, but ample and hot day temperatures (~32°C) and warm night temperatures (~23°C) combined to permit rapid sugarcane growth. The rains and high winds came in August and September causing cane to lodge. Over 325 mm of rain fell in August and a similar amount accumulated in September. The rains create problems for planting of the 1978 crop and prevented the 1977 sugarcane crop from maturing.

Cultural Practices

Like the weather, cultural practices greatly influence the results of an agricultural study. Certain developments in cultural practices of sugar crops aid greatly in increasing production per unit area.

Sugarcane

Sugarcane cultural practices vary widely from location to location; therefore, a clear presentation of these activities is necessary to understand their effect on yield.

Belle Glade, Florida

Experimental Design. The experimental design consisted of a completely randomized block having treatments of 0.5 and 1.5 meter row spacings and four (4) blocks of each treatment. Each plot had dimensions of 24.4 x 33.5 m, and the plots were spaced at intervals of 6.1 m.

Cultivation. Prior to planting, the plots were plowed once and disced several times in early December to incorporate residues from a previous crop. The plots were also disced to incorporate fertilizer.

For planting, a total of 48 and 16 furrows were opened in the plots having 0.5 m and 1.5 m row spacing, respectively. Furrow depth was approximately 0.1 m. A double row of CP 65-357 sugarcane was planted in each furrow and chopped to lengths of approximately 0.5 m. The date of planting was December 20-21, 1976. Furrows were covered by hand hoes after the application of insecticide.

Pesticides. Furadan 10G® was applied as an insecticide in the furrows at the rate of 0.75 kg/100 m row. Herbicide treatment consisted of a pre-emergence spray consisting of 4.5 kg/ha of atrazine and 7 kg/ha of Randox®. These herbicides were applied on January 7, 1977. Additional herbicides, silvex and Dalphon M®, were applied with a hand-carried sprayer to control grass and broadleaf weeds which appeared during the growing season.

Irrigation. The water table immediately below the field plots was automatically maintained at 0.6 m from the soil surface.

Fertilizer. An application of 800 kg/ha of 0-8-45 with 1, 2, 1, and 1 percent of CuO, MnO, ZnO,and B_2O_3, respectively, was incorporated in the test plots on December 16, 1976.

Baton Rouge, Louisiana

Experimental Design. Experimental plots in this study were 5.5 m in width and 22 m in length. Treatments consisted of 1-, 2-, 3-, 4-, and 5-drilled rows planted in beds 1.8 m in width. All multiple-drilled rows were spaced 0.3 m apart within each bed. The design was replicated four (4) times.

Cultivation. The sugarcane was seeded in October 1976 using a CP 65-357 variety. The plots were cultivated in April with a rotary hoe and a Lilliston cultivator.

Pesticides. Immediately after planting, Sinbar® and Fenac® were applied at rates of 0.56 kg and 1.9 liter per hectare, respectively. On May 10, 1977, an application of Asulox® and 2, 4-D amine was made at rates of 1.9 and 0.95 liter/ha, respectively. Finally, 1.4 liters per hectare of Sencor® was applied on May 15, 1977.

Fertilizer. Fertilizer was applied at rates of 269 and 180 Kg/ha of N and K, respectively.

Houma, Louisiana

Experimental Design. The experimental design at this site consists of a Randomized Split-Plot with five (5) blocks. Treatments consisted of the following: (1) conventional 183 cm row spacing, (2) double row with 61 cm width between double rows, and 183 cm width between centers of the double rows, (3) single row with 91.4 cm row spacing, and (4) single row with 61.0 cm row spacing. In addition, main plots were split with respect to fertilizer ammendment. Each subplot received 336 kg/ha of NO_3-N as a bulk application or as a liquid through trickle irrigation. All plots were 6.1 m in length, and 0.61 and 0.91 row-spaced plots were 9.8 m in width, while conventional and double-rowed plots were 19.5 m in width.

Cultivation. Sugarcane variety CP 65-357 was planted on October 7 and 8, 1977. Beds were opened with a tractor-mounted plow. Sugarcane was then laid in the beds and subsequently covered using tractor-mounted discs. The planted sugarcane was covered to an approximate depth of 2.5 cm.

Pesticides. The entire experimental field area was sprayed with aluminum simazine at a rate of 1.12 kg/ha immediately after planting. Karmax® was applied at a rate of 1.12 kg/ha on April 8, 1977.

Fertilizer and Irrigation. Approximately 56 g per meter-row of solid ammonium nitrate was surficially applied on the nonirrigated plots. Irrigated plots received nitrate in dissolved form from drip irrigation tubes in three equal applications during the growing season. Each application of dissolved fertilizer was followed by an application of 4.7 ha-cm of irrigation water. The total nitrate application on the irrigated plots were equivalent to the nonirrigated.

Sweet Sorghum

Sweet sorghum, although similar in morphology to sugarcane, has different types of cultural practices employed to increase its yield. The following activities should be contrasted to those of sugarcane agriculture.

Weslaco, Texas

Experimental Design. The sweet sorghum project at Weslaco was initiated at the Texas Agricultural Experiment Station on a Willacy fine, sandy loam soil. A split-plot design, with five (5) blocks was used with sorghum varieties as main plots and row spacing as split-plots. Rio, a sugar variety, and Sart, a syrup variety, were the sweet sorghum varieties used in this study. Row spacings were 0.69 and 1.02 m in width.

Cultivation. The plot area was left fallow from June, 1976, to March, 1977, following a crop of cantaloupes. The plots were disced and kept free of weeds until March, 1977, at which time they were chisled 0.46 m deep. The soil was then disced, planed and shaped into 0.69 and 1.02 m wide beds. Rio and Sart sweet sorghum varieties were seeded on April 27, 1977. The plants were thinned on May 3, 1977, to a population level of 40 plants per meter of row. At this time, some areas of the plots had to be replanted due to bird damage.

Fertilization and Irrigation. Two separate fertilizer applications were made on May 12 and June 1, 1977. On each date, fertilizer was applied at rates of 61.6 and 86.2 kg/ha on the 1.02 and 0.69 m rows, respectively. Irrigation water was applied 3 times during the growing season at the rate of 4.11 ha-cm.

Pesticides. Propazine (Milogard®) was applied at the rate of 2.24 kg/ha on April 30, 1977, for weed control.

Baton Rouge, Louisiana

Experimental Design. The experiment at Baton Rouge was carried out at the Louisiana Agricultural Experiment Station on a silt soil. The plot configuration was designed to determine the effects of three planting methods on the yield of two sweet sorghum varieties. The planting methods were broadcast (hand-scattered seeds on a flat seedbed), and single and double drill (machined-drilled on raised 30 cm beds) all on rows 1.83 m in width. Two sugar varieties of sweet sorghum, Rio and Meridian 69-13, were chosen for the study. Six replicates of each treatment were included in the experiment, with all plots having dimensions of 10.66 m in length and 13.70 m in width.

Cultivation. Land preparation was initiated by discing and tilling in the fall of 1976. Seedbeds were prepared in the spring by the use of a drag-harrow, followed by the shaping of beds into flat and raised beds within a 1.83 m row. Broadcast planting was done by hand, while single- and double-row spacings were accomplished by raised beds on 30 cm centers within each 1.83 m row. A cultipacker was used in each case to cover the seed and firm the seedbed after planting was completed.

Fertilization and Irrigation. The sweet sorghum plots were fertilized with 68 kg of nitrogen on June 6, 1977. Since the lack of water is not a limiting factor in Louisiana, no irrigation treatments were applied.

Pesticides. At planting time, an application of propazine was made at the rate of 3.37 kg/ha. On May 28, 1977, 1 month after planting, the plant population was adjusted by thinning to a desired stand. To eliminate any weed problems, cultivation with a two-row cultivator was performed on June 7, 1977.

FUTURE POTENTIAL FOR INCREASING SUGAR CROP YIELD

Sugarcane and sweet sorghum are the best, most efficient solar energy devices we have today on a large scale. However, there is much room for improvement since photosynthetic efficiency of sugar crops is only 1 to 2 percent.

Sugarcane

Sugarcane has received much attention from breeders over the past few decades, however, they have looked at sugarcane as a food crop and not a fuel crop. Presently, it appears that there are a number of viable methods to increase production per unit area for energy purposes.

Drip Irrigation

To increase production of sugarcane in Florida, expansion of sugarcane hectarage onto sandy soils must occur. Because of the physical characteristics of sandy soils, only small amounts of water are held in the root zone, thus the leaching of nutrients and higher water requirements for crops commonly occur. These factors cause higher production costs and create a need for more efficient use of fertilizers and water. One possible solution to this problem would be the introduction of drip irrigation techniques to the sandy soil sugarcane cultures. However, the use of drip irrigation is dependent on the rainfall characteristics of the region. Under humid conditions drip irrigation may not be successful, but if rainfall patterns are infrequent during the "grand growth period" drip irrigation may be an asset. Also drip irrigation may prove useful in areas where there is stiff competition for water between urban and agricultural demands.

Drip irrigation is the frequent, slow application of water to soil through mechanical devices called emitters that are located at selected points along water-delivery lines. Most emitters are placed on the ground, but they can be buried at shallow depths for protection.

Water enters soil from the emitters, and most water movement to wet the soil between emitters occurs by capillarity beneath the soil's surface (University of California, Agricultural Leaflet 2740, 1975). The first successful installation of this basic system was completed by the Kunia, Hawaii, substation of the Hawaiian Sugar Planters' Association in March 1970. At that time, 0.08 hectare was irrigated,whereas,by the end of 1975, over 6,200 ha of land was irrigated by the drip irrigation system (Gibson, 1975).

The volume of soil wetted by drip irrigation usually is much less than that wetted by other irrigation methods. It may be only 10 percent of the soil in the root zone for newly planted crops. Researchers and experienced operators believe that at least 33 percent of the soil in the root zone under mature crops must be wetted, and that crop performance improves as the amount wetted increases to 60 percent or higher (University of California, Agricultural Leaflet 2740, 1975).

Drip irrigation can reduce operating costs, and this has been the main interest in this method. Drip systems can irrigate crops with significantly less water than is required by other common irrigation methods.

Labor costs for irrigating also can be cut, since water applied by drip irrigation merely needs to be regulated, not tended. Such regulation usually is accomplished by labor-saving automatic timing devices (University of California, Agricultural Leaflet 2740, 1975).

Because much of the soil surface never is wetted by irrigation water, weed growth is reduced by drip irrigation. This lowers labor and chemical costs for weed control.

Prolonging the life of the lateral distribution tube by going underground sufficiently deep to protect the tube during harvesting operations is an obvious opportunity for an overall cost reduction (this practice has been labelled "subsurface" irrigation) (Gibson, 1975).

Fertilizers can be injected into drip irrigation waters to avoid labor needed for ground application. Several highly soluble materials are available for this purpose. Greater control over fertilizer placement and timing through drip irrigation may lead to improved fertilization efficiencies.

Frequent irrigations maintain a soil moisture condition that does not fluctuate between wet and dry extremes and also keeps most of the soil well aerated. Less drying-down between irrigations keeps salts in the soil water more dilute, and this makes possible the use of more saline waters than can be applied with other irrigation methods (University of California, Agricultural Leaflet 2740, 1975).

Growth Regulators

Normal ripening involves changes in the balance of metabolism within the cane plant. It is not an irreversible process, and late applied nitrogen or irrigation may cause a reversal and resumption of vegetative growth. Optimum yields and maturity result from vigorous growth during the production period and a ripening period when active growth is curtailed and the reducing sugars are converted to sucrose and stored (Humbert, 1968).

Currently, much work is being done with the chemical ripener, Polaris®. Under adverse ripening conditions (i.e., wet weather), Polaris® has been used to increase the sucrose content of the maturing stalks. Therefore, it appears that the chemical ripening is feasible, but further research is necessary to define the conditions under which response can be expected with a given chemical.

The use of Polaris® and MON 8000® as growth enhancers currently is being tested in Puerto Rico (Alexander, 1978). Dilute applications of these chemicals have been found to increase the growth rates of sugarcane under greenhouse conditions. No field tests have been conducted as of yet.

From preliminary studies with narrow-spaced sugarcane in Florida, it appears that there is a large amount of biomass present by July which could be harvested. However, the total sugar levels are low (~7 percent). If it would be possible to increase the total sugar level with some type of artificial ripener, it would seem feasible to harvest cane twice within one growing season (harvests would occur in July and December).

Another growth regulator which could be used in this scheme is gibberellic acid. After the July harvest, the sugarcane ratoon could be treated with gibberellic acid to enhance regrowth rates.

Hopefully, continued work in this area will be encouraged because the potential of increased yields is enchanced by the judicious use of chemical growth regulators.

Variety Selection

By attempting to increase sugarcane yields with narrow-row spacings, breeders must move to revise their current guidelines. Bull (1975) found that about 10 percent of the noncommercial varieties out-yielded commercial varieties when spaced in narrow rows (0.5 m). Therefore, it appears that the potential of increasing yields is large when the sugarcane breeders attempt to re-analyze their genetic stock. However, this process of releasing commercial varieties of sugarcane (whether for sugar or energy production) is slow. Currently, it takes approximately 13 years to release a commercial variety.

Important characteristics which need to be included in future commercial varieties grown in narrow rows are:

- High tonnage
- Fermentable sugars
- Erect growth
- Lodging resistance
- Rapid tillering
- Early maturing
- Good ratooning

A major limitation to sugarcane production for energy is the limited area on which sugarcane can be produced. Therefore, to increase hectarage of sugarcane, breeders must improve both cold and drought tolerance of the sugarcane plant.

Sweet Sorghum

Unlike sugarcane, sweet sorghum has not received the attention it deserves from the breeders and agronomists. It has a tremendous potential which should be exploited for energy purposes.

Ratooning

Sweet sorghum, like sugarcane, has the ability to "ratoon", or to regrow from basal buds on the stem after cutting. Because of the length of its growing season (110-130 days), sweet sorghum can be double cropped and possibly triple-cropped in some areas of the southern United States (Cowley and Smith, 1972). In an attempt to reduce overall costs of sweet sorghum production, ratooning should be considered. Obviously, it will reduce costs because of the elimination of replanting the crop. However, the yields of the following ratoons must be high enough to support this technique.

Currently, at Weslaco, Texas, a ratooning demonstration is being carried out. Three varieties of sweet sorghum (Rio, Roma, and Ramada) have been ratooned at two cutting heights (ground level and 3 cm) and the results are being recorded. Further documentation will occur in future reports, but it appears that: (1) planting date of the sweet sorghum and ratooning date have a large effect on ratoon yield; (2) some varieties ratoon better than others; (3) ratoon yields are greatly affected by cutting height; (4) ratoon yields are greatly affected by herbicide and fertilizer treatments.

Multiple Cropping

Sweet sorghum can be multiple cropped in many areas of the United States. In the southern United States it could be put in rotation with sugarcane and grown on fallow sugarcane land. In the northern and western United States, sweet sorghum could be grown on fallow sugar beet land. These developments could possibly aid the ailing sugar beet industry and the Louisiana sugarcane industry.

In Ohio, sweet sorghum can be multiple cropped with winter wheat. Possibly in the future, the American farmer will have the opportunity to utilize two markets, food and the energy market. Because of its drought and cold tolerance, sweet sorghum has a tremendous potential to expand throughout the United States.

Growth Regulators

If, in the future, sweet sorghum is ratooned like sugarcane, the use of growth regulators may be useful in increasing yields. After ratooning, the sweet sorghum crop could be treated with gibberellic acid to speed up regrowth rates.

Possibly other chemicals could be used to "ripen" sweet sorghum and increase sucrose production. The use of growth regulators could be used to increase the uniformity of maturity of sweet sorghum.

Since little work has been carried out with growth regulators with sweet sorghum, we encourage work in this area to increase overall production throughout the United States.

Variety Selection

Like sugarcane, the introduction of the cultural practice of narrow-row plantings will cause the sweet sorghum breeder to revise his criteria for variety selection.

Important characteristics which need to be included in future commercial varieties grown in narrow rows are:

- High tonnage
- Fermentable sugars
- Erect growth
- Lodging resistance
- Rapid tillering
- Early maturity
- Good ratooning
- Uniform maturity.

In addition to these characteristics, additional emphasis should be placed on increasing drought and cold tolerance of sweet sorghum.

Sweet sorghum has responded well to a relatively low level of genetic improvement effort. The ingenuity and funding used to make the dramatic improvements in yield obtained in corn, sugar beets, and sugarcane have not been applied to sweet sorghum. Therefore, it may be possible to increase the sweet sorghum yields with the introductions of such genetic manipulations as hybridization.

RESULTS

The effect of narrow-row spacings on sugarcane and sweet sorghum biomass production is significant. The magnitude of the yield increase also is dependent on such factors as crop variety, weather, cultural practices (other than row spacing), and length of the growing season.

Sugarcane

In all cases, the yield of sugarcane was significantly greater with the implementation of narrow-row spacing (Table III-1). Plants grown closer together collect more solar radiation per unit land area than do conventionally spaced crops.

The level of increased production of sugarcane is greatly affected by the length of the growing season. As expected, the yield increases caused by the use of narrow-row spacings were less in Florida than in Louisiana, due to the length of the growing season (Lipinsky et al., 1976). In areas where the growing season is short, narrow-row spacings show a greater advantage for production purposes by capturing more solar radiation early in the season before the canopy develops and by developing a full canopy sooner than conventionally spaced crops. However, the advantage is minimized in areas with a longer growing season.

TABLE III-1. SUGARCANE HARVEST DATA SUMMARY, 1977

Location	Yields		
	Total Dry Wt. (t/ha)	Total Sugar[1] (t/ha)	Sucrose[1] (t/ha)
Belle Glade, Fla.			
0.5 m rows	39.6	16.6	15.7
1.5 m rows	36.0	15.0	13.9
Baton Rouge, La.[2]			
Conventional "V"	21.3	7.6	6.3
2 Drills	28.3	11.4	9.6
3 Drills	29.5	12.9	10.8
4 Drills	31.3	14.0	11.7
5 Drills	30.4	10.6	9.0
Houma, La.[3]			
0.6 m rows	50.4	23.7	19.9
0.9 m rows	39.6	17.6	14.8
1.8 m rows - SD	31.0	14.4	12.1
1.8 m rows - DD	34.6	15.7	13.2

[1]Total sugar and sucrose in stalks.

[2]Each treatment was planted on a 1.83 m wide seedbed, and drills were 0.3 m apart centered on that seedbed. Total sugar was calculated as 119 percent of sucrose level.

[3]"SD" stands for "Single Drill" and "DD" stands for "Double Drill". Total dry weight was calculated as 27 percent of gross fresh weight. Sucrose yield was calculated as percent sucrose in stalks multiplied by net fresh weight, and net fresh weight equals 76 percent of gross fresh weight. Total sugar was calculated as 119 percent of sucrose level.

Sources: Florida AREC, Belle Glade, Florida
Louisiana State University, Baton Rouge, Louisiana
U.S. Department of Agriculture, Houma, Louisiana.

Belle Glade, Florida

The early growth advantage of narrow-row spacings of sugarcane on muck soil was agronomically and statistically significant; however, these monthy yield increases were not as great as those found in Louisiana. At harvest, the total dry matter production reached approximately 40 metric tons per hectare at the 0.5 m spacing and 36 metric tons per hectare at the conventional 1.5 m row spacing (Figure III-8). This final difference was not statistically significant at the 5 percent level using the least significant difference test (LSD). On the other hand, total sugar production and sucrose production per hectare were significantly greater (total sugar at the 1 percent level and sucrose at the 5 percent level) at the narrow-row spacing (Figures III-9 and III-10). These results are a combination of the percent total sugar and sucrose of the stalk and the stalk number per hectare (Figure III-11), being significantly greater at the 0.5 m spacing. These findings were enhanced by the use of sugarcane "ripener" Polaris® later in the season. Polaris®-treated sugarcane yielded a higher percentage of total sugar per stalk than did the untreated material.

The fertilizer application used in this experiment was 800 kg/ha of 0-8-45; this converts to an application of 28 kg/ha of elemental phosphorus and 298 kg/ha of elemental potassium. Because of the high organic matter content (approximately 93 percent) of the soil, no nitrogen fertilizer was added. Uptake of the nutrients by the sugarcane crops is documented in Figures III-12 to 14. Slightly more nitrogen was taken up by the narrow-spaced sugarcane. Uptake at harvest reached 222 kg/ha N at the 0.5 m spacing and 198 kg/ha at the 1.5 m spacing (not significantly different). Because there was no difference in percent nitrogen of the plant tissue, the slight difference in total uptake of nitrogen by the crop can be attributed to the slightly higher production rate of the narrow-row spacing. Total phosphorus uptake peaked in December at 46 kg/ha at the 0.5 m spacing and 42 kg/ha at the 1.5 m row spacing (not significantly different). Total potassium uptake peaked in August at 548 kg/ha at the 0.5 m

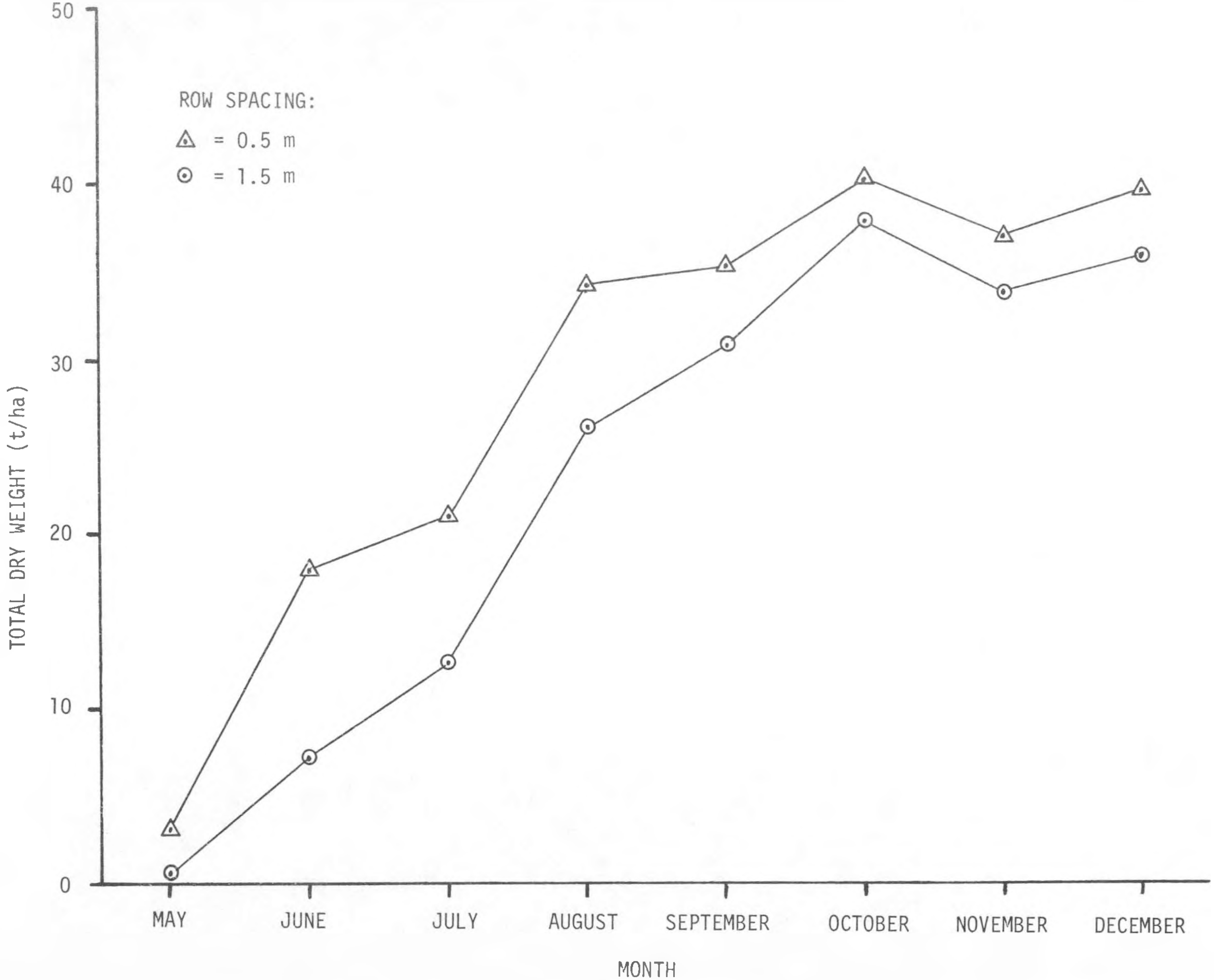

FIGURE III-8. SUGARCANE DRY BIOMASS PRODUCTION, BELLE GLADE, FLORIDA, 1977.

Source: Florida AREC.

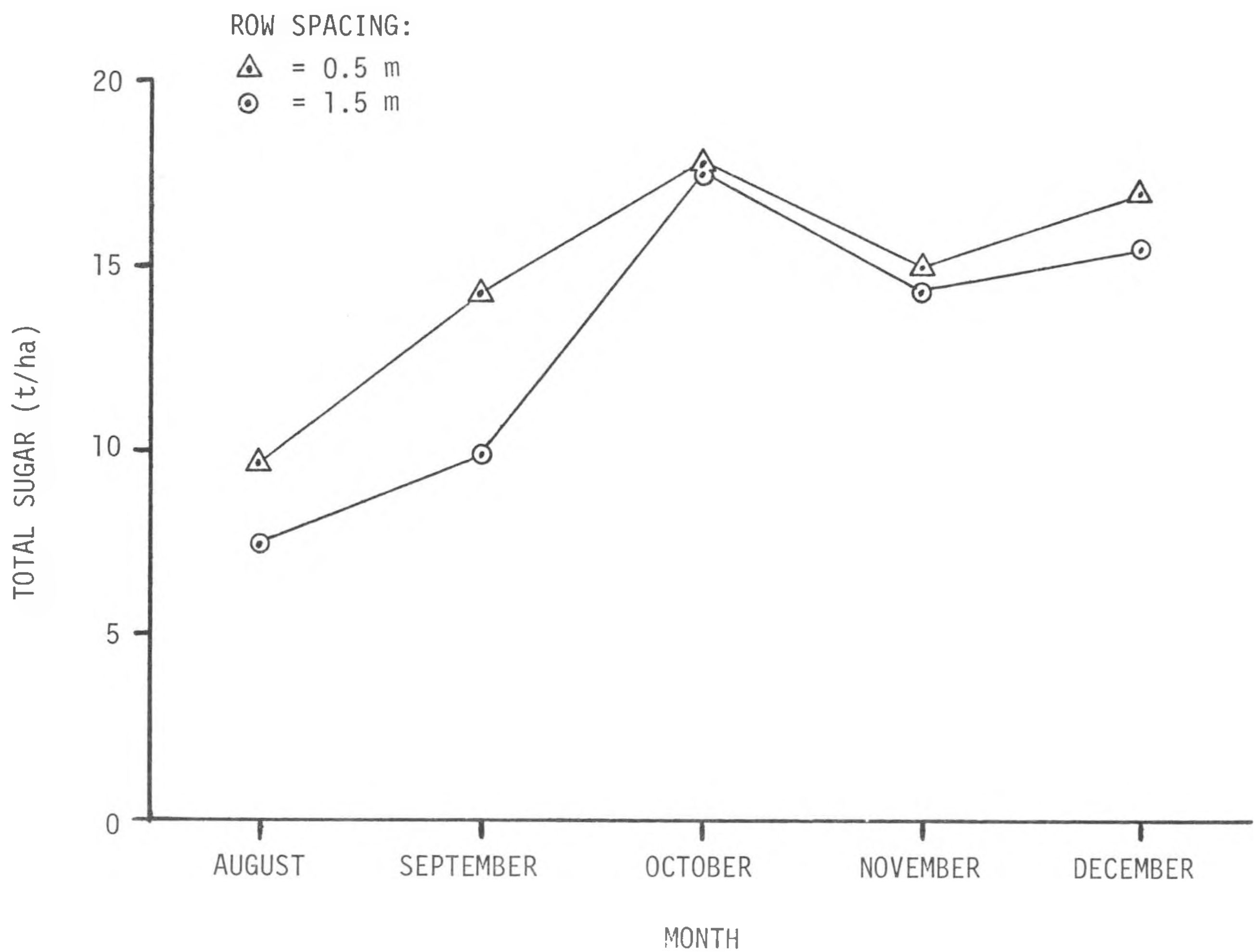

FIGURE III-9. SUGARCANE TOTAL SUGAR PRODUCTION IN STALKS, BELLE GLADE, FLORIDA, 1977.

Source: Florida AREC.

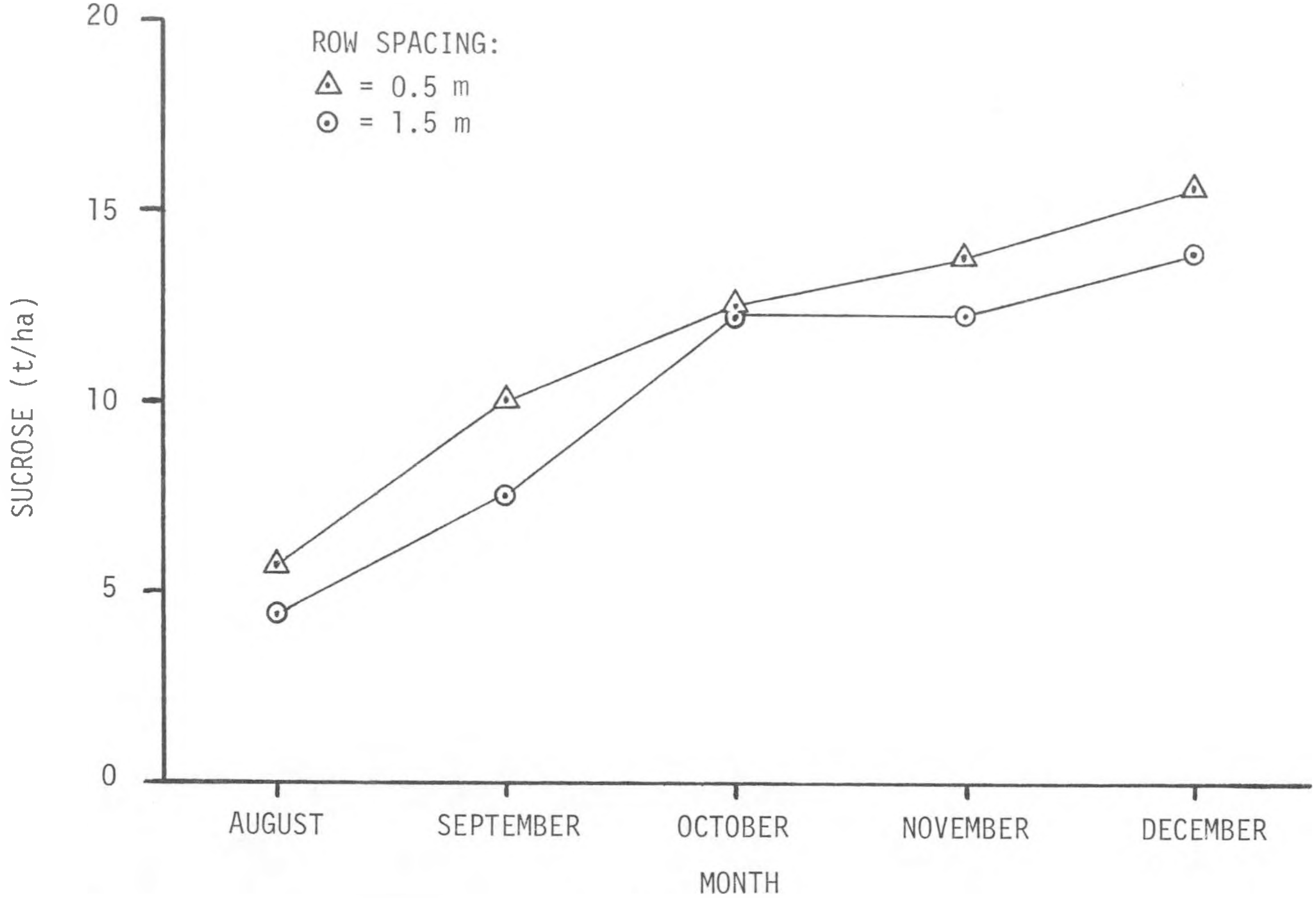

FIGURE III-10. SUGARCANE PRODUCTION IN STALKS, BELLE GLADE, FLORIDA, 1977.

Source: Florida AREC.

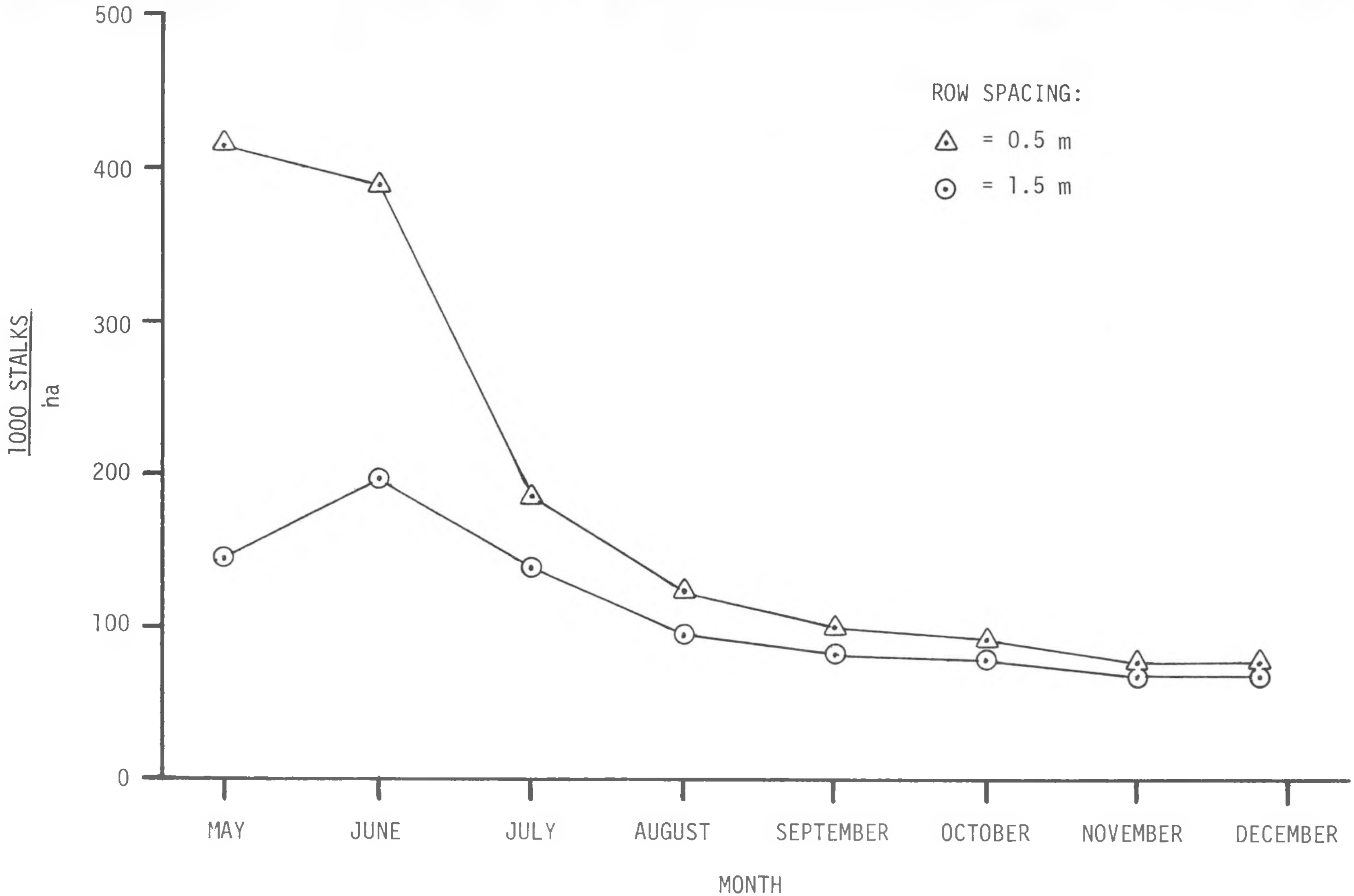

FIGURE III-11. SUGARCANE STALK COUNT PER HECTARE, BELLE GLADE, FLORIDA, 1977.

Source: Florida AREC.

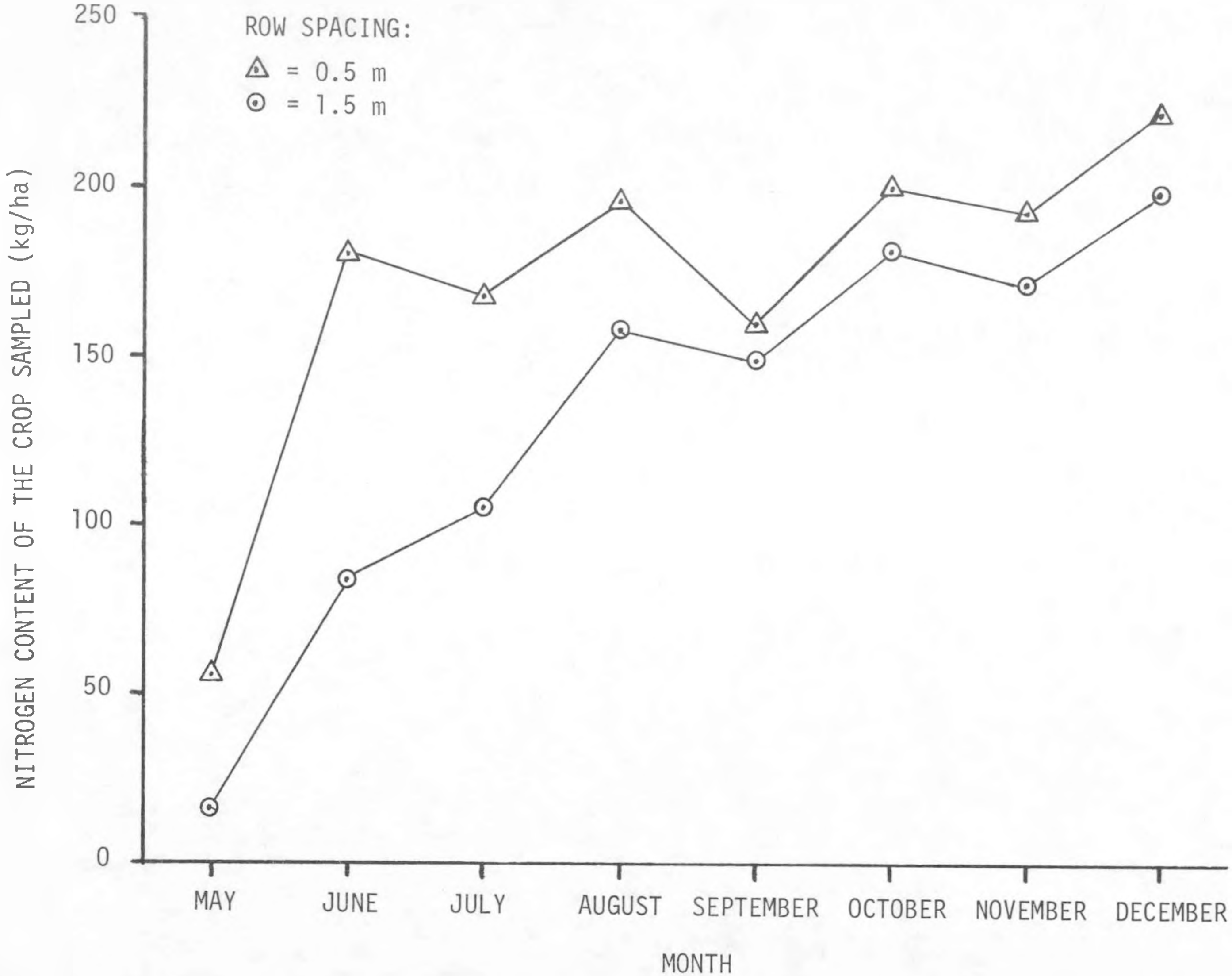

FIGURE III-12. TOTAL NITROGEN UPTAKE BY SUGARCANE, BELLE GLADE, FLORIDA, 1977.

Source: Florida AREC.

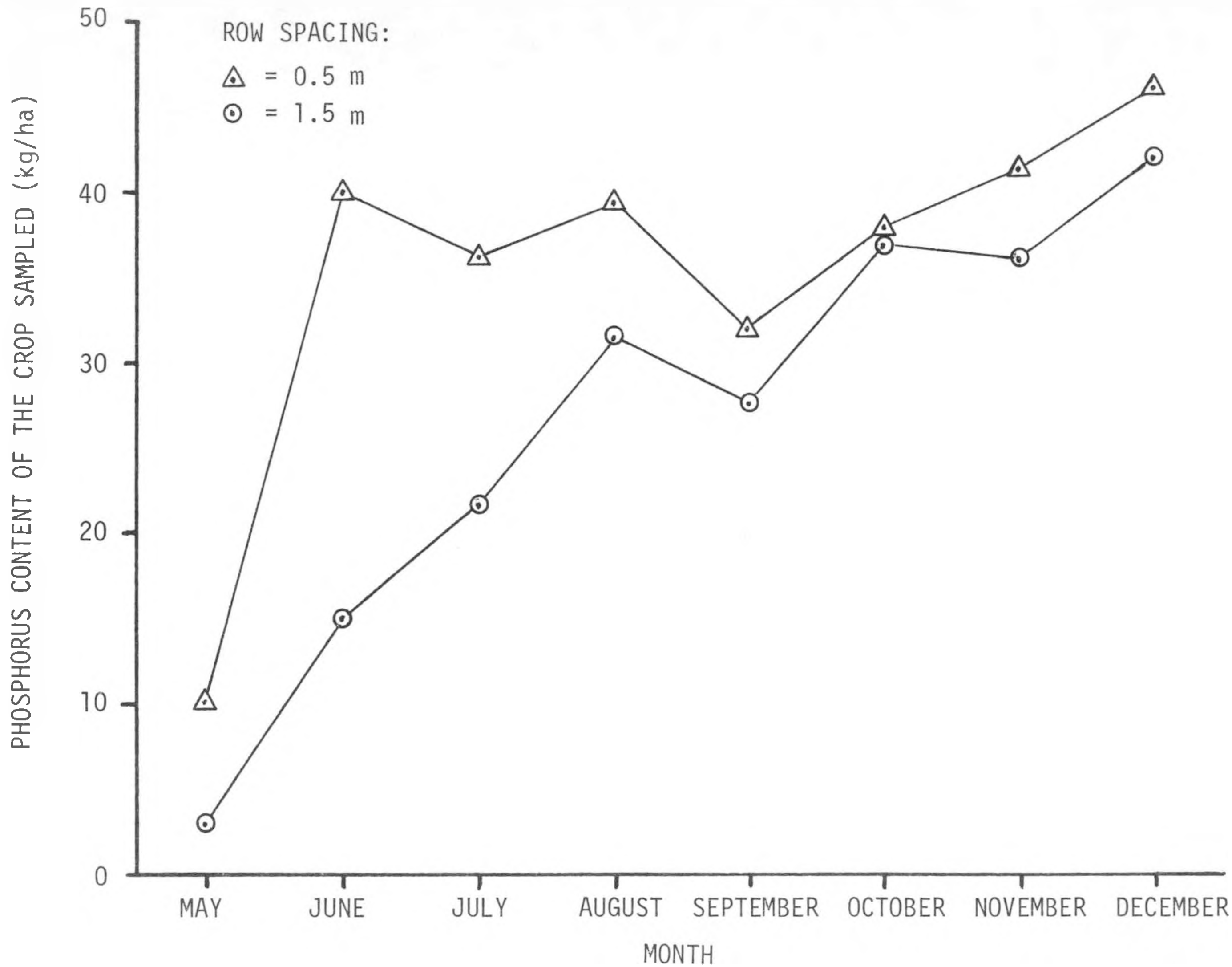

FIGURE III-13. TOTAL PHOSPHORUS UPTAKE BY SUGARCANE, BELLE GLADE, FLORIDA, 1977.

Source: Florida AREC.

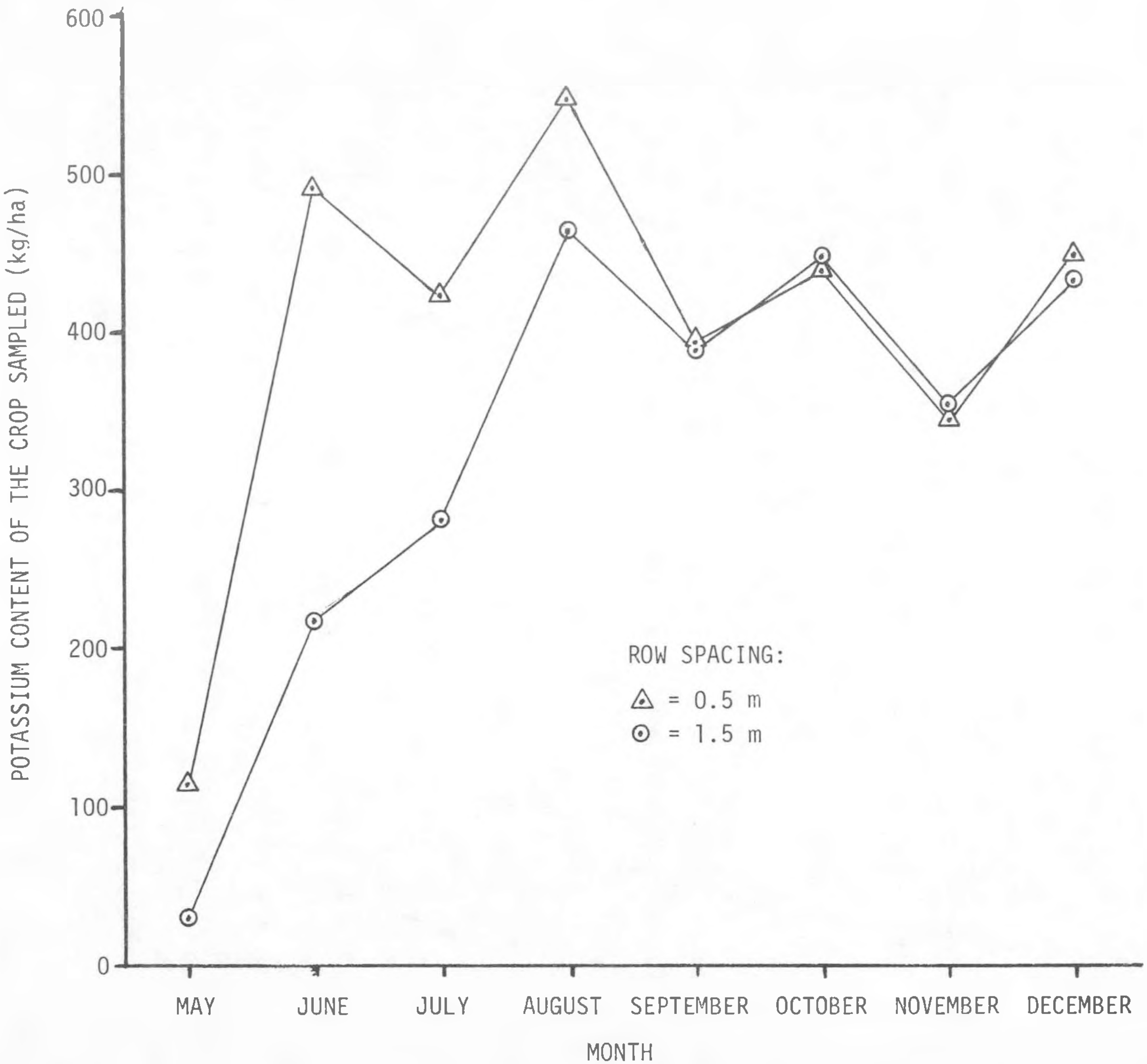

FIGURE III-14. TOTAL POTASSIUM UPTAKE BY SUGARCANE, BELLE GLADE, FLORIDA, 1977.

Source: Florida AREC.

row spacing and 465 kg/ha at the 1.5 m row spacing, and like the nitrogen and phosphorus uptake, the potassium uptake was not significantly different between row spacings.

Baton Rouge, Louisiana

Louisiana is characterized as a marginal area for sugarcane production due to its short growing season. The introduction of narrow-row spacing into the Louisiana sugarcane agricultural system can significantly increase production levels per unit area. From this demonstration, data indicate that all modified narrow-row planting arrangements significantly out-yielded the conventional "V" single-drill, raised-bed treatment on 1.83 m rows due to the greater stalk number in the multiple-drill treatments (Figures III-15 and III-16). This conventional treatment yielded approximately 21 metric tons per hectare which the 2 through 5 drills per 1.83 m row yielded approximately 28, 30, 31, and 30 metric tons of dry matter per hectare, respectively (Table III-2). There was no significant difference in dry matter yield between multiple-drill treatments. Total sugar yield was 7.6 metric tons per hectare employing the conventional spacing. For the 2- through 5-drill treatments, total sugar yields were 11.4, 12.9, 14.0, and 10.6 metric tons per hectare (all significantly higher than the check at the 5 percent level), respectively. Sucrose yields were similar in that the conventional 1.83 m single-drill row spacing yielded 6.3 metric tons per hectare which was significantly lower than the multiple-drill treatments; yields ranged from 9.0 to 11.7 metric tons per hectare. The total sugar and sucrose yields were significantly higher (at the 5 percent level) with the 3 and 4 drills per 1.83 m row than the 2- and 5-drill treatments (Table III-2).

Houma, Louisiana

As in Baton Rouge, the results of the narrow-row spacing trials at Houma document the advantages of high density plantings in a marginal

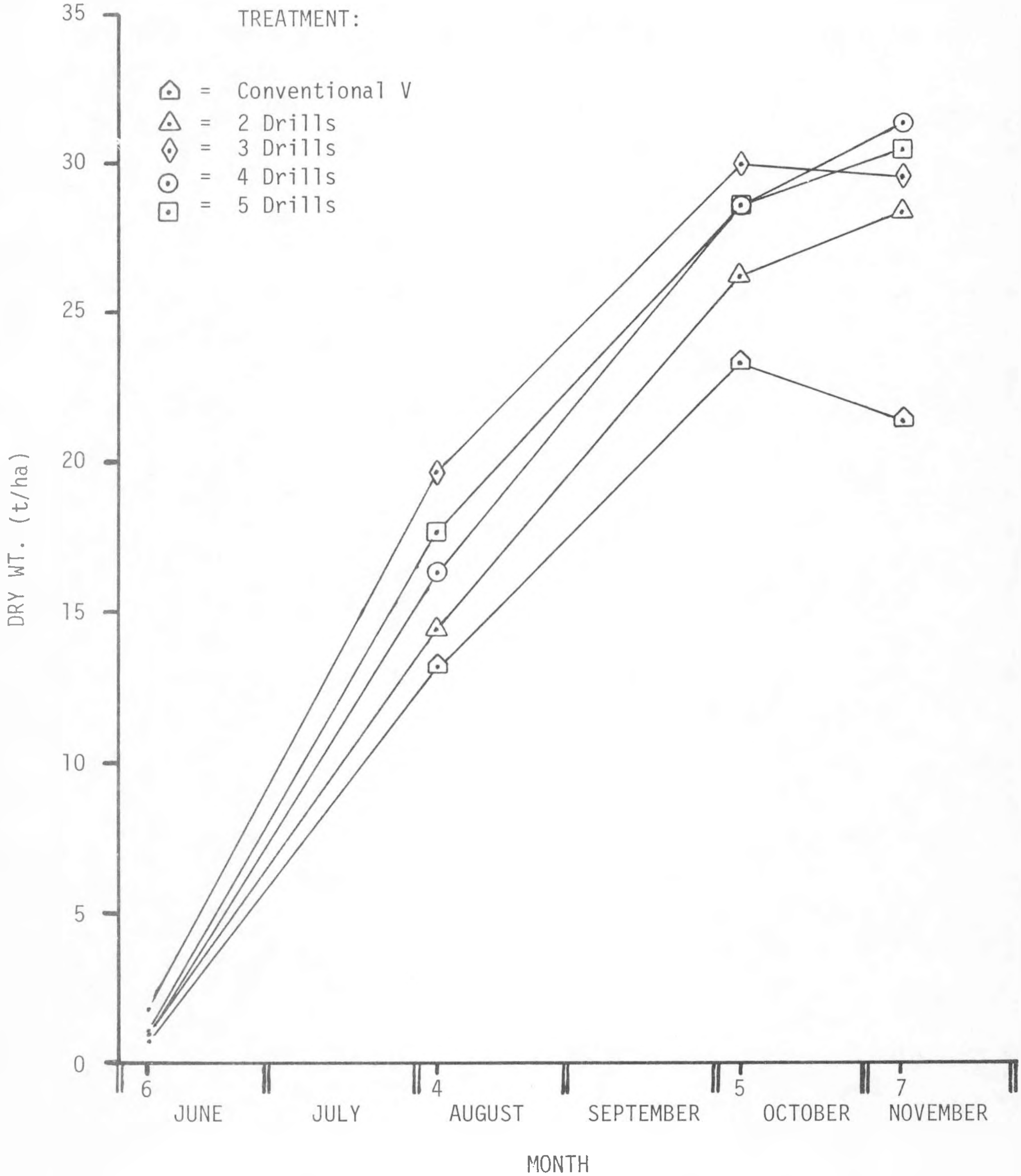

FIGURE III-15. SUGARCANE DRY BIOMASS PRODUCTION, BATON ROUGE, LA., 1977.

Source: Louisiana State University.

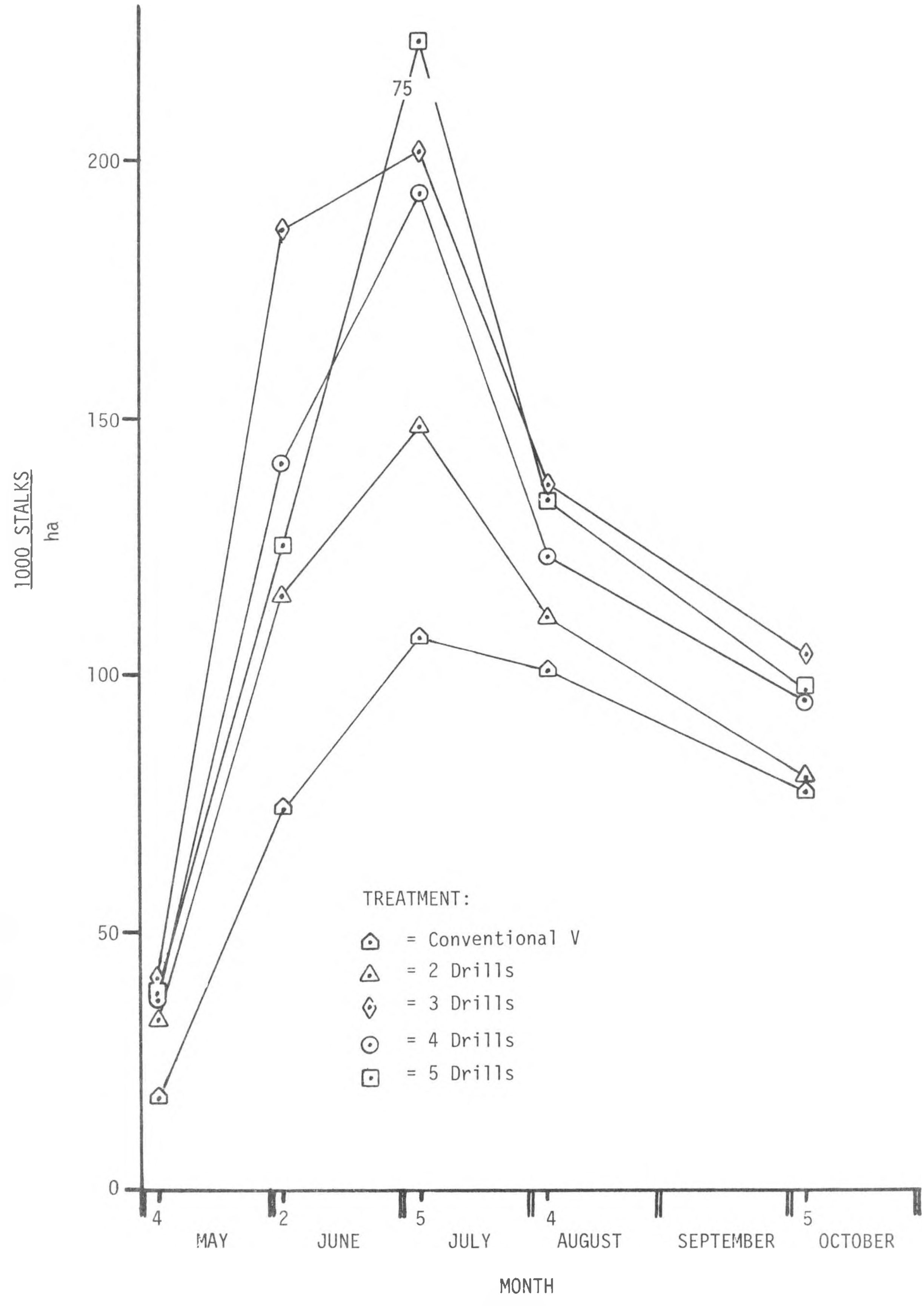

FIGURE III-16. SUGARCANE STALK COUNT PER HECTARE, BATON ROUGE, LA., 1977.

Source: Louisiana State University.

TABLE III-2. SUGARCANE DATA AT HARVEST, BATON ROUGE, LA., NOVEMBER 7, 1977

Treatment	Total Dry Wt. (t/ha)	Total Sugar Yield[1] (t/ha)	Sucrose Yield (t/ha)
Conventional "V"	21.3	7.6	6.3
2 Drills	28.3	11.4	9.6
3 Drills	29.5	12.9	10.8
4 Drills	31.3	14.0	11.7
5 Drills	30.4	10.6	9.0

[1]Total sugar yield was calculated as 119 percent of sucrose yield.

Source: Louisiana State University.

climate. Rapid canopy closure, characteristic of narrow spacing makes for more efficient capture of solar radiation. A survey of the data shows that a significant increase (using the LSD test at the 5 percent level) in yield is attributed to the use of narrow-row spacing. These results fit very well with previous work done on narrow-row spacing at Houma. The conventional single-drill sugarcane on 1.83 m rows yielded 31 metric tons of dry mattery per hectare (Figure III-17). The double-drill treatment on the 1.83 m row yielded 34.6 metric tons of dry matter per hectare, but this was not significantly different from the check. However, total dry matter yields per hectare with the 0.6 m and the 0.9 m treatments were significantly higher than the yield from the conventional treatment. Dry matter yield per hectare was approximately 40 metric tons with the 0.9 m row spacing and 50 metric tons with the 0.6 m row spacing (Figure III-17)—all results relating back to the stalk counts per unit (Figure III-18). Total fermentable sugar yield (Figure III-19) was 14.4 metric tons per hectare with the conventional planting, while the 1.83 m double-drill planting yielded 15.7 metric tons per hectare; the 0.9 rows yielded 17.6 metric tons per hectare; and the 0.6 m rows yielded 23.7 metric tons per hectare (both the 0.6 m and 0.9 m yields were significantly greater than the yield of the conventional planting). Similarly, sucrose yields per hectare were significatnly higher in the 0.6 m and 0.9 m spacing when compared to the check (Figure III-20). The conventional 1.83 m single-drill planting yielded 12.1 metric tons of sucrose per hectare, whereas the 0.6 m row spacing yielded 19.9 metric tons of sucrose per hectare.

The fertilizer application in the test plots was 610 kg/ha of solid ammonium nitrate on the 0.9 m and 18.3 m single- and double-drilled rows and 916 kg/ha of ammonium nitrate on the 0.6 m rows. These rates are equivalent to 500 kg/ha of elemental nitrogen on the 0.9 m and 1.83 m single- and double-drilled treatements and 750 kg/ha of elemental nitrogen on the 0.6 m row spacing. From earlier studies at Houma, no response was found with the application of other elements, therefore none were used. Nitrogen uptake was approximately 250 kg/ha at the 0.6 m spacing and approximately 150 kg/ha at the 1.83 m row spacing (Figure III-21). Analyses of plant tissues indicate that the difference in N uptake is due to more

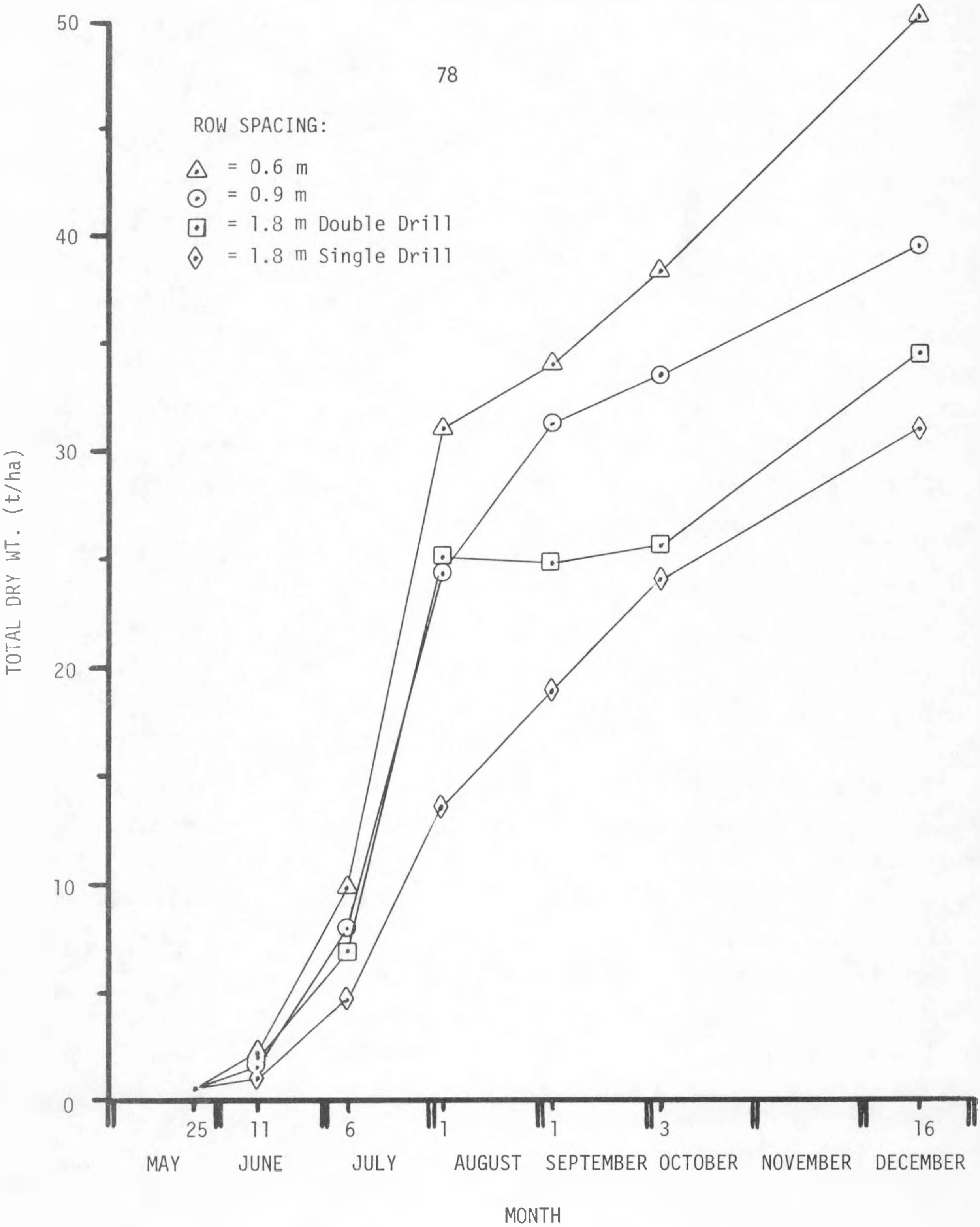

FIGURE III-17. SUGARCANE DRY BIOMASS PRODUCTION, HOUMA, LA., 1977.

(Total dry weight equals 27 percent of gross fresh weight.)

Source: U.S. Department of Agriculture.

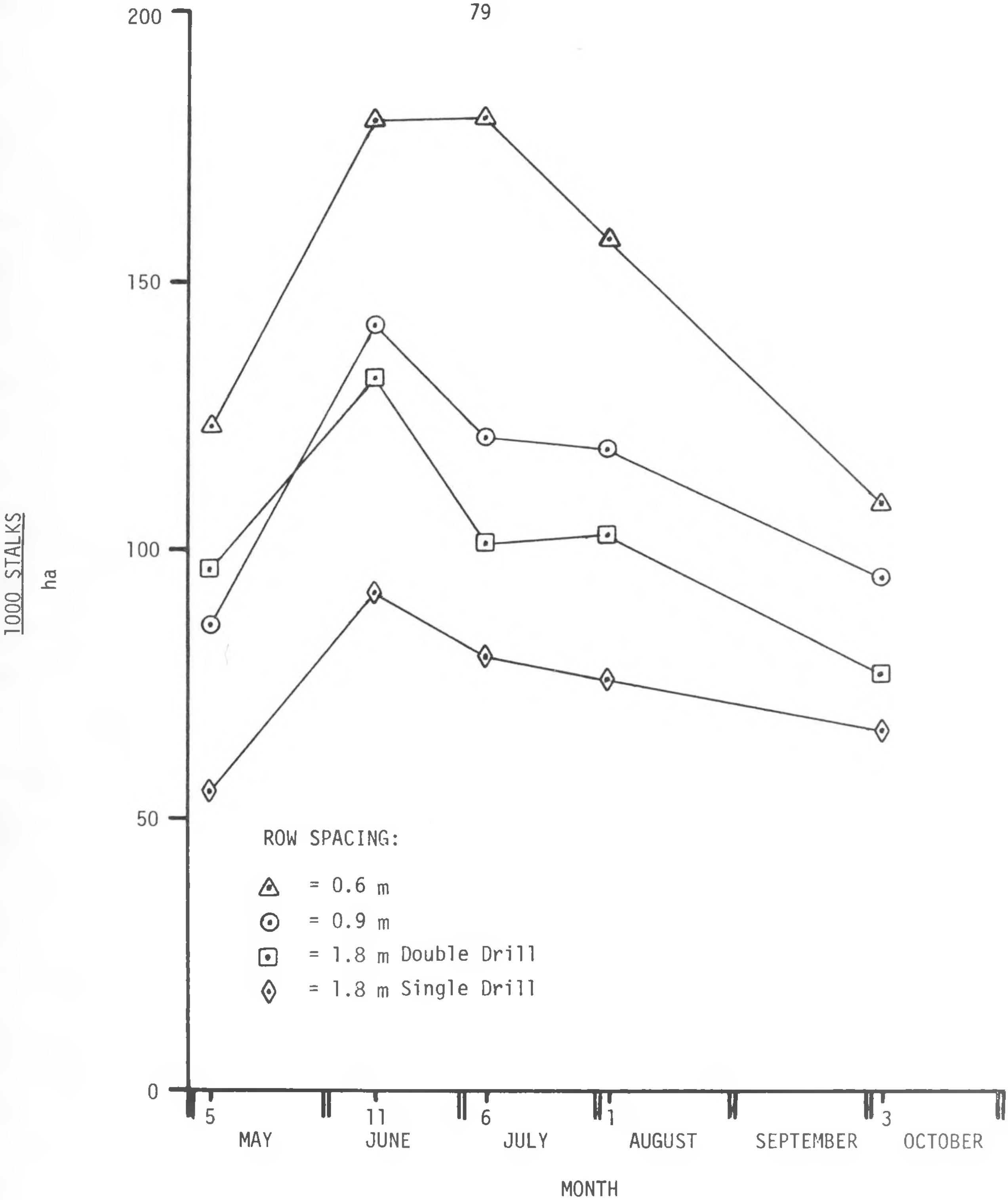

FIGURE III-18. SUGARCANE STALK COUNT PER HECTARE, HOUMA, LA., 1977.

Source: U.S. Department of Agriculture.

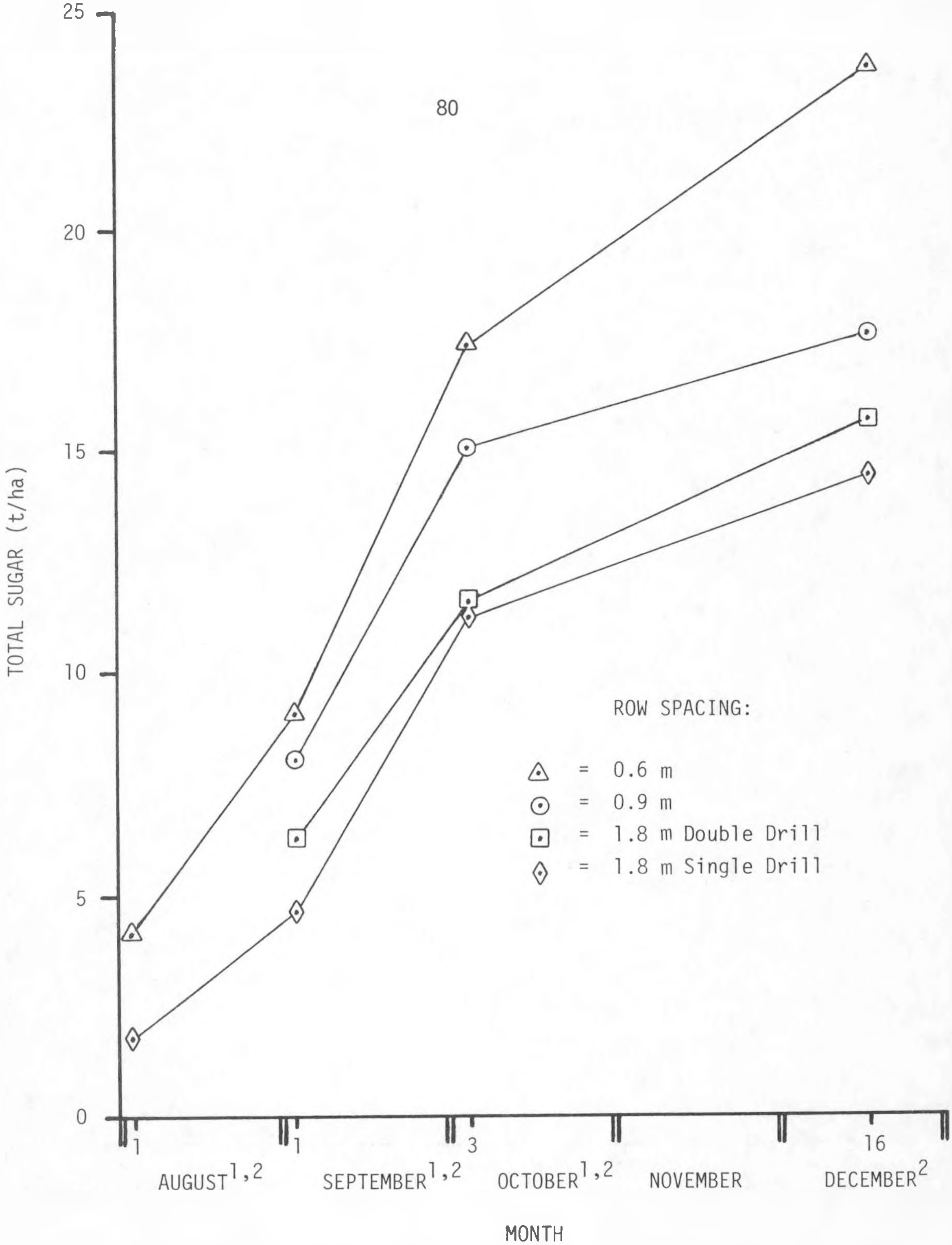

FIGURE III-19. SUGARCANE TOTAL SUGAR PRODUCTION IN STALKS, HOUMA, LA., 1977.

Source: U.S. Department of Agriculture.

[1] Sucrose yield was calculated as percent sucrose in stalks multiplied by net fresh weight and net fresh weight equals 76 percent of gross fresh weight (see Footnote 2).

[2] Total sugar yield was calculated as 119 percent of sucrose yield.

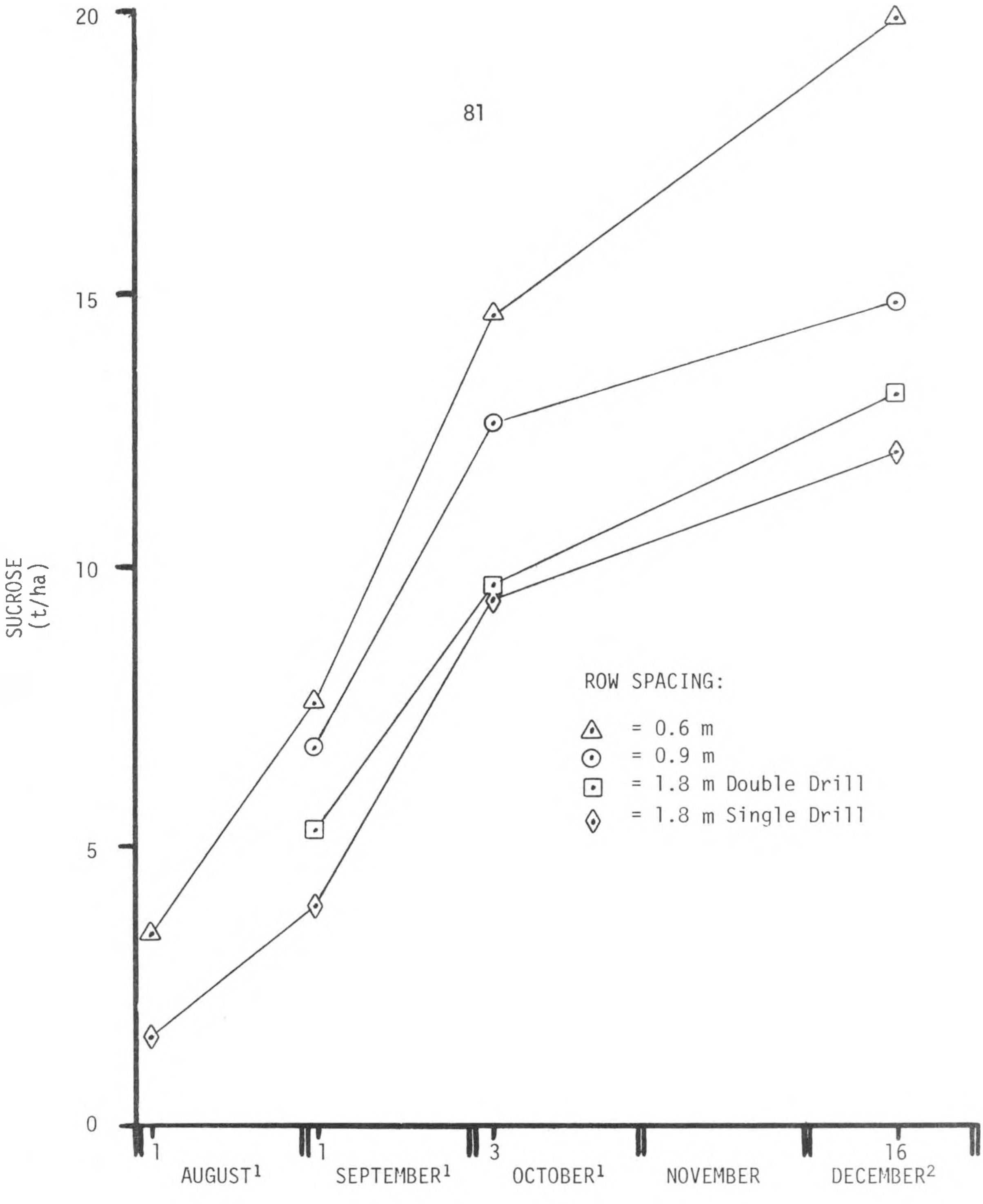

FIGURE III-20. SUGARCANE SUCROSE PRODUCTION IN STALKS, HOUMA, LA., 1977.

Source: U.S. Department of Agriculture.

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[1]Sucrose yield was calculated as percent sucrose in stalks multiplied by net fresh weight and net fresh weight equals 76 percent of gross fresh weight.

[2]Direct data from Houma—yield of sugar from stalks only.

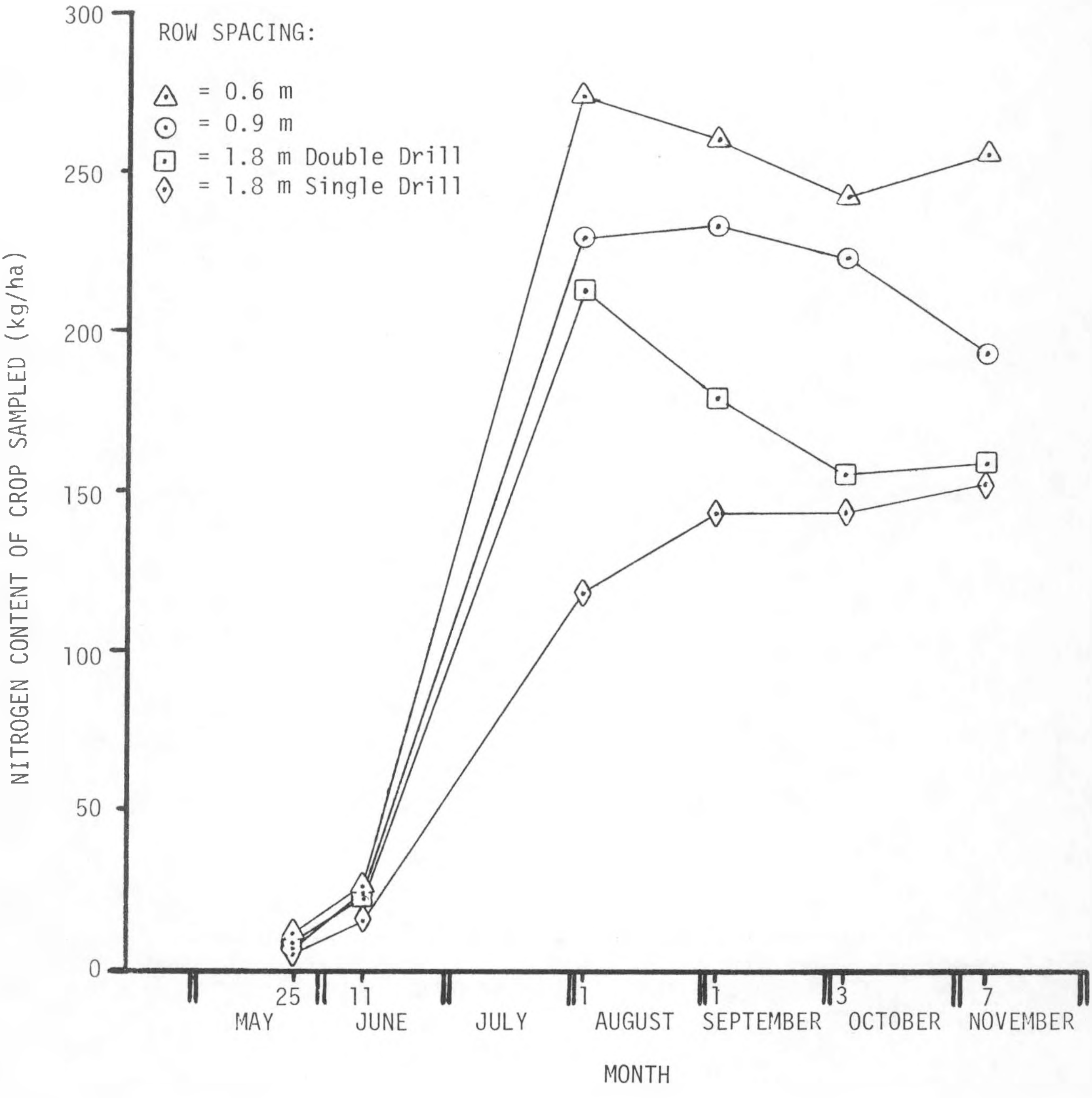

FIGURE III-21. TOTAL NITROGEN UPTAKE BY SUGARCANE, HOUMA, LA., 1977.

Source: U.S. Department of Agriculture.

material being present in the 0.6 m row rather than a more efficient use of nitrogen by the wide-row sugarcane. Results of phosphorus and potassium uptake show values of 40 kg/ha of phosphorus and approximately 370 kg/ha of potassium taken up by the 0.6 m rows and approximately 24 kg/ha of phosphorus and 229 kg/ha of potassium taken up by the 1.83 m rows (Figures III-22 and III-23). Similar to the nitrogen uptake data, these results indicate that more of these elements were taken up in the narrow-row treatments due to more plant biomass produced and not because of a more efficient use of the elements by the wide-row sugarcane.

Comparisons of nutrient applications through irrigation water versus direct use of solid material showed no differences in results at any row-spacing treatment.

Sweet Sorghum

The research conducted on sweet sorghum initially included only two sites—Weslaco, Texas, and Baton Rouge, Louisiana; however, additional information was collected from the USDA Sugar Crops Field Laboratory at Meridian, Mississippi, and from a demonstration conducted by Battelle's facilities at West Jefferson, Ohio. All results and trends pointed to the great potential of narrow-row spaced sweet sorghum (Table III-3). It appears that large yields of sweet sorghum can be produced through implementation of narrow-row spacing. In addition, sweet sorghum may be highly adaptable to areas of production like the midwestern Corn Belt. If this is possible, sweet sorghum may be a highly valued asset in the biomass from energy program.

Weslaco, Texas

The most valuable information which came out of the study of narrow spacing in sweet sorghum came through unforeseen circumstances. The syrup variety, Sart, was destroyed by the sugarcane borer (*Diatraea saccharalis*) and the corn earworm (*Heliothis zea*) and in its place data were then collected on another variety, MN 1500. MN 1500, which was planted

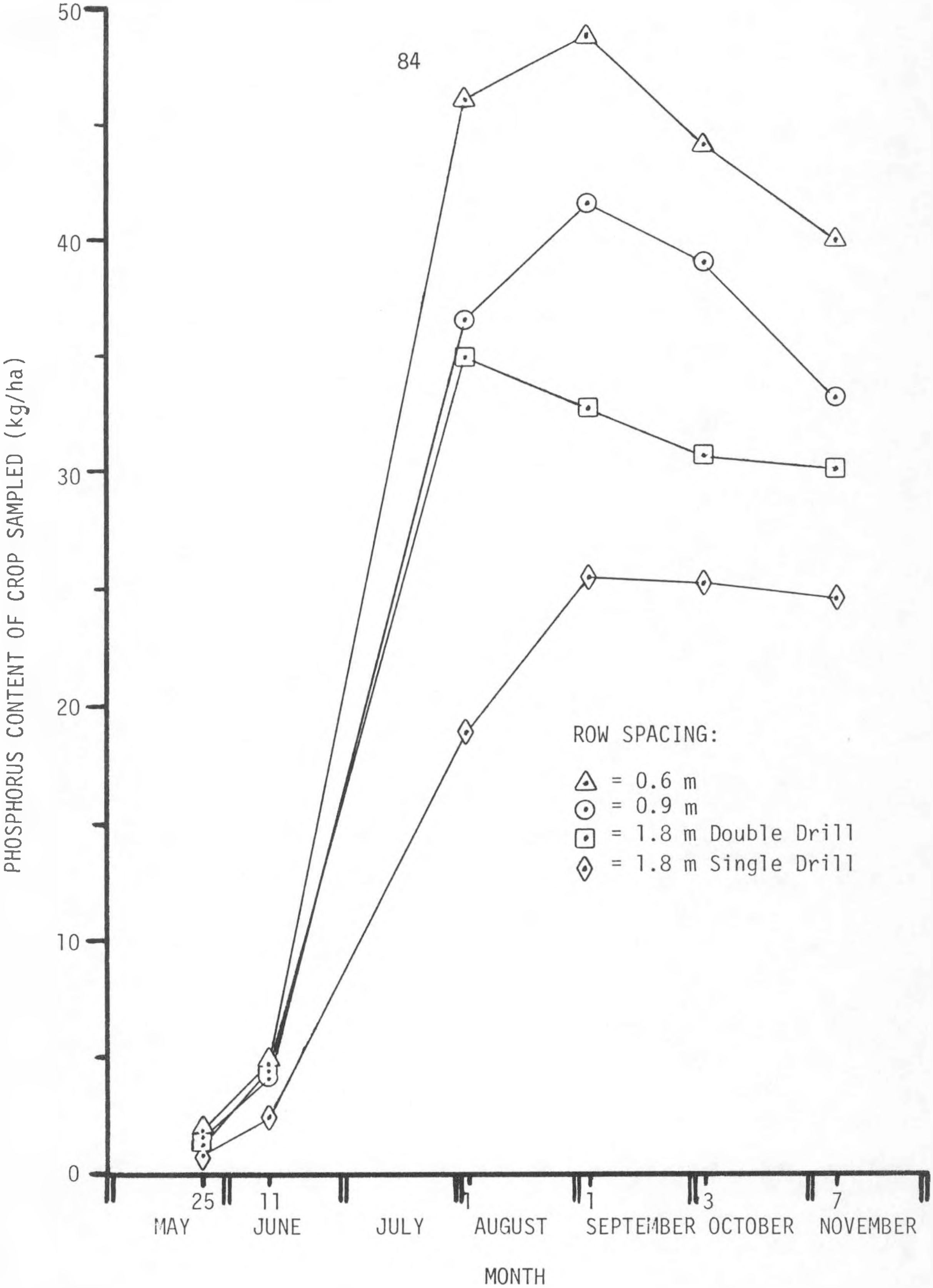

FIGURE III-22. TOTAL PHOSPHORUS UPTAKE BY SUGARCANE, HOUMA, LA., 1977.

Source: U.S. Department of Agriculture.

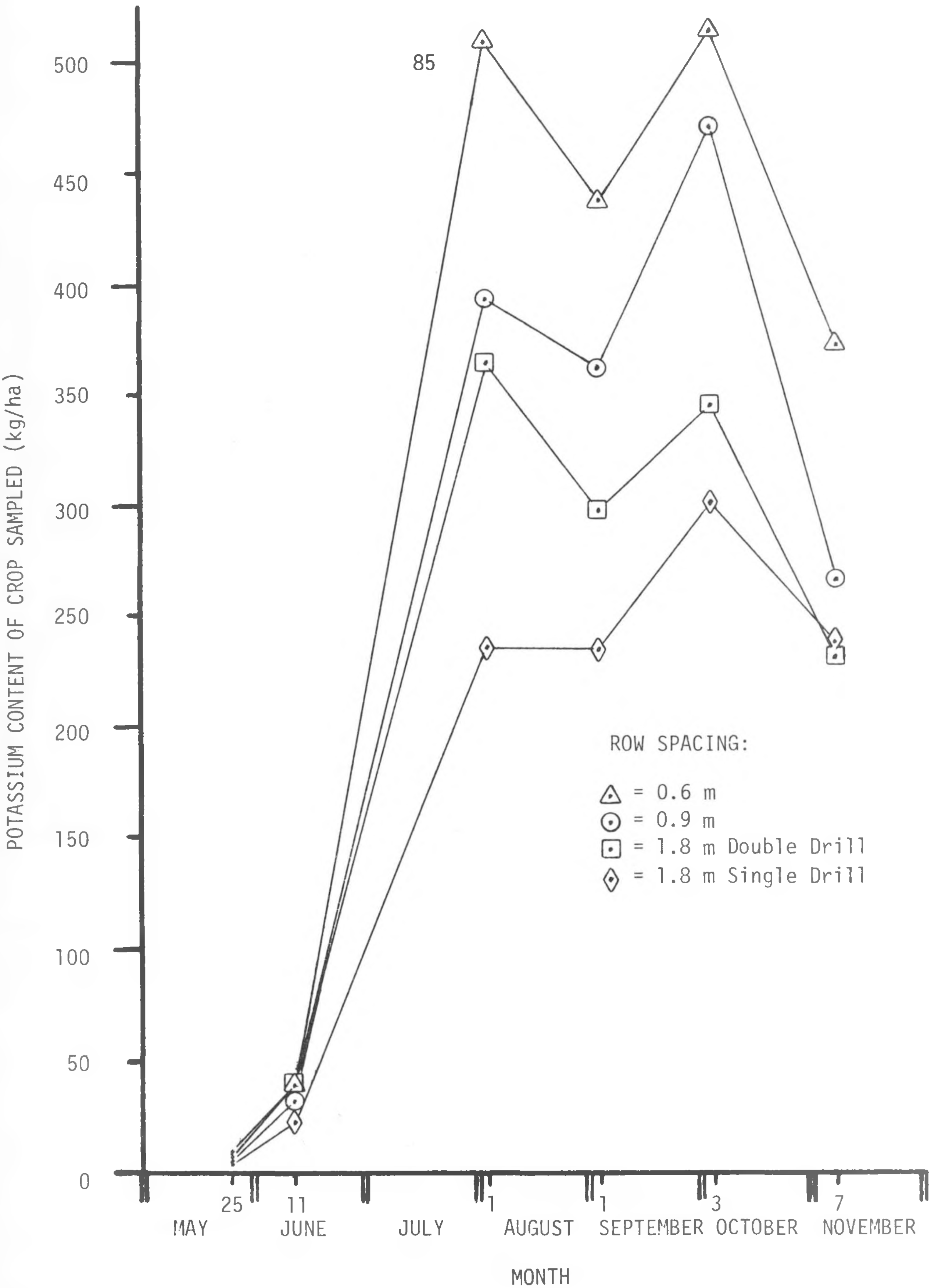

FIGURE III-23. TOTAL POTASSIUM UPTAKE BY SUGARCANE, HOUMA, LA., 1977.

Source: U.S. Department of Agriculture.

TABLE III-3. SWEET SORGHUM HARVEST DATA SUMMARY, 1977

Location	Yields: Total Dry Wt. (t/ha)	Total Sugar[1] (t/ha)	Sucrose[1] (t/ha)
Weslaco, Texas			
Sart - 0.7 m rows	16.9	--	--
- 1.0 m rows	15.9	--	--
Rio - 0.7 m rows	21.7	5.0	4.2
- 1.0 m rows	13.6	--	--
MN 1500 - 0.7 m rows	43.7	8.3	7.0
West Jefferson, Ohio			
Sart - 0.5 m rows	25.6	--	--
Ramada - 0.5 m rows	18.1	--	--
Rio - 0.5 m rows	15.4	--	--
MN 1202 - 0.5 m rows	9.4	--	--
Meridian, Mississippi[2]			
Rio - 0.6 m rows	25.4	5.5	4.6
- 0.8 m rows	25.1	5.5	4.6
- 0.9 m rows	23.4	5.2	4.4
- 1.1 m rows	20.3	4.4	3.7
(2 drills)- 1.1 m rows	24.0	4.8	4.0

[1]Total sugar and sucrose in stalks only. Sucrose yield was calculated as 84 percent of total sugar yield.

[2]Total dry weight equals 35 percent of total fresh yield.

Sources: Texas A & M University, Weslaco, Texas
Battelle Columbus Laboratories, West Jefferson, Ohio
U.S. Department of Agriculture, Meridian, Mississippi.

on narrow 0.7 m rows, matured in approximately 180 days compared to the usual 120-140 days. It yielded approximately 44 metric tons of dry biomass per hectare (Figure III-24). Total sugar yield of MN 1500 was 8.3 metric tons per hectare with a sucrose yield of 7.0 metric tons per hectare (Figure III-25). These yields are approximately double those of sweet sorghum grown with commercial varieties and conventional cultural practices.

MN 1500 developed stalks which were much thicker in diameter than common commercial varieties of sweet sorghum. These thicker stalks appeared to be high in fiber content with a relatively moderate fermentable sugar level.

With the commercial variety, Rio, yields were significantly higher with the 0.7 m row spacing than with the 1.0 m row spacing. The 0.7 m row spacing yielded 21.7 metric tons of dry matter per hectare while the 1.0 m row spacing yielded 13.6 metric tons of dry biomass per hectare. Total sugar yield of the 0.1 m row spacing was 5.0 metric tons per hectare and sucrose yield per hectare reached 4.2 metric tons (Figures III-26 and 27). Both of these values are greater than yields with conventional-row spacings.

Split applications of ammonium nitrate were made to provide 61.6 kg N/ha to the different size areas dictated by the row spacings. As noted in Figure III-28 more nitrogen per unit area was taken up by the narrow-row spaced sweet sorghum; however, the nitrogen level of the plants did not differ significantly. This fact indicates that row spacing has no effect on the efficiency of utilization of nitrogen by the plant. Nitrogen uptake was 75 kg/ha by the conventional 1.0 m row spaced Rio sweet sorghum, whereas the narrow-spaced Rio utilized 137 kg/ha. The narrow-spaced MN 1500 took up 314 kg/ha of nitrogen (Figure III-28). Phosphorus uptake was (Figure III-29) 13 kg/ha by the wide-row Rio variety, 22 kg/ha by the narrow-row Rio variety, and 37 kg/ha by the narrow-row MN 1500 variety. The trend indicated that the removal of phosphorus increased with time as the growth period advanced to maturity. Tissue analyses indicated there were no differences in the phosphorus contents due to varieties or row spacings, and the differences in uptake per unit area were due to different amounts of biomass produced. Plants of the narrow-row spacing removed more potassium than did those of

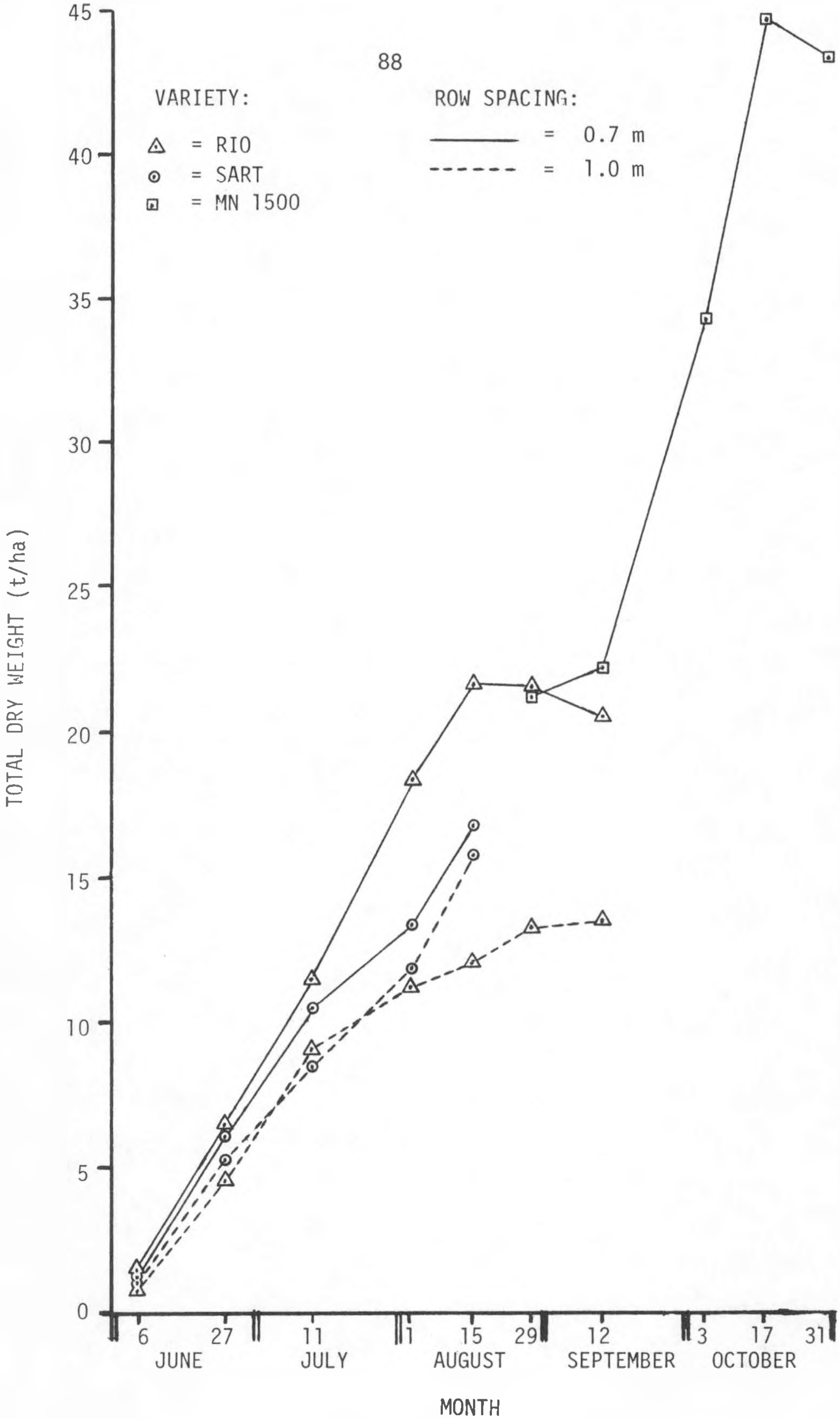

FIGURE III-24. SWEET SORGHUM DRY BIOMASS PRODUCTION, WESLACO, TX., 1977.

Source: Texas A & M Univeristy.

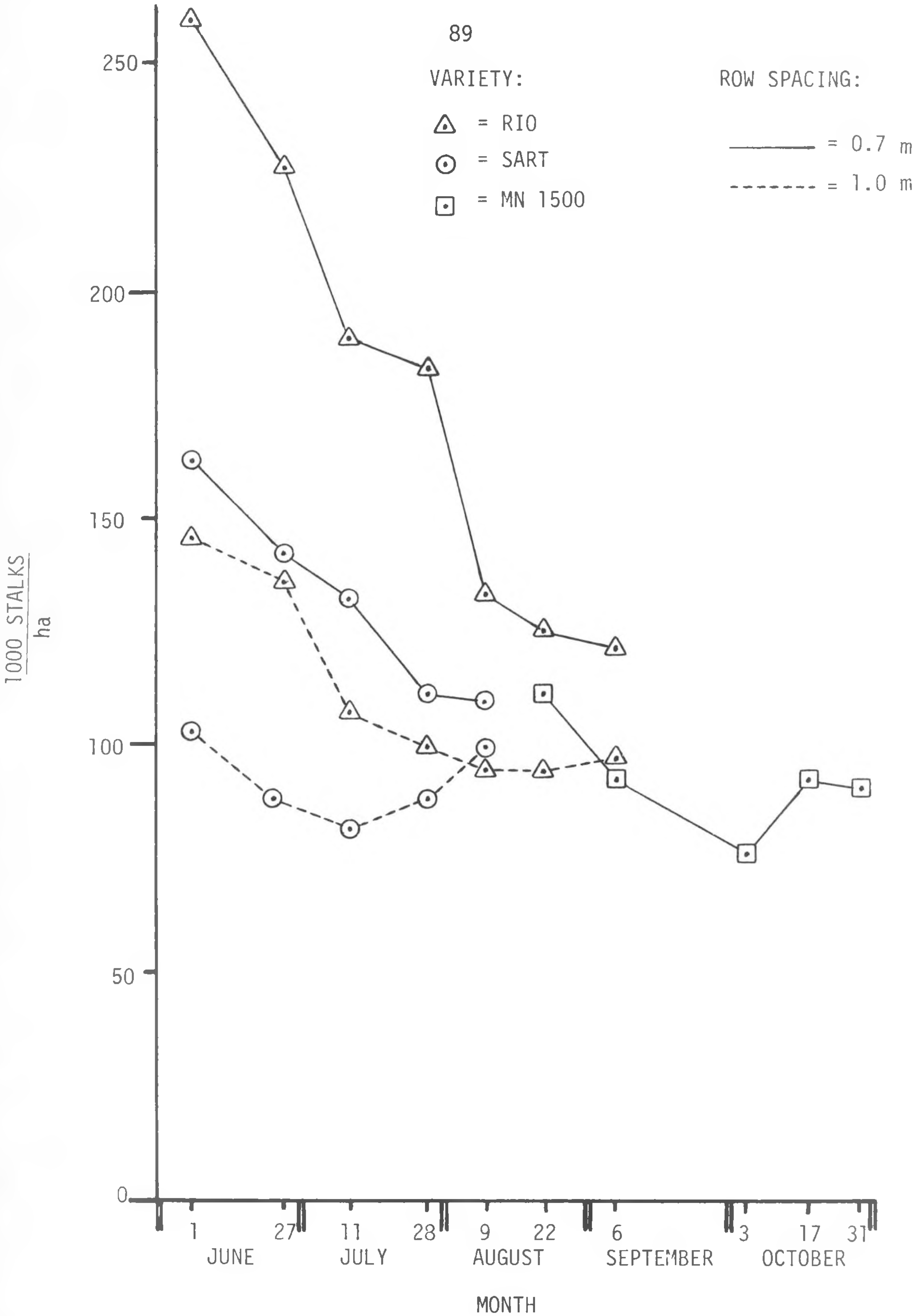

FIGURE III-25. SWEET SORGHUM STALK COUNT PER HECTARE, WESLACO, TX., 1977.

Source: Texas A & M University.

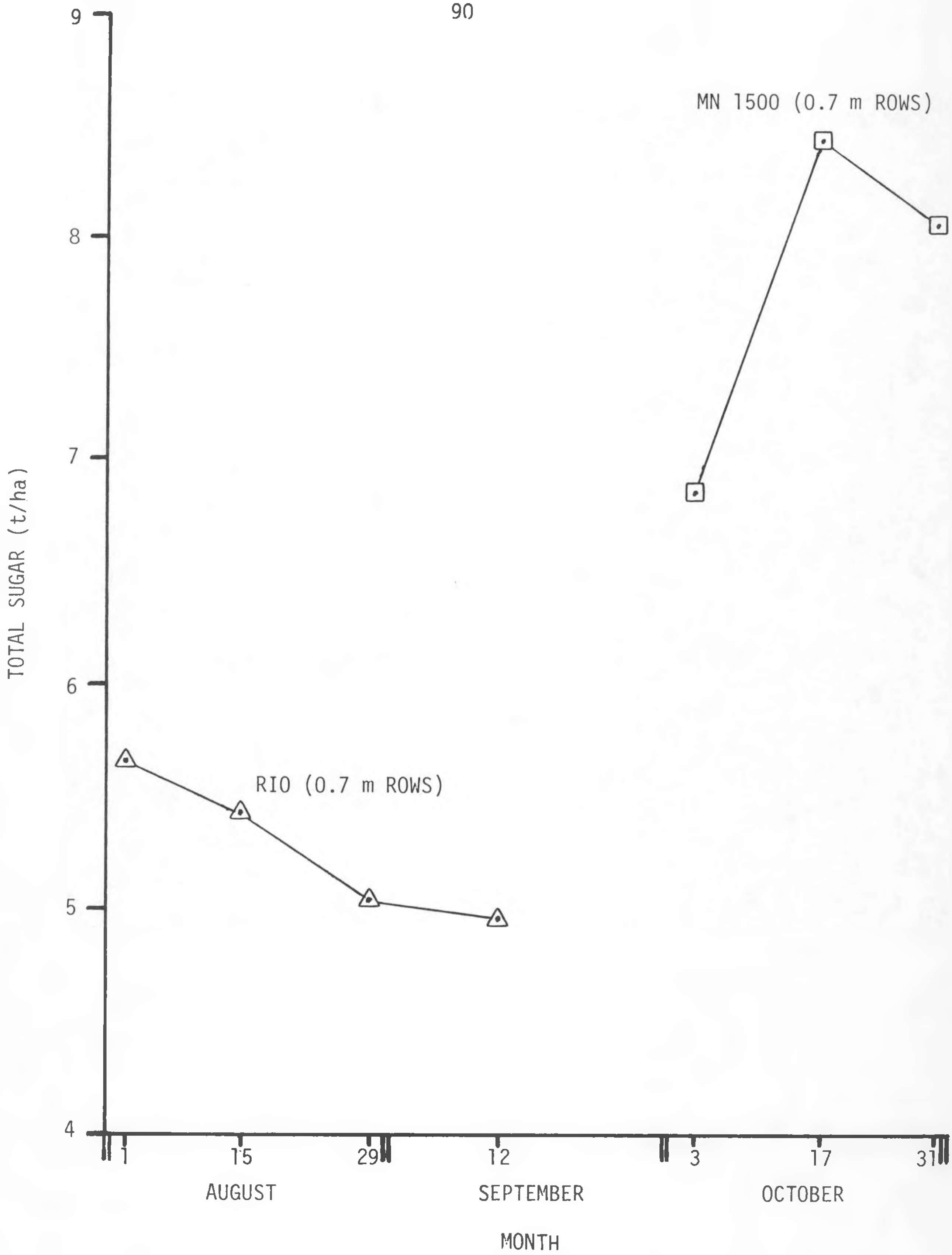

FIGURE III-26. SWEET SORGHUM TOTAL SUGAR PRODUCTION IN STALKS, WESLACO, TX., 1977.

Source: Texas A & M University.

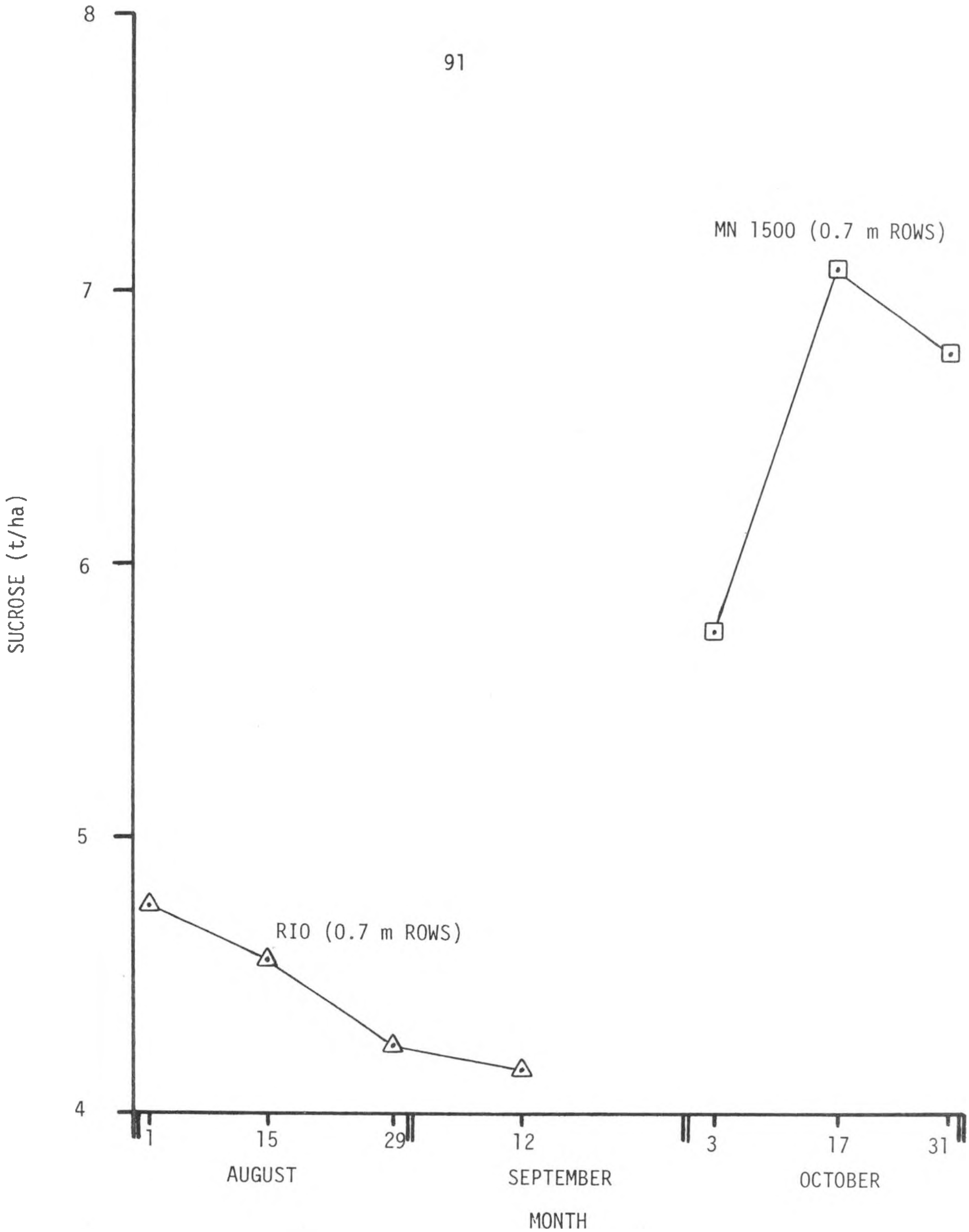

FIGURE III-27. SWEET SORGHUM SUCROSE PRODUCTION IN STALKS, WESLACO, TEXAS, 1977.
(Sucrose yield was calculated as 84 percent of total sugar yield.)
Source: Texas A & M University.

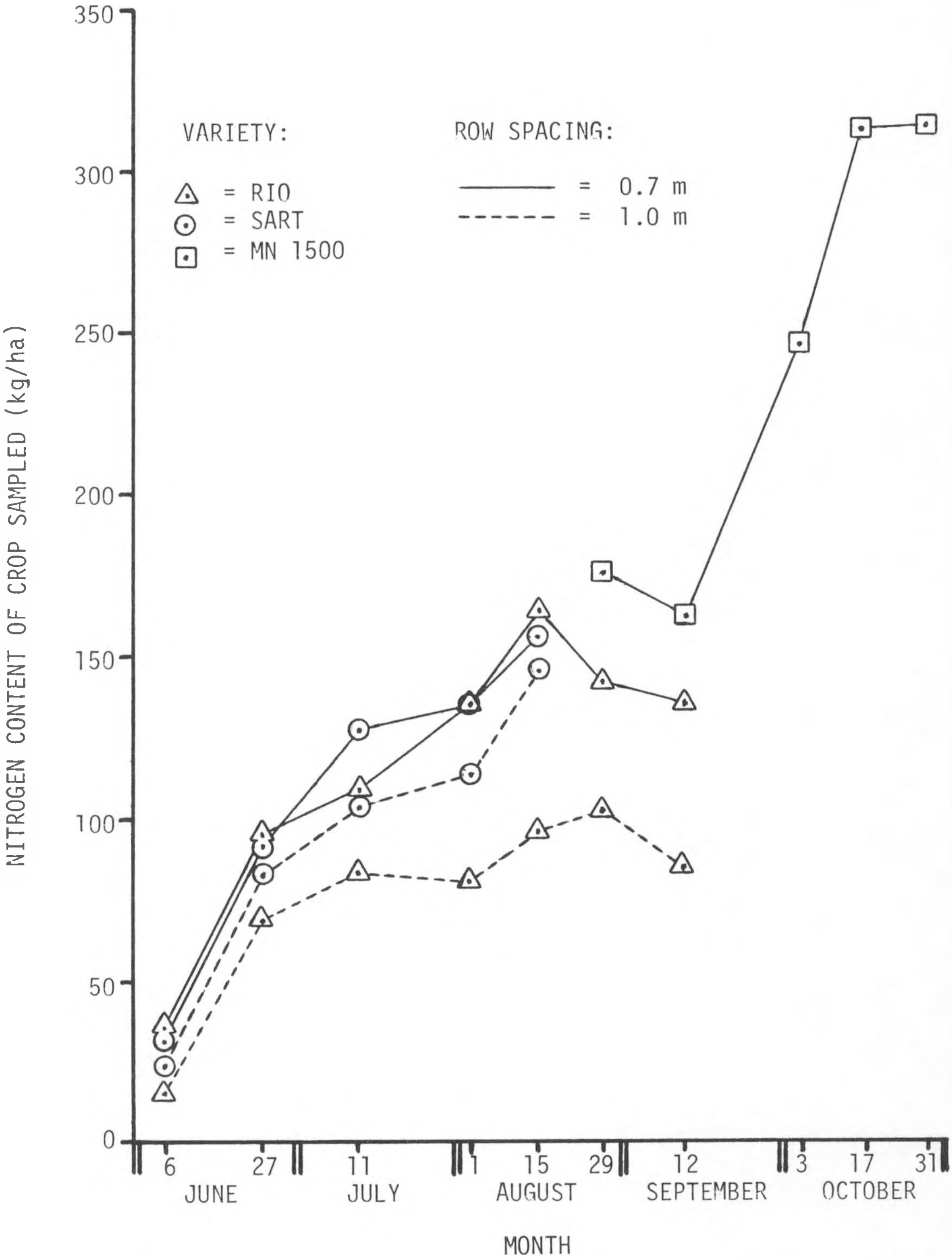

FIGURE III-28. TOTAL NITROGEN UPTAKE BY SWEET SORGHUM, WESLACO, TX., 1977.

Source: Texas A & M University.

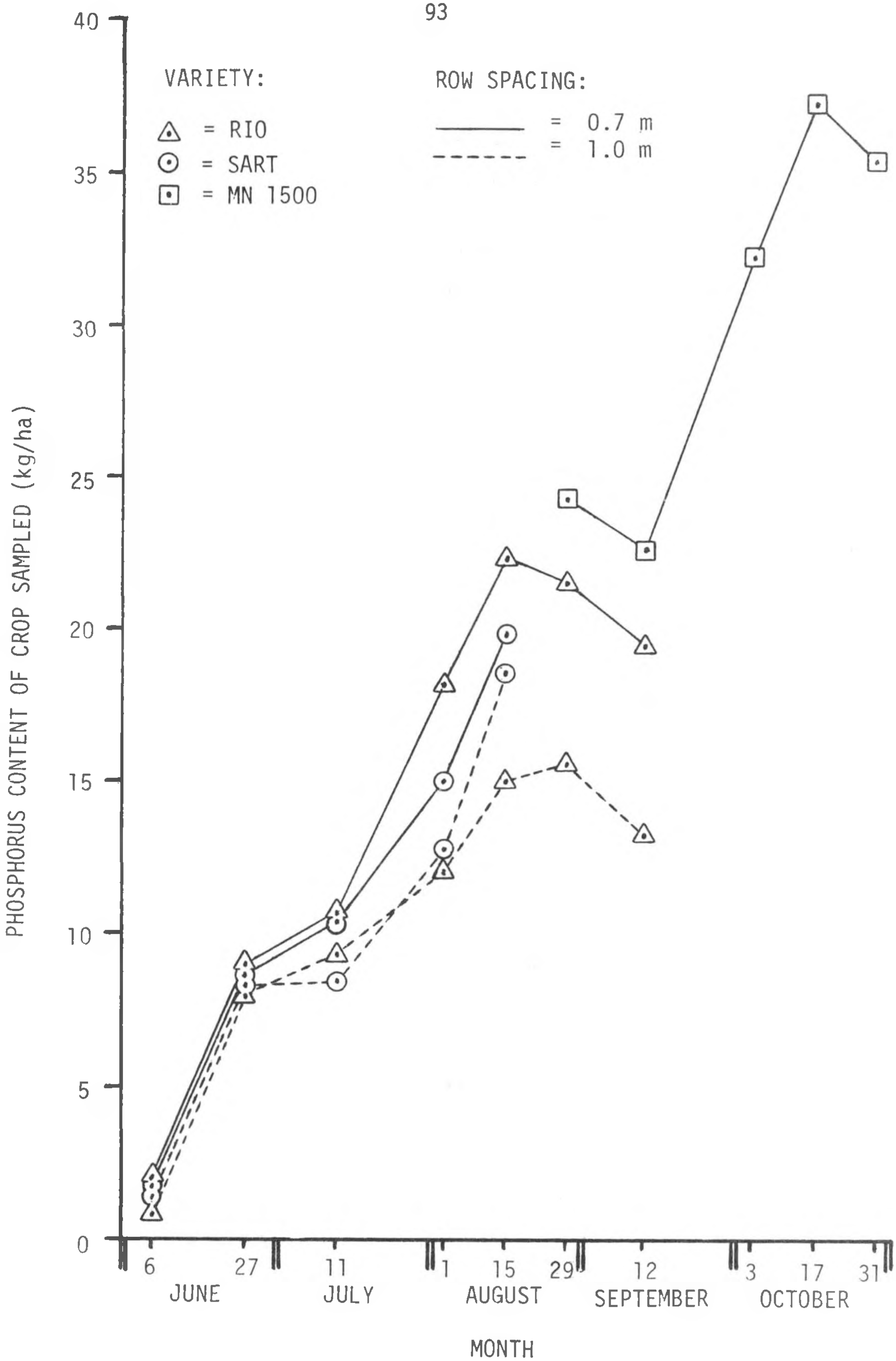

FIGURE III-29. TOTAL PHOSPHORUS UPTAKE BY SWEET SORGHUM, WESLACO, TX., 1977.

Source: Texas A & M University.

the wide rows. The wide-row Rio variety removed 146 kg/ha of potassium, the narrow-row Rio variety removed 259 kg/ha of potassium, while the narrow-row MN 1500 variety removed 515 kg/ha of potassium (Figure III-30). However, treatments had no effect on potassium levels of plant tissues and, like nitrogen and phosphorus, potassium uptake differences between treatments and varieties were due to different amounts of biomass produced.

Baton Rouge, Louisiana

Data regarding sweet sorghum yields as affected by row spacing were also collected in Baton Rouge. The two varieties and planting arrangements demonstrated a tremendous potential for sweet sorghum production in Louisiana. The total dry matter production of the Rio variety was high at both row spacings. A yield of 19.6 metric tons per hectare was achieved with broadcast planting and the double-drill planting on 1.83 m rows yielded 19.5 metric tons per hectare of dry biomass. The variety Meridian 69-13 yielded 19.8 metric tons per hectare when broadcast and 18.4 metric tons when double drilled on a 1.83 m row (Table III-4).

The weather during the growing season was dry in July and August, possibly preventing yields from achieving their full potential. However, the yields from this study approximately double current yield values of conventional-spaced sweet sorghum in Louisiana.

One drawback encountered with the broadcast planting arrangement was that, due to high plant population, interplant competition was increased and thin stalks were produced with both the Meridian 69-13 and Rio varieties.

West Jefferson, Ohio

As stated previously, a demonstration of sweet sorghum biomass production in Ohio was conducted by Battelle's Columbus Division. Averaged random samplings gave the following results. Total dry biomass production at a 0.5 m row spacing was 25.6 metric tons per hectare by the Sart variety, 18.1 metric tons per hectare for the Ramada variety, 15.4

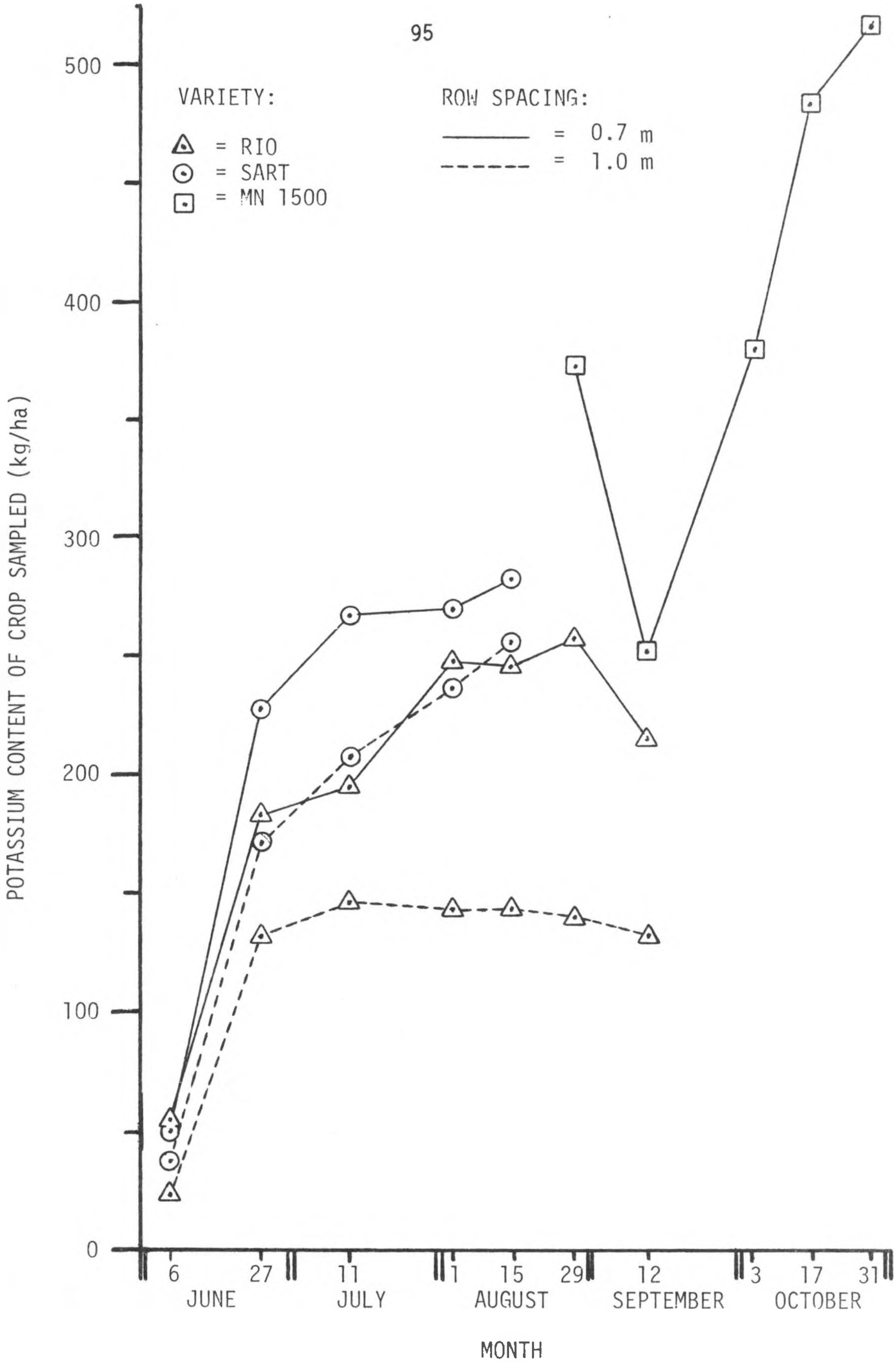

FIGURE III-30. TOTAL POTASSIUM UPTAKE BY SWEET SORGHUM, WESLACO, TX., 1977.

Source: Texas A & M University.

TABLE III-4. SWEET SORGHUM HARVEST DATA, BATON ROUGE, LA., AUGUST 14, 1977

Variety and Treatment	Stalk Count, 1000 Stalks/ha	Total Dry Weight, t/ha
Rio (BC)[1]	145.4	19.6[3]
(DD)[2]	102.3	19.5[3]
Meridian 69-13 (BC)[1]	168.9	19.8[3]
(DD)[2]	99.3	18.4[3]

[1]BC = Broadcast 1.22 meters wide on 1.83-meter rows.

[2]DD = Double drill, planted four plants per hill and hills 0.3 meters apart in drills 0.46 meters apart on 1.83-meter rows.

[3]Calculated using the actual dry weight percentage of fresh weight:

Rio(BC) = 25.1 percent dry matter
Rio(DD) = 23.7 percent dry matter
Mer 69-13(BC) = 22.0 percent dry matter
Mer 69-13(DD) = 20.4 percent dry matter

Source: Louisiana State University, Baton Rouge, Louisiana.

metric tons per hectare for the Rio variety, and 9.4 metric tons per hectare for the MN 1202 variety (Table III-5). These results would indicate that sweet sorghum may be produced in the midwestern United States with reasonable yield levels.

Meridian, Mississippi

Row-spacing trials of the Rio variety were conducted at the USDA Sugar Crops Field Laboratory at Meridian, Mississippi, during 1977 (Broadhead, unpub.). These results have been forwarded to Battelle to present the more complete picture on the effects on narrow-row spacings on sweet sorghum yields. The conventional 1.1 m row yielded 20.3 metric tons of total dry biomass per hectare, while the 1.1 m double-drill treatment yielded 24.0 metric tons, the 0.9 m treatment yielded 23.4 metric tons, the 0.8 m treatment yielded 25.1 metric tons, and the 0.6 m treatment yielded 25.4 metric tons (Table III-6). (All treatments were significantly higher yielding than the conventional planting arrangements.) Yields of total sugars per hectare were significantly higher in all narrow-row spacing treatments when compared with the conventional-row spacing. The 1.1 m row yielded 4.4 metric tons per hectare of total sugars with the double-drill treatment yielding 4.8 metric tons, the 0.9 m treatment yielding 5.2 metric tons, and the 0.6 and 0.8 m treatments yielding 5.5 metric tons. Sucrose yield followed the same trend with the conventional 1.1 m row yielding 3.7 metric tons per hectare, the 1.1 m double-drilled rows yielded 4.0 metric tons, the 0.9 m rows yielded 4.4 metric tons, and the 0.6 and 0.8 m rows yielding 4.6 metric tons per hectare. As with dry matter yields, all sugar yields were significantly higher in the narrow rows when compared with the conventional treatment. Table III-7 shows that row-spacing decreases cause a significant increase in total dry matter production independent of interplant arrangement. In addition, total sugar and sucrose production usually increases with decreasing row spacings.

TABLE III-7. RIO SWEET SORGHUM HARVEST DATA, U.S. SUGAR CROPS FIELD STATION, MERIDIAN, MISSISSIPPI, 1967-1970 AND 1972

Treatment			Results		
Seeds/Hill	Distance Between Hills (m)	Row Width (m)	Total Dry Wt.[1] (t/ha)	Total Sugar Yield (t/ha)	Sucrose Yield[2] (t/ha)
1	0.15	0.5	26.9	4.5	3.8
		1.1	22.0	4.5	3.8
2	0.30	0.5	26.5	5.0	4.2
		1.1	21.8	4.3	3.6
3	0.46	0.5	26.7	5.0	4.2
		1.1	22.0	4.2	3.5
4	0.61	0.5	26.2	4.5	4.0
		1.1	21.6	4.4	4.0

[1]Total dry weight was calculated as 35 percent of gross fresh weight.

[2]Sucrose yield equals 84 percent of total sugar yield.

Source: U.S. Department of Agriculture.

Equipment Aspects of Growing and Harvesting Sugar Crops

When considering the introduction of a new crop production system into a region, many factors must be investigated before the system can be deemed feasible, much less successful. Commercialization of the production of narrow-row sugar crops is dependent upon the ability of the farmer to modify or design machinery which is both efficient and economical.

Land Preparation and Cultural Practices

The first steps in a crop production scheme include land preparation and planting activities. With the introduction of narrow-row spacing of sugar crops, both equipment and techniques must be devised to insure proper seedbed preparation and good stand development.

Interdependency of Cultural Practices and Processing

The goals of production are to increase the potential availability of fermentable sugars and fiber and to reduce the unit cost of these materials. To maximize this efficiency, the agricultural practices and processing must be an integrated system. The decision of which practices should be employed during agricultural production is highly dependent on the choice of processing technology. For example, if the Tilby process is used for stalk rind and pith separation, the stalks processed must display certain characteristics; that is, the cut billets must be relatively straight and must have a certain stalk diameter to be processed by the Tilby separator. If the stalk is too thin, processing cannot occur; therefore, we have a trade-off. To maximize fermentable sugars and fiber production per unit area, we would attempt to plant the crop at very close spacings; however, this would increase our chances of bent, thin stalks being produced (due to lodging and competition). A balance must be struck in that we should maximize production per unit area while maintaining stalks of a certain thickness and straightness.

If the German elevated temperature process is used to extract fermentable sugars from the stalk, no specific stalk morphology is required. Therefore, no processing constraints affect cultural practices.

Close-Spacing Effects on Sugar Crops Cultural Practices

The results from the 1977 Fuels from Sugar Crops Program demonstrates the value of the implementation of narrow-row spacing into sugar crop agriculture. As predicted (Lipinsky et al., 1976), the increase in total biomass production in areas with a long growing season (as in Florida) is minor (but statistically significant), whereas the improvement in biomass production in areas where the growing season is short for sugarcane production (as in Louisiana) is great.

A major obstacle to the commercial production of narrow-row sugar crops is the lack of equipment for major operations. Both design of new equipment and modification of current equipment will be necessary for efficient land preparation, planting, and cultivation of sugar crops on narrow rows.

Currently at Houma, experiments are being conducted and equipment is being developed for seedbed preparation and covering of sugarcane. A modified FMC sidewinder rototiller fitted with bed shapers is being used to open furrows with 0.6 m spacings, or three furrows on a 1.83 m row spacing.

Covering tools vary for each spacing arrangement. The sugarcane planted at the 0.6 m spacing is being covered with a front-mounted hipping ridger. A high clearance Ford 8000 tractor is fitted with auxiliary hydraulic rams, lift arms, and a bracket for a three-point hitch on the front of the tractor. A tool bar is mounted and fitted with rigid 0.46 m single discs spaced on 0.6 m centers. The discs are arranged so that eight 0.6 m rows can be covered at a time. Front-end covering is necessary so the tractor tires do not roll over and crush unprotected seed cane.

Covering the triple drill is done with a set of 2 gauge 0.46 m scalloped discs, supplemented by a pair of single 0.36 m discs set to cover the center drill (Irvine, personal communication). These are mounted on a 1.83 m tool bar behind the Ford 8000 tractor.

Sweet sorghum has fewer problems because seeds are planted, as opposed to whole stalks planted in sugarcane agriculture. However, problems will be encountered when cultivating the young crop. In addition to equipment design and modification, techniques must be designed or modified to facilitate production of narrow-row sugar crops for energy.

Harvesting

New planting techniques developed to increase yields of sugar crops will cause changes in harvesting techniques and equipment. Narrow-row plantings of sugar crops cannot be harvested with current equipment. This problem is compounded by the increase in fresh weight tonnage of the sugar crops and our desire to harvest the whole plant.

Interdependency of Harvesting and Processing

As with other cultural practices, harvesting equipment and techniques are highly dependent on the processing technology employed for juice extraction. If the Tilby process is used for separation of stalk pith and rind and ultimately, juice extraction, then a combine-type harvester is best suited for use. The stalks needed for processing ideally should be approximately 20 to 25 centimeters in length. Currently, combine harvesters are able to cut stalks into those lengths.

Because of the increase in fresh weight tonnage caused by the use of narrow-row spacings, harvesters will have to be designed to be heavy enough to push through the material. This must be accomplished by the use of a design which will avoid destroying sugarcane ratoons and soil compaction due to excess weight.

If the decision is made to perform multiple harvests in one growing season, then a heavier machine may not be necessary because the individual harvests of fresh biomass will not be as large as with the conventional, single-harvest system.

The use of the German elevated temperature process for the extraction of fermentable sugars would have an impact on the harvesting system. Hot water extraction requires that the stalk be cut into pieces approximately 3 to 5 centimeters long to insure complete fermentable sugar removal. In the field, forage-type harvesters are able to cut stalks into those lengths.

The completion of a successful transition of material from field to processing site requires a harvester that fulfills the desires of both the farmer and processor. Future equipment must be designed to achieve maximum efficiency for the integrated energy production system.

Close-Spacing Effects on Sugarcane Harvesting

The results from the 1977 Fuels from Sugar Crops Program demonstrated the value of narrow-row spacing of sugarcane. Production can be greatly increased by the use of narrow-row spacings; however, these results, and the cultural practices used to obtain them, create problems regarding the use of current harvesting equipment and techniques. The first problem arises from the design of the narrow-row spacing. When rows are spaced at 0.6 m or less, the harvester cannot pass through the field without knocking down and crushing stalks of sugarcane. The tires or tracks of the machine destroy rows adjacent to the rows which are being harvested. At Louisiana State University, researchers have maintained the 1.83 m raised-bed row by planting a number of lines of sugarcane on each row (Figure III-31). Interline spacing is 0.3 m, and one through five lines of sugarcane are planted. Even with five lines planted on one row, there is still approximately 0.6 m between rows for the harvester's tires to pass.

The second problem is that tremendous amounts of fresh material accumulate during the season due to the use of narrow-row spacing. Due to the sheer mass of material, it becomes necessary to have a large, heavy machine to cut the sugarcane. For example, conventional soldier-type harvesters (common in Louisiana) are probably too light to be used. It becomes difficult for the harvester to stay on the row while cutting.

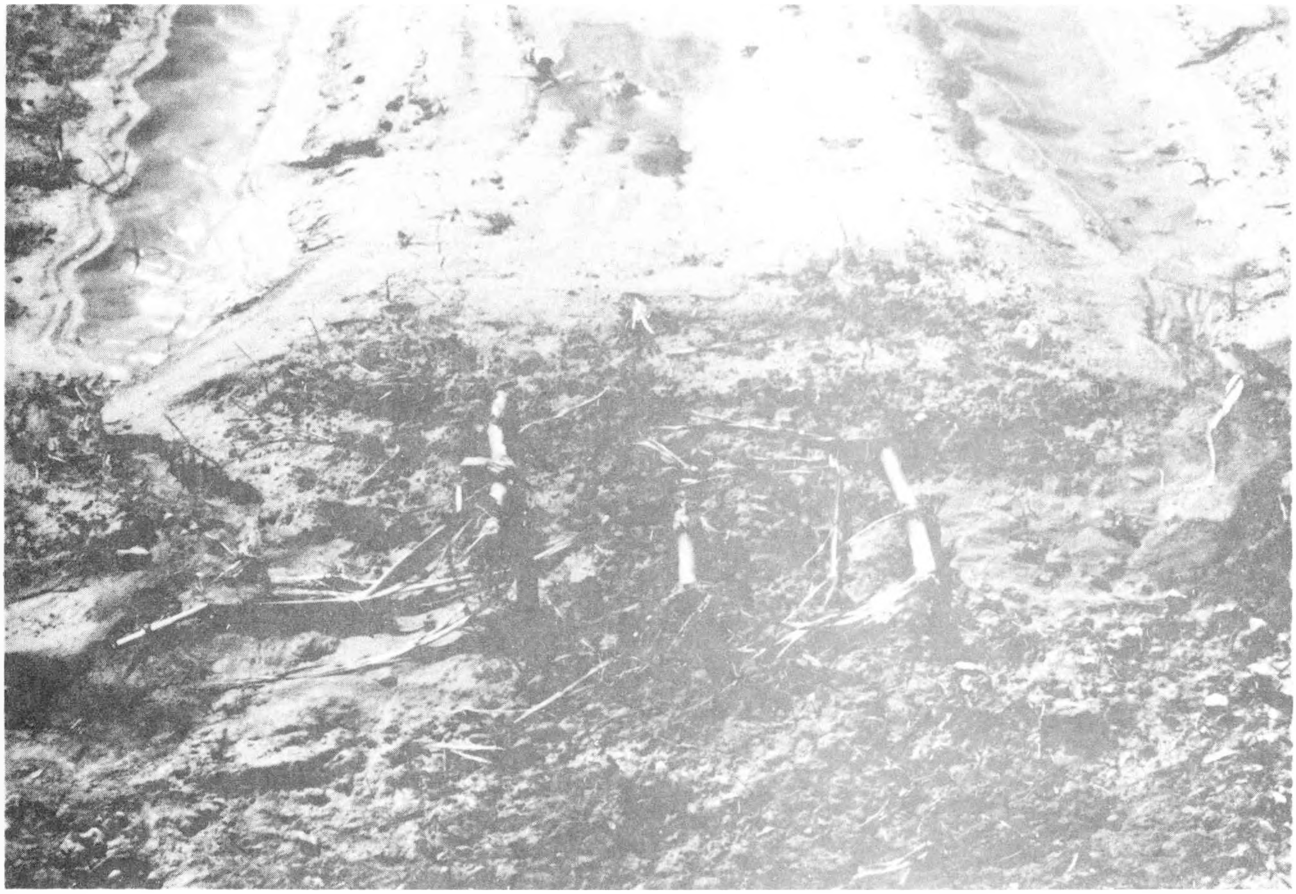

FIGURE III-31. A MODIFIED, CONVENTIONAL-ROW SPACING TESTED AT LOUISIANA STATE UNIVERSITY, THIS PLANTING ARRANGEMENT USES A FLAT BED WITH THREE LINES OF CANE AS OPPOSED TO THE CONVENTIONAL ONE LINE PLANTING ON A V-SHAPED BED.

The use of massive sugarcane harvesters is not the solution. Massive machines tend to increase soil compaction, especially during wet weather. A compromise must be arranged where harvester cutting efficiency remains high, while machine weight is kept as low as possible.

The third problem has been created by the use of the multiple lines of cane on wide beds. Due to the large number of stalks produced on the wide bed, a single blade soldier-type harvester is inefficient at cutting the cane. The effective cutting edge of the single blade is too narrow to cut all of the stalks on the bed. The Louisiana State University research team has modified a conventional soldier-type harvester by adding another cutting blade. With two blades, the equipment is very efficient at cutting the material. In addition, combine harvesters also are very efficient at harvesting a number of lines of sugarcane on a wide bed.

Forage-Type vs. Conventional Sugarcane Chopper Harvesters

Many approaches are now being taken to determine what type of harvester would operate most efficiently on narrow-row spaced sugarcane. Modification of currently used equipment is an approach which may be more economical to farmers than, perhaps, to design a completely new piece of equipment. However, some problems, such as crushing narrow rows of sugarcane or selective separation of plant parts, may require the design of new equipment.

This section is included to point out the advantages and disadvantages of the forage-type harvester and the conventional sugarcane chopper harvester when employed to harvest narrow-row sugarcane. The primary advantage of a forage-type harvester is its cost. A typical forage harvester costs $60,000-$80,000, whereas a conventional sugarcane chopper harvester costs approximately $160,000 - $180,000 (J. Clayton, personal communication). Therefore, when it becomes necessary to purchase equipment to harvest narrow-row cane, a forage harvester is more economically accessible to the farmer. If the Tilby process is used to extract juice, a forage harvester would need modifications to cut a larger size billet; however, if the German elevated temperature process is used to extract sugarcane juice, then the smaller, 3- to 9-centimeter long section of stalk, which the forage harvester produces, would be more desirable. A major disadvantage of the forage harvester is its lightness. Due to the large increases of fresh biomass produced with narrow-row spacing, it appears that a forage harvester would lack the weight and power to harvest large amounts of sugarcane. On the other hand, if the practice of multiple harvests of sugarcane in one season proves feasible, then a modified forage harvester could be highly satisfactory.

The conventional sugarcane chopper harvester has a number of advantages. First, if the Tilby process is used in juice extraction, the chopper harvester cuts stalks in the proper size to be processed. Second, the chopper harvester is both powerful and heavy enough to harvest the additional biomass which is produced by the implementation of narrow-row spacing. Problems incurred with the use of the chopper harvester are that, due to its weight, soil compaction is more likely and harvesting in inclement weather is difficult.

In summation, both pieces of equipment have definite advantages and disadvantages. Future use depends on the development of other agricultural and processing practices. Both will need modifications to selectively separate plant parts, i.e., tops, leaves, and stalks. Possibly, a new piece of equipment will be designed to incorporate valuable characteristics of both types of harvesters. The choice of harvesting equipment is an integral decision to the successful commercialization of sugarcane production for energy.

Green Cane Harvesting

With conventional sugarcane agriculture, a common practice prior to harvesting is the burning of the sugarcane field. This action removes much of the "trash" from the stalk without damaging it. The reasons for sugarcane burning are: (1) higher harvesting efficiency, (2) lower transportation costs since tops and leaves do not contribute to sucrose production, and (3) more efficient sugarcane milling and juice extraction result with a minimum quantity of tops and leaves.

With the increase in biomass production per unit area caused by the implementation of narrow-row spacings, it may seem initially advantageous to burn the crop in the field in order to increase harvesting efficiency. This may be a misconception. Green cane harvesting has a number of advantages. Initial attempts at green cane harvesting were a short-term response by a farmer in an effort to harvest cane when weather conditions prevented burning. When considering sugarcane production for energy, the burning of "trash" is a wasteful act. To decrease costs of energy production, the leaves and tops should be collected and transported to the mill to be used as fuel source for direct combustion. In addition, if some green material were left in the field, an improvement in soil structure would occur. Improved water-holding capacity, better infiltration, better aeration, and increased fertility would result.

Obviously, the engineering and economic aspects of green cane harvesting must be studied. However, the production potential of an agricultural system should not be limited by engineering constraints. It appears more desirable if the equipment and techniques employed in agriculture are developed to support biological potential, as opposed to fitting the production system to the equipment and techniques available. In an efficient ecological system, no waste occurs; agricultural systems must strive for that end.

Controlled Harvesting of Whole Plants vs. Millable Stalks

Current sugarcane harvesting equipment and techniques are designed to efficiently cut and collect the millable stalks. Producers and processors are concerned with the maximization of sucrose per unit area. No regard is given to other plant parts, specifically leaves and tops. Presently, leaves and tops are burned in the field to make harvesting and processing activities easier. Commercial harvesters are not as effective at harvesting green stalks as they are at harvesting burned stalks. No commercial harvester has been designed to selectively separate plant parts, which would be necessary if burning is prohibited.

When considering sugarcane as a raw material for energy production, controlled whole-plant harvesting appears to be a valuable alternative. If the sugarcane plant could be mechanically, selectively separated, energy production would become more effective. Sugarcane leaves could be transported to the mill and used as a fuel for direct combustion. Possibly, the tops could be collected and used as an animal feed or fuel. These parts could be sold and used as a co-product credit for energy production from sugarcane.

Before integration of whole-plant harvesting systems into sugarcane agriculture, both engineering and economic inputs are required. Initially, these systems would be more expensive to purchase than current sugarcane chopper systems. However, with additional salable products, the purchase of a whole-plant harvesting system may return more income to the producer than the conventional system. Engineering and design questions always arise from the development of a new harvesting system, but none of these appear to create roadblocks to progress. Selective, controlled whole-plant harvesting, along with green cane harvesting should be thoroughly researched if energy production from sugarcane is to become an economic reality.

Harvesting Sweet Sorghum Seed

Sweet sorghum harvesting methods vary from strictly hand-harvesting to fully mechanized, depending largely on the amount of land cultivated and on local customs. Seedheads are usually removed by hand or machine before milling. Some growers use modified silage harvesters to cut the stalks into 10- to 20-centimeter sections. Seeds and leaves are pneumatically separated while the stalk sections are being conveyed to a trailer body.

Seeds are a valuable co-product of sweet sorghum. An average yield of seed is approximately 2.5 metric tons per hectare. The processed ground seeds of sweet sorghum have 92 to 94 percent of the feed value of corn. However, many farmers are concerned only with topping the stalks and care little about seed collection.

Future sweet sorghum production systems must consider efficient ways of harvesting and collecting seed. These techniques may include a modified threshing system for seed collection along with a stalk harvesting system. Sequentially, the seedhead could be cut and collected, followed by stalk harvest. Another avenue would be to develop a method for simultaneous collection of seeds and stalks. The engineering know-how is available, but the economics of alternative systems must be determined. Sweet sorghum has tremendous potential as both an energy and feed crop if methods are developed to efficiently use all plant parts.

Detrashing of Sweet Sorghum

Many subtle differences exist between sugarcane and sweet sorghum which go unforeseen in many instances. However, these differences have a profound effect on the mechanized aspects of production.

Sweet sorghum has a large quantity of high moisture material which prevents efficient burning. Sweet sorghum billets are smaller in diameter and lighter than sugarcane billets; sweet sorghum leaves are wrapped tightly around the stalk. Thus, pneumatic separation of leafy trash from sweet sorghum billets may not be feasible (Ruff et al., in press).

Because of the difference in yields between sugarcane and sweet sorghum, the capacity and ground speed of the sugarcane harvesters must also be considered if they are used for sweet sorghum. Equivalent harvesting capabilities in the two crops can be obtained by increasing either the cutting width of the harvester or its ground speed in sweet sorghum (Ruff et al., in press). Combinations of a forage harvester head mounted on a sugarcane harvester have produced a satisfactory billet, but detrashing was poor. Future work must address this problem if the potential of sweet sorghum as an energy crop is to be achieved.

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IV. CROPLAND DEVELOPMENT

Factors Affecting Potential Cropland Development

Land resources are sometimes thought to be a free gift of nature. However, in its natural state, land is seldom ready for immediate use as a productive resource. Before acquiring much economic value, land must usually be processed or developed through application of capital and labor.

Land resource development decisions are characterized by a concern about economic productivity over time. Resource developers like to make certain that the time has "arrived" for their developments--i.e., that there is a ready market for their products (Barlowe, 1972). The development of new lands for sugarcane production to manufacture chemicals or fuels also falls into this category. Developers have an interest in potential product (fuels, chemicals, and sugarcane) prices and probable future levels of demand, since these factors will influence total expected returns. Costs must be kept within reasonable limits so that projects will pay off and so that reasonable returns can be expected both to the land factor and to managerial inputs. Land resource development will not proceed unless a gross benefit is anticipated that equals or exceeds the expected costs.

The first costs to be considered in bringing new land into production are the costs of conversion, i.e., clearing the land of unwanted vegetation, installation of drainage systems, and (at least in the Rio Grande Valley of Texas) installation of an irrigation system. Once the land has been readied for the first crop, the question of potential productivity and production costs must be considered. The productivity and production costs will determine the potential net profit per hectare. The anticipated net returns from sugarcane production for energy or chemicals presumably must be competitive with alternative crops that might be grown on the land, such as soybeans, cotton, vegetables, grain sorghum, etc.

Subsequent sections of this chapter will examine land availability for sugarcane production in the continental United States, and cropland activities and costs necessary to bring new land into sugarcane production. Some preliminary calculations of minimum sugarcane prices and yields required to pay for the costs of land conversion will be described. A description of "most likely" areas to be brought into sugarcane production, including current land use, elevation and topography, climate, water availability and soil characteristics, also are presented in Appendix A.

Land availability for sweet sorghum production is not specifically included in this discussion. Due to the nature of the crop, sweet sorghum can be grown over wide geographic regions in the United States, from the Gulf Coast to Minnesota. Although some land not currently devoted to row crops may be brought into production for sweet sorghum, much sweet sorghum is likely to be grown on land currently devoted to corn, soybeans, small grains, cotton, and other crops, if the grower returns are competitive with existing crops. Depending on the production economics (see Chapter V), the amount of land devoted to sweet sorghum could range from a few hundred thousand to several million hectares.

Land Availability for Sugarcane Production

In Volume II of the first Battelle study on "Fuels from Sugarcane, Sweet Sorghum, and Sugar Beets", some of the factors playing an important role in sugar crops area selection were identified (Lipinsky, et al, 1976). Some of these key factors are:

(1) Temperature patterns
(2) Water availability and water quality
(3) Weather hazards
(4) Existing land use patterns
(5) Terrain
(6) Soils
(7) Proximity to existing mills or good mill sites
(8) Latitude, day length, and other factors relating to photoperiod
(9) Environmental considerations.

Land Resource Areas

This section of the report seeks to identify the areas in Texas, Louisiana, and Florida "most likely" to be brought into sugarcane production in a fuels from biomass program (see pages 37 to 43 for other information on site selection). The most likely areas (shown in Figure IV-1, along with identification of land resource areas) are based on temperature, potential water availability, and proximity to existing sugarcane production regions (Lipinsky, et al, 1976). The designated areas in Texas and Florida generally will have more than 300 days of frost-free temperatures annually. The frost-free period in the designated Louisiana area is approximately 240 or more days. The area potentially capable of growing sugarcane in Texas might be enlarged considerably if irrigation water could be provided. However, Battelle took a conservative approach and included only the region in the Rio Grande Valley and along the Gulf Coast of the state.

Nine different land resource areas are shown within the potential area of sugarcane production in Figure IV-1. A description of the land use, elevation and topography, climate, and water availability in each region is presented in Table IV-1. More detailed information is presented in Appendix A.

Table IV-2 indicates the quantity of land used for various purposes in each of the nine potential sugarcane growing regions. These data are based upon recently released information from the 1974 Census of Agriculture. Based on the patterns shown in Figure IV-1, BCD estimated the total area within each region and the amount of cropland, woodland, and other land contained.

The estimated total area in the entire region of "potential" sugarcane production is approximately 20.5 million hectares. Roughly 10 million hectares of this area is classified as land in farms; out of the 10 million hectares, approximately 3.2 million hectares is cropland that is either harvested or used for pasture, slightly less than 1 million hectares is woodland, and approximately 5.9 million hectares is "other land in farms". Within the category "cropland harvested or used for pasture", approximately 800,000 hectares is pastureland. Cropland used

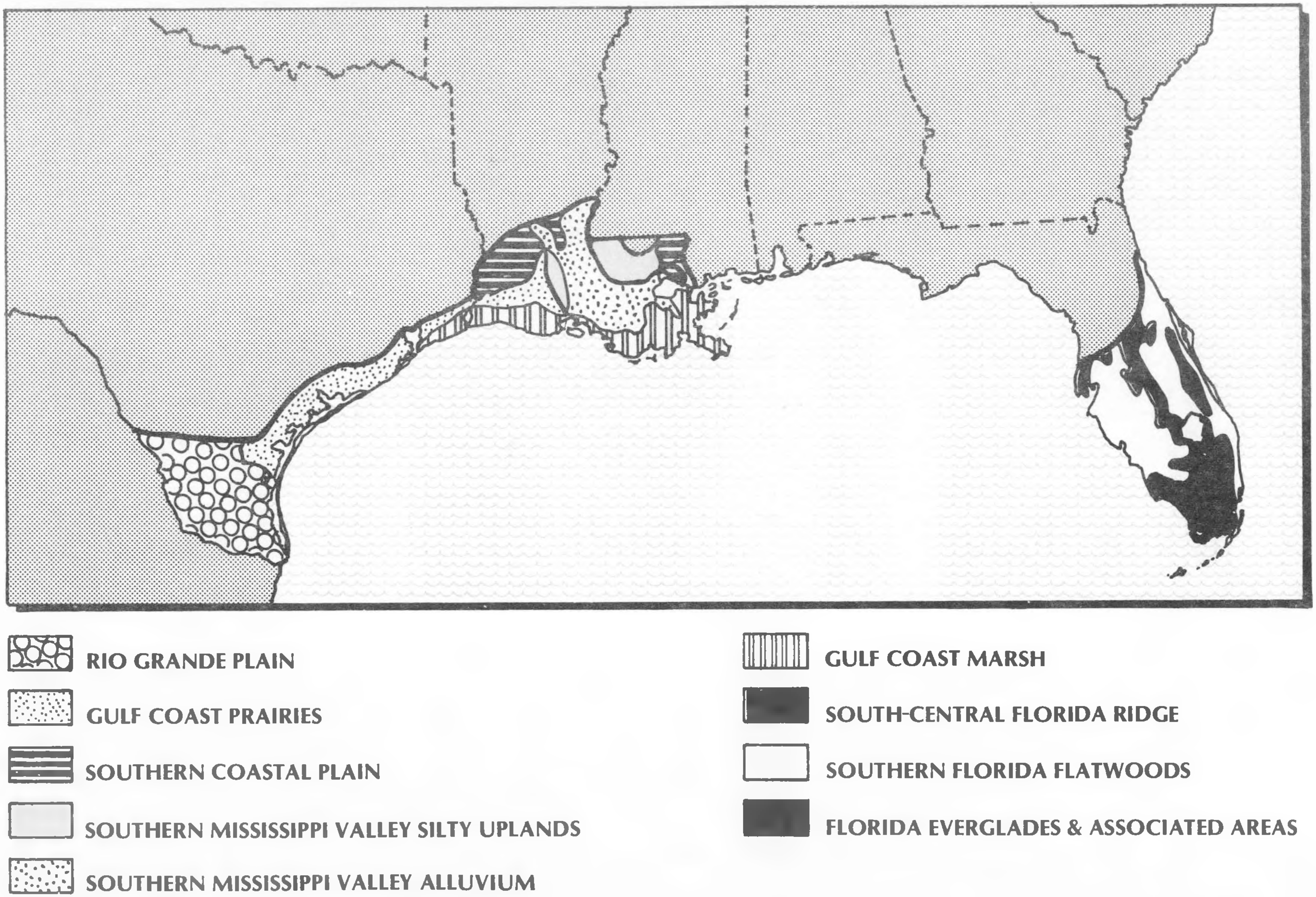

FIGURE IV-1 MAJOR LAND RESOURCE AREAS WITHIN POTENTIAL REGIONS OF SUGARCANE PRODUCTION

TABLE IV-1. LAND RESOURCE INFORMATION FOR NINE SELECTED REGIONS

Region	Present Land Use	Elevation, meters	Topography	Precipitation, millimeters	Average Temperature, Centigrade	Freeze-Free Period, days	Water
Rio Grande Plain, Texas	Farms & ranches	Sea level-304.8	Level to undulating	508-889	21.1	280-320	Abundant ground water & Rio Grande River
Southern Mississippi Valley Alluvium	Farms	Sea level-152.4	Level to gently sloping	1,143-1,651	14.4-21.1	200-280	Abundant rainfall, ground water, lakes, bayous, Mississippi R.
Southern Coastal Plain	Farms	30.48-182.88	Gently to strongly sloping	1,016-1,524	15.5-20.0	260-280	Abundant rainfall, ground water
Southern Mississippi Valley Silty Uplands	Farms	30.48-182.88	Extremely varied	1,169-1,524	15.4-20.0		Abundant ground water
Gulf Coast Prairies	Farms	Sea level-60.96	Level	635-1,397	20.0-21.1	280-320	Abundant ground water; perennial streams
Gulf Coast Marsh	Hunting, fishing, trapping	Sea level-1.52	Level	1,397-1,651	21.1	280-300	Flooding
South Central Florida Ridge	Forests	15.24-45.72	Level to gently rolling	1,270-1,448	21.1-23.3	300-350	Abundant ground water; lakes
Southern Florida Flatwoods	Privately owned; forests; pastures	Sea level-30.48	Level	1,270-1,524	21.1-23.9	300-365	Abundant ground water
Florida Everglades & Associated Areas	Indian reservations; parks; forests	Sea level-7.62	Level	1,270-1,626	22.2-23.9	335-365	Abundant flood control practices

SOURCE: Land Resource Regions and Major Land Resource Areas of the United States, Agriculture Handbook No. 296, U.S. Department of Agriculture, 1972

TABLE IV-2. LAND USE IN POTENTIAL REGIONS OF SUGARCANE PRODUCTION, 1974

(1000 hectares)

Land Resource Area and State Where Located	Estimated Total Area	Total Cropland Harvested or Used for Pasture	Woodland	Other Land in Farms[a]
Rio Grande Plain (Texas)	3,380	760	70	2,345
Gulf Coast Prairies (75% Texas, 25% Louisiana)	2,690	705	80	870
Southern Coastal Plain (5% Texas, 95% Louisiana	2,005	235	125	105
Southern Mississippi Valley (Louisiana) Silty Uplands	690	230	60	75
Southern Mississippi Valley (Louisiana) Alluvium	2,185	380	85	110
Gulf Coast Marsh (15% Texas, 85% Louisiana)	2,350	175	55	305
South-Central Florida Ridge (Florida	1,275	150	65	225
Southern Florida Flatwoods (Florida)	3,765	420	335	1,310
Florida Everglades and (Florida) Associated Areas	2,145	185	100	510
Total	20,485	3,240	975	5,855

Source: Calculated by Battelle from Austin, M. E., Land Resource Regions and Major Land Resources Areas of the United States and Census of Agriculture, 1974, U.S. Department of Commerce.

(a) Includes pastureland and rangeland other than cropland and woodland pasture, and house lots, farm lots, ponds, roads, wasteland, etc.

for pasture plus woodland equals approximately 1.8 million hectares; this compares to approximately 250,000 hectares of sugarcane currently being produced in these three states. If, for example, the current area devoted to sugarcane production were to be doubled, it would take approximately 6 percent of the total cropland and woodland area of 4.2 million hectares.*

The largest quantity of agricultural land is contained in the Rio Grande Plain (Texas), the Gulf Coast Prairies (primarily Texas, with a small quantity in Louisiana), and the southern Florida flatwoods are (Table IV-3). Combined, these three areas account for 58 percent of the total cropland harvested or used for pasture, 50 percent of the total woodland, and 77 percent of all other land in farms contained in the nine regions. For sugarcane production, irrigation would be necessary in the Rio Grande Plain and part of the Gulf Coast Prairie regions.

Wet Lands

An important consideration in considering the potential future production of sugarcane is the large areas in Florida and Louisiana that are classified as natural wet lands. Wet lands include swamps, marshes, bogs, and other places where the land surface usually is covered to some extent by water. These lands generally are productive fish and wildlife habitats. There is concern in some circles that these wet lands are unappreciated by land developers and home owners as being a desirable part of the community and environment. Warren (1977) indicates that without protection many of these critical wet land areas are destroyed. He indicates that south Florida has lost 25 percent of its wet lands in

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* Approximately one-half of the total area within the potential region of sugarcane production is classified as non-agricultural land. This includes urban areas, state and national parks, and land held by corporations for non-agricultural purposes. For example, in Louisiana, a considerable amount of timberland is owned by companies engaged in pulp and paper manufacturing.

TABLE IV-3. LAND USE IN POTENTIAL REGIONS OF SUGARCANE PRODUCTION, AS PERCENTAGE OF TOTAL AREA, 1974

Land Resource Area and State Where Located	Estimated Total Area, 1000 hectares	Cropland Harvested or Used for Pasture, percent	Woodland, percent	Other Land in Farms, percent	Land Not in Farms, percent
Rio Grande Plain (Texas	3,380	22.4	2.1	69.4	6.1
Gulf Coast Prairies (75% Texas, 25% Louisiana)	2,690	26.1	3.0	32.4	38.5
Southern Coastal Plain (5% Texas, 95% Louisiana)	2,005	11.7	6.2	5.4	76.7
Southern Mississippi Valley Silty Uplands (Louisiana)	690	33.4	8.8	10.6	47.2
Southern Mississippi Valley Alluvium (Louisiana)	2,185	17.4	4.0	4.9	73.7
Gulf Coast Marsh (15% Texas, 85% Louisiana	2,350	7.5	2.3	13.1	77.1
South-Central Florida Ridge (Florida)	1,275	11.7	5.2	17.6	65.5
Southern Florida Flatwoods (Florida)	3,765	11.1	8.8	34.9	45.2
Florida Everglades and Associated Areas (Florida)	2,145	8.5	4.7	23.7	63.1
TOTAL	20,485	15.8	4.8	28.6	50.8

Source: Calculated from Table IV-2.

the last 20 years and that Louisiana's wet lands also are decreasing rapidly. Often, the wet lands are dredged and filled for housing tracts, shopping centers, pastureland, marinas, or waterways.

The 1972 Federal Water Pollution Control Act established protection of these wet lands as an integral part of the national water system (Warren, 1977). Currently, there is Congressional debate over the extent of federal protection of these lands, with the House having recently passed an amendment removing federal protection from almost all inland wet lands. The Senate, however, along with President Carter, supports continued protection of the wet lands.

The ultimate resolution of the degree of protection extended to wet land regions could be an important factor affecting the development of large areas for sugarcane production in Florida and Louisiana. Strong protective measures would certainly reduce the amount of new land that might be considered suitable for sugarcane production.

Cropland Development Activities and Costs

Several activities are involved in bringing new land into sugarcane production. There are basically three types of operations necessary to prepare land for the first crop. These include land clearing, installation of drainage systems, and installation of an irrigation system where rainfall is not sufficient to sustain optimum sugarcane growth.

Land clearing costs vary according to location and depend upon the type of soil (clay or sand), kind and size of tree cover, general characteristics of the terrain (flat or hilly), amount of drainage required, and to a lesser extent, labor costs.

Land is usually cleared on a per hectare or a per hour contract basis by a local contractor who uses a crawler tractor equipped with a special V-shaped blade. Trees and brush are sheared off slightly below ground level. Another crawler tractor or bulldozer fitter with a raking blade piles the cut trees into windrows and stirs and repiles them as they are burned. The remaining small chunks of wood are picked up by hand or by a special rake attached to a farm tractor. The land must be left clean of debris or these pieces will invariably cause breakdowns in farm equipment, such as cane harvesting machinery (Davis, 1972).

Construction of surface drainage ditches, where required, is done either with a drag line or with a bulldozer, depending upon the circumstances. Not all land that is cleared requires drainage. However, most wet land in the potential sugarcane growing regions would have to be drained.

The following sections provide information on land clearing, drainage, and irrigation system costs for Florida, Louisiana, and the Texas regions (see again Figure IV-1). Sources of information include land clearing contractors, large equipment companies, U.S. Soil Conservation Service personnel, and university and USDA agricultural engineers, agronomists, and agricultural economists. Where necessary, additional information is presented in Appendix B.

Florida

Current estimated costs of clearing land, plus installation of a water control system,are estimated to range from $480-$670 per hectare in Florida. These costs are based upon an update of information contained in two studies of establishing land for cattle raising operations in southern and central Florida. Anderson and Hipp (1974) indicate bulldozer costs and rotovator costs in land clearing of $25 and $62 per hectare, respectively, in 1974. Currently, based on an inflation factor of 1.95, these costs would be approximately $49 per hectare for a bulldozer and $121 per hectare for a rotovator. An additional charge of approximately $27 per hectare for use of a tractor and a disc also would be incurred. Therefore, the total estimated cost of land clearing in the flatwoods soil region of Florida is approximately $197 per hectare (Table IV-4).

Anderson and Hipp (1974) indicate that the cost of installation of ditches, culverts, wells, drains, and pumps would approximate $145 per hectare in 1973. Based on current costs, this figure is estimated to jump to approximately $283 per hectare. Therefore, the total cost of

TABLE IV-4. ESTIMATED COSTS PER HECTARE OF LAND CLEARING AND WATER CONTROL SYSTEM INSTALLATION IN FLORIDA, 1978

	Soil Type	
	Flatwoods	Organic
	$/Hectare	
Land clearing	197	223
Ditches, culverts, drains, and pumps	283	300
TOTAL	480	523

Source: Battelle Columbus Division estimates based on Anderson and Hipp (1974) and Walker (1973).

land clearing and installation of a water control system in the Florida flatwoods area is approximately $480 per hectare.

Walker (1973), in a similar study, estimated the cost of various inputs and operations necessary to prepare land for a cow-calf operation on the organic soils of south Florida. The sum of the various operations (including stumping, piling brush for burning, chopping, chiseling, discing, and installation of mole drains) is estimated at $223 per hectare in 1977. The establishment of drainage ditches, canals, culverts, etc, is estimated at approximately $263 per hectare. The cost of pumps and other ancillary equipment is based at about $37 per hectare, making the total cost of the water control system $300 per hectare. This amount, added to the land clearing costs of $223, results in total land development costs of $523 per hectare (Table IV-4).

The above cost derivation, based on updating of detailed information, is reasonably close to estimates provided by Kidder (1977), who indicated total clearing costs plus installation of ditches at $495-$620 per hectare.

One source indicated that land clearing costs increase approximately at the same rate as fuel costs and machinery and equipment costs (Three P&F Co., 1977). Based on the change in the wholesale price indices of these two items from 1972 through 1977, costs have been increasing at an average annual rate exceeding 15 percent. Costs of refined petroleum products have been increasing at an annual rate of 23.3 percent annually, while the cost of construction equipment has been increasing at 11.1 percent annually (U.S. Bureau of the Census, 1977).

Prior to 1972, the rate of increase in costs of construction equipment and refined petroleum products was much slower, ranging from about 2 to 5 percent annually. Using the average annual rate of increase in prices of refined petroleum products and construction equipment from 1968 through 1977 as a basis for projecting future land development costs, the annual rate of increase would approximate 10 to 12 percent.

Louisiana

Estimated land development costs in Louisiana in 1977 range from approximately $730-$1,655 per hectare, with a figure of approximately $1,100-$1,200 per hectare being "most likely" (Irvine, 1977). These costs include stump removal, clearing, piling, burning, reburning, installation of surface drainage ditches, rough crowning, pumps, culverts, field roads, and engineering. The costs will be in the high end of the range in those areas where substantial quantities of cypress trees must be removed. This hardwood species remains in the soil without deteriorating for decades. In some areas, cypress trees may be buried in the soil up to 4 feet deep, and costs of clearing such land may be twice as much as for other clearing operations (Rice, 1977).

In the coastal plain lands of North Carolina, which is somewhat similar to southern Lousiana, land development costs range from about $1,200 to $1,350 per hectare. This land also has substantial quantities of cypress. Further inland in North Carolina where the land is covered primarily by softwood tree species such as pine, land development costs range from about $650-$850 per hectare.

Table IV-5 indicates land development costs per hectare in Concordia Parish of Louisiana in 1969, along with estimated 1978 costs for these same operations. Corty (1972) indicates considerable variation in development costs because of variability in size and shape of fields, topography, type of soil, density of vegetative growth, and nature of contractual arrangements.

Total estimated land development costs in Table IV-5 for 1978, based on an annual inflation rate of approximately 12 percent, range from about $600 to $725 per hectare. It should be noted that Concordia Parish lies north and east of the potential sugarcane growing regions of Louisiana. If the Louisiana situation is analogous to that in North Carolina, development costs closer to the coast would be approximately 75 percent higher, primarily due to the need for removal of larger amounts of cypress. This would put land development costs in the range of roughly $1,050-$1,275 per hectare, which would be comparable with estimates previously cited by Irvine.

TABLE IV-5. LAND DEVELOPMENT COSTS PER HECTARE, CONCORDIA PARISH (LOUISIANA), 1969 AND ESTIMATED, 1977[a]

	Range		Most Frequent	
	1969	Est. 1978	1969	Est. 1978
	$/Hectare			
Clearing	84-309	220-810	124-136	325-355
Drainage	5-111	15-290	49-74	130-195
Leveling	7-49	20-130	25-37	65-95
Fencing	10-62	30-165	3C	80
TOTAL	106-531	285-1395	228-277	600-725

Source: Battelle Columbus Division estimates for 1978 based on 1969 data from F. L. Corty, "The Impact of Land Clearing and Development on the Economy of a Rural Area in Louisiana", D.A.E. Research Report #441, Department of Agricultural Economics, Louisiana State University (June, 1972).

(a) Concordia Parish lies north of the potential sugarcane growing regions of Louisiana; closer to the coastal region the cost of land development is estimated to be $1000-$1300 per hectare, depending on the amount of cypress to be removed.

Drainage. In Louisiana, two types of drainage are in use: (1) lateral ditches every 45.7 to 76.2 meters with quarter drains draining to the lateral ditches and (2) precision grading (Breaux, Matherne, et al, 1972).

Lateral ditches have been used since sugarcane was first planted in Louisiana. The area between two lateral ditches, called "squares" or "cuts", ranges from approximately 150-300 meters in length. Quarter drains (small ditches) at right angles to the rows drain the water from the cut to the ditches. Larger ditches and canals drain the water from lateral ditches into bayous or swamps.

A more recent system of precision grading eliminates the quarter drains and many lateral ditches. This is recommended for the sandy "light" soils. Lateral ditches are spaced approximately 175-250 meters apart, so only about one-fifth as many ditches are required to drain the same area. The land is graded to slope towards one end of the cut (row drainage) and also towards one of the lateral ditches (side fall). Precision grading may require the movement of considerable soil by scrapers, which move soil from the high spots and fill in the low spots. A land plane is used for the final smoothing operation.

The elimination of many lateral ditches and quarter drains by precision grading permits more efficient preparation of multi-row equipment and also eliminates many of the weed infestation and maintenance costs associated with lateral ditches and quarter drains.

Crowning is recommended for the "heavy" clay soils. This is accomplished by sloping the land from the center of the cut towards the lateral ditches.

Texas

Land clearing costs for cropland production (exclusive of drainage and irrigation costs) in the Texas Gulf Coast area range from about $65-$90 per hectare for grassland up to $400 per hectare on land carrying heavy woody species (Vavra, 1977). The bulldozer is the main piece of equipment utilized in clearing land in Texas. The various operations include (Whitson, 1977):

(1) Bulldozing (cutting the brush off at ground level)

(2) Stacking in piles

(3) Burning

(4) Restacking and burning

(5) Root raking

(6) Disking with heavy disks to break up the soil.

Land clearing is usually contracted on a per hour basis, with bulldozer costs running between $35 and $45 per hour. Approximately 3.75-5 hours are required to clear 1 hectare of "heavy" brush.

Based on information supplied by Vavra (1977), Battelle estimated the average costs of cropland development in the Rio Grande Plain and Gulf Coast regions of Texas for 1977 (Table IV-6). Total costs, including clearing, leveling, installation of surface drainage, and installation of irrigation pipe is estimated at $1,000-$1,165 per hectare. Subsurface drainage has increased during the past 2 years for areas planted to sugar-cane. If subsurface drainage is included, the total development costs are increased by approximately $650 per hectare, making a total land development cost of $1,650-$1,815 per hectare.

Summary

Table IV-7 indicates a summary of total estimated costs of cropland development for sugarcane in each of the three designated states. These costs vary over a wide range, from a low of $450 per hectare in some parts of Florida, up to over $1,200 per hectare in heavily wooded areas of Louisiana. The inclusion of subsurface drainage in Texas sugarcane growing regions could increase total land development costs to $1,700-$1,800 per hectare.

The following section will examine some of the "economics" of land conversion to sugarcane in a fuels from biomass program relative to the minimum prices and yields that would be necessary to pay for these development costs.

TABLE IV-6. ESTIMATED AVERAGE COSTS OF CROPLAND DEVELOPMENT IN THE RIO GRANDE PLAIN AND GULF COAST REGIONS OF TEXAS, 1978

	Dollars Per Hectare
Land clearing	215
Land leveling	360
Surface drainage	135-200
Irrigation (material and installation) (12-inch pipe for water delivery)	290-390
TOTAL, excluding subsurface drainage	1,000-1,165
Subsurface drainage (optional) (6-inch plastic tubing)	650
TOTAL, including subsurface drainage	1,650-1,815

Source: Calculated by Battelle's Columbus Division, based on personal communication with Martin E. Vavra, Civil Engineer, Soil Conservation Service, U.S. Department of Agriculture, Austin, Texas.

TABLE IV-7. SUMMARY OF APPROXIMATE TOTAL COSTS OF CROPLAND DEVELOPMENT FOR SUGARCANE IN FLORIDA, TEXAS, AND LOUISIANA, 1978

Region	Dollars Per Hectare
Florida	480-670
Louisiana	1,000-1,300
Texas (furrow irrigated)	1,000-1,165[a]

Source: Battelle's Columbus Division, based on information from various sources.

(a) Does not include installation of subsurface drainage pipe, which would increase costs by approximately $600 per hectare, assuming 6-inch plastic tubing was utilized.

Land Development Costs Relative to Total Sugarcane Production Costs

Whether or not new land is developed to produce sugarcane for energy or chemicals depends upon the potential returns realized by land developers and sugarcane producers. Assuming that the sugarcane producer is also the holder of currently unutilized land, the producer will need to earn a sufficient income to pay for the cost of land development plus annual sugarcane production expenses. This section examines land development costs relative to total sugarcane production costs for close-spaced sugarcane in newly developed areas of Florida, Louisiana, and Texas.

The total sugarcane production costs indicated in this section are based upon estimates reported in detail in Chapter V. Rough estimates also are included here for the Texas Rio Grande Valley, even though close-spaced sugarcane was not grown on an experimental basis during the past year. Annual production costs for close-spaced cane in Texas are based on current production and harvesting costs for conventional production (Cowley, 1978) and Battelle estimates based on data provided for Florida and Louisiana reported in Chapter V.

Table IV-8 shows the cost of undeveloped land plus those costs necessary to develop the land (from Table IV-7) for sugarcane production in the three designated regions. These costs are then annualized, assuming a payout period of 30 years at an interest rate of 9 percent. The annualized land and development costs are estimated to range from \$210-\$285 per hectare on Florida sandy soils, from \$180-\$235 per hectare in Louisiana, and approximately \$185-\$240 per hectare in the Texas Rio Grande Valley. Naturally, the cost on an annual basis would vary according to the designated payout period and interest rate. For example, if the payout period was reduced from 30 to 15 years, the annualized costs would increase by approximately 26 percent.

Annualized land and development costs relative to total sugarcane production costs are shown at the bottom of Table IV-8. The cost of under-developed land as a percentage of total sugarcane production costs is

TABLE IV-8. IMPACT OF LAND DEVELOPMENT COSTS ON TOTAL COSTS OF SUGARCANE PRODUCTION ($ per Hectare)

	Florida Sandy Soils	Louisiana	Texas Rio Grade Valley
Cost of undeveloped land	1700-2300	850-1,150	900-1,325
Land development costs	480- 670	1,000-1,300	1,000-1,165
Total	$2180-2970	$1,850-2,450	$1,900-2,490
Annualized land and development costs (9%, 30 years)	210-285	180-235	185-240
Average sugarcane production costs, excluding land	1850-1950	1,525-1,625	1,650-1,750
Total annual sugarcane production costs	$2060-2235	$1,705-1,860	$1,835-1,990
Annualized land and development costs as percentage of total annual sugarcane production costs			
Land	8-10%	5-6%	5-6%
Land development	2-3%	6-7%	5-6%
TOTAL	10-13%	11-13%	10-12%

Source: Estimated by Battelle Columbus Division estimated to be 5-6 percent in Louisiana and the Rio Grande Valley, and 8-10 percent on Florida sandy soil. However, the cost of developing the land for sugarcane production is only 2-3 percent in Florida, versus 5-7 percent in Texas and Louisiana. Overall, the cost of acquiring and developing land for sugarcane production is estimated to comprise approximately 10-13 percent of the total cost of producing and harvesting sugarcane and delivering it to a mill for processing.

Table IV-9 indicates estimated "break-even" sugarcane yields necessary to cover total annual production costs in Florida sandy soils, Louisiana, and the Texas Rio Grande Valley. These computations assume that only the stalk portion of the plant would be utilized, and that the tops and leaves or "trash" would remain in the field. (Detailed cost production estimates in which the tops and leaves would be collected are shown in Chapter V.) The assumed prices for sugarcane per metric ton of fresh stalks are $15, $20, and $25. By comparison, from 1975-1977, sugarcane prices in each of these three U.S. mainland producing regions ranged from approximately $13-$22 per metric ton. Prices in the most recent 1977/78 harvest season for sugarcane delivered to a mill are estimated at approximately $14-$20 per metric ton (Angelo, 1978, and Birkett, 1978).

If the price of sugarcane is $20 per metric ton, yields of 103-112 metric tons per hectare would be necessary to cover estimated annual production, harvesting, and transportation costs on Florida sandy soils. Similar "break-even yields" at a sugarcane price of $20 per metric ton in Louisiana are 85-93 metric tons per hectare, and 92-100 metric tons per hectare in the Texas Rio Grande Valley. Current average yields of conventionally-spaced sugarcane for production of raw sugar are 72 metric tons in Florida (obtained primarily on muck soils), 53 metric tons in Louisiana, and 80 metric tons per hectare in the Texas Rio Grande Valley. Experimental yields of close-spaced sugarcane in 1977/78 were 110 metric tons in Florida, and ranged from 110-150 tons in Louisiana.

The above estimates indicate that Louisiana exhibits good potential for close-spaced sugarcane production for biomass production if sufficiently

TABLE IV-9. ESTIMATED SUGARCANE YIELDS REQUIRED TO "BREAK-EVEN" AT SPECIFIED PRICES FOR SUGARCANE STALKS (MILLABLE CANE)

	Florida Sandy Soils	Louisiana	Texas Rio Grande Valley
Total annual sugarcane production costs ($ per ha)	2060-2235	1705-1860	1835-1990
Assumed price of sugarcane (stalks, fresh weight basis)[a]		("Break-Even Yields")	
$15 per metric ton	137-149	114-124	122-132
$20 per metric ton	103-112	85- 93	92-100
$25 per metric ton	82- 89	68- 74	73- 80
Current average yields of conventionally spaced sugarcane for sucrose	72[b]	53	80
Experimental 1977/78 yields of close-spaced sugarcane	110[b]	110-150	-[c]

SOURCE: Estimated by Battelle Columbus Division.

(a) From 1975-1977, United States sugarcane prices (for raw sugar production) ranged from approximately $13-$22 per metric ton..

(b) Obtained on muck soils; relatively small quantity of commercial sugarcane produced on sandy soils

(c) No experimental data available.

high yields can be obtained on newly developed land. The Florida situation is more uncertain due to the lack of information on production yields and costs on sandy soils. Even though no experimental data is available for close spaced sugarcane in Texas, this state certainly warrants future consideration since current yields are relatively close to the break-even yields shown in Table IV-9. The biggest obstacle to developing greater sugarcane production in Texas is the lack of water to irrigate large volumes of additional acreage.

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V. COST OF RAW MATERIALS

This chapter examines the costs of producing, harvesting, and transporting sugarcane and sweet sorghum to a facility where the material would undergo processing and conversion to fuels. Processing and conversion include cleaning, juice extraction and fermentation, along with collection of usable by-products. Processing and conversion technology and costs are discussed in Chapters VI and VII. The following data, with qualifying statements and assumptions where indicated, provide estimated raw materials costs, based on utilizing either sugarcane or sweet sorghum as the raw material in fermentation processes.

Even though the raw materials costs presented in this chapter are based on estimated actual production costs, the "opportunity costs" of growing sugar crops for fuel as opposed to conventional food uses must not be ignored. That is, sugar will naturally flow to those markets willing to pay the higher price. Currently, the support price of raw sugar (sucrose) produced in the United States is about $0.147 per pound, and several bills are being considered by Congress to raise this price, perhaps to $0.17 per pound. At these artificial price levels, the U.S. sugar industry will continue to direct its production to conventional food uses. To obtain fermentable sugars for ethanol production, it will be necessary to develop government support for such a program. Policy alternatives are the subject of another investigation being conducted for DOE as part of the 1978/79 Fuels from Sugar Crops Program.

Economic Analysis of Sugarcane

Yield and Composition Assumption

Detailed information on the 1977 experimental yields obtained for close-spaced sugarcane in Florida and Louisiana are reported in

Chapter III. This section summarizes these results as a basis for preparing cost estimates associated with close-spacing.*

Since identical types of measurements were not taken at each of the three experimental locations (Belle Glade, Florida; Baton Rouge, Louisiana; and Houma, Louisiana), some of the data on experimental yields expressed in Table V-1 have been estimated by Battelle. For example, some stations reported dry weight yields, but not fresh weight, Also, the Louisiana yields of fermentable sugars are estimated based on the reported sucrose production. In Florida, sucrose accounted for approximately 93.6 percent of total sugars based on experimental results. However, based on reported commercial production of raw sugar and molasses (USDA, Crop Production, 1978), Battelle estimates that commercial production of crystalline raw sugar is approximately 83 percent of total fermentable sugars in Louisiana, and 82 percent in Florida. Therefore, the estimated fermentable sugars in the Louisiana experiments summarized in Table V-1 were obtained by dividing reported sucrose yields by 0.83.

The inclusion of drip irrigation and its potential effect on sugarcane yields and total production costs on Florida sandy soils is not included in any of these analyses. This is another topic for future investigation. The experiments conducted in Houma, Louisiana, included sugarcane measurements on land that was "fertigated" via drip irrigation. This resulted in approximately 12 percent more dry matter and approximately 15 percent more fermentable sugars produced per hectare compared to the "unfertigated" plots at the Houma station. Analysis needs to be conducted on the cost/benefits of drip irrigation on close-spaced sugarcane in various locations.

The amount of combustible organic material reported in Table V-1 was estimated by taking the difference between the dry weight measurements and the quantity of fermentable sugars, after deducting noncombustible material such as ash, inorganic minerals, and a small quantity of fermentable sugars obtained in the tops and leaves. The combined total of

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* The terms "close-spacing" and "narrow-row" are synonomous as used throughout this report.

TABLE V-1. 1977 CLOSE-SPACED SUGARCANE EXPERIMENTAL YIELDS
(Metric tons per hectare)

Location	Fresh Weight: Stalks	Fresh Weight: Total Biomass	Dry Weight: Stalks	Dry Weight: Total Biomass	Fermentable Sugars in Stalks	Combustible Organic Material[d]: Stalks	Combustible Organic Material[d]: Total Biomass
Belle Glade, FL							
Muck soils, 50 cm	110.2	130.0	32.0	39.6	16.6	13.3	18.9
Baton Rouge, LA[b]	110.2	136.9	25.3	31.3	14.1[a]	8.9	13.3
Houma, LA							
No "fertigation"[e]	134.1	176.4	36.2[c]	47.6[c]	22.3[a]	10.6	20.1
"Fertigated" via drip irrigation	150.0	197.3	40.5[c]	53.3[c]	25.6[a]	11.2	21.8

Source: 1977 experimental results and estimates by Battelle's Columbus Division.

(a) Estimated on basis of normal molasses yields and composition from commercial sugarcane mills.

(b) Mean of four replications for four-drill planting technique.

(c) Estimated to be 27 percent of fresh weight.

(d) Estimated on basis of dry weight and fermentable sugars content.

(e) "Fertigation" refers to the application of fertilizer nutrients dissolved in water through drip irrigation tubes. In the Houma, Louisiana, experiment, three applications of ammonium nitrate were made during the growing season using this technique.

combustible organic material plus fermentable sugars is estimated to be approximately 91-93 percent of the total dry weight of sugarcane.

Estimated commercial sugarcane yields utilizing close-spacing are shown in Table V-2. These commercial yields were estimated by multiplying the experimental yields presented in Table V-1 by 0.75.* In Louisiana, the average of the Houma and Baton Rouge experimental yields, multiplied by 0.75, was used to estimate potential commercial yields without "fertigation". The 0.75 factor reflects decrease in yield obtained on land that is (on average) of lower quality than that used for experimentation, reduction in management in commercial conditions, and adjustment for the "border effect".

The fresh weight stalk yields from close-spaced cane on Florida muck soils of 93 metric tons per hectare compares with current statewide Florida average yields, utilizing conventional practices, of approximately 72 metric tons per hectare. In Louisiana, current average yields utilizing conventional practices are approximately 54 metric tons of millable cane per hectare. If close-spacing is as successful as the experimental results indicate, commercial yields in Louisiana could exceed 90 metric tons per hectare of millable cane by 1980.

Table V-3 projects commercial sugarcane yields, utilizing close-spacing, under three different conditions to the year 2000. These projections were made utilizing 1980 commercial yields (Table V-2) as a starting point, increasing at an average annual rate of 1.5 percent per year to the year 2000.** Under this growth rate assumption, commercial yields in the

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* Except in Florida, where reported experimental yields of sucrose were divided by 0.82 to obtain estimated fermentable sugars under experimental conditions then multiplied by 0.75 to obtain anticipated yield.

** A 1.5 percent per year growth rate was arbitrarily chosen, based on the average change in U.S. crop productivity levels from the late 1940's through the mid-1970's. Some crops, such as corn, have experienced yield increases averaging over 3.5 percent per year, while other crops, such as sugarcane (with conventional spacing), have shown little change in yields (Agricultural Statistics, 1977).

TABLE V-2. ESTIMATED COMMERCIAL SUGARCANE YIELDS OBTAINABLE BY 1980 UTILIZING CLOSE-SPACING[a]
(Metric tons per hectare)

Location	Fresh Weight		Dry Weight		Fermentable Sugars in Stalks	Combustible Organic Material	
	Stalks	Total Biomass	Stalks	Total Biomass		Stalks	Total Biomass
Florida							
Muck soils	93	108	24	30	14.2	8.3	12.5
Louisiana							
"Fertigated" via drip irrigation	113	148	30	40	19.2	8.4	16.3
No "fertigation"[b]	92	117	23	30	13.6	7.4	12.6

Source: Estimated by Battelle from 1977 experimental data.

(a) Estimated by multiplying 1977 experimental yields by 0.75.

(b) Average of Baton Rouge and Houma experimental yields, multiplied by 0.75.

TABLE V-3. PROJECTED COMMERCIAL SUGARCANE YIELDS UTILIZING CLOSE-SPACING, ASSUMING 1.5% AVERAGE ANNUAL GROWTH

(Metric tons per hectare)

	Dry Weight		Fermentable Sugars in Stalks	Combustible Organic Material	
	Stalks	Total Biomass		Stalks	Total Biomass
Florida, Muck Soils					
1980	24	30	14.2	8.3	12.5
1985	26	32	15.3	8.9	13.5
1990	28	35	16.5	9.6	14.5
1995	30	38	17.8	10.4	15.6
2000	32	40	19.1	11.2	16.8
Louisiana, "Fertigated" via Drip Irrigation					
1980	30	40	19.2	8.4	16.3
1985	32	43	20.7	9.0	17.6
1990	35	46	22.3	9.7	18.9
1995	38	50	24.0	10.5	20.4
2000	40	54	25.9	11.3	22.0
Louisiana, No "Fertigation"					
1980	23	30	13.6	7.4	12.6
1985	25	32	14.7	8.0	13.6
1990	27	35	15.8	8.6	14.6
1995	29	38	17.0	9.3	15.8
2000	31	40	18.3	10.0	17.0

Source: Battelle's Columbus Division.

year 2000 are approximately equal to experimental yields obtained in 1977. The yields of fermentable sugars per hectare in Louisiana is approximately 14 metric tons per hectare in 1980, without "fertigation", and 19 metric tons per hectare with "fertigation". By the year 2000, fermentable sugars yields would range from 18-19 metric tons per hectare up to approximately 26 metric tons under the above conditions. In Florida's muck soil, fermentable sugars' yields would be approximately 14 metric tons per hectare in 1980, increasing to 19 metric tons by 2000.

Costs of Close-Spaced Sugarcane

The agronomic experiments conducted in Florida and Louisiana in 1977/78 provide an indication of potential yields from sugarcane planted in rows spaced approximately one-third to one-half the normal distance between conventional rows. Obviously, a key consideration affecting the future potential of close-spaced sugarcane is the costs and returns associated with this cultural practice compared to conventional production methods. Cost analyses have been conducted for the U.S. mainland sugarcane producing regions, which provide a basis for estimating potential costs of growing and harvesting close-spaced sugarcane. Since no close-spacing has actually been practiced under commercial conditions, the costs necessarily are judgments based on certain assumptions regarding necessary changes from conventional practice.

The following section will compare the costs of conventional versus close-spaced sugarcane in Florida and Louisiana. Close-spacing also may be practiced in the Texas Rio Grande Valley; however, no close-spacing agronomic experiments were conducted there under the 1977/78 DOE contract. Sweet sorghum experiments were conducted in this region and are reported elsewhere in this study.

It is important to note that adoption of close-spacing will require significant changes in cultural practices and harvesting equipment for sugarcane. Increases in quantity of seed cane planted and higher fertilization rates are factors that contribute to higher costs for close-spaced cane. On the other hand, chemical weed control costs may be reduced due to more rapid canopy closure. The number of cultivations likely will be reduced, but it is probable that effective sugarcane borer control will be more difficult.

The most significant unknown factor regarding close-spaced sugarcane production is harvesting. In Louisiana, for example, it is unlikely that the soldier harvester system can be utilized for close-spaced cane. Combine harvesters or some other system, such as a heavy-duty modified forage harvester, are likely to be necessary. It also is not known if close-spaced cane on flat beds can be harvested mechanically in wet weather. The effect of mechanical harvesting on ratooning ability of close-spaced cane will not be known until tests have been harvested mechanically under varied conditions (Matherne and Irvine, 1977). Also, if the entire plant is harvested for total biomass production, the sugarcane presumably would not be burned as is currently practiced. Harvesting unburned cane with conventional harvesters reportedly would cut harvesting capacity to approximately one-third that of burned cane (Clayton, 1978).

Some of the equipment aspects of adopting close-spacing of sugarcane are discussed in more detail beginning on Page 101 of this report.

Florida. Costs of producing sugarcane and processing raw sugar in south Florida were reported in detail by Brooke (1977). Brooke's data covered the 1975/76 crop year and were updated to 1978/79 levels by Battelle, using price indices from various inputs used in sugarcane production (USDA, Agricultural Prices, 1978, and Fairbanks, 1978). The updated costs provided a current estimate of producing sugarcane on muck soils, utilizing conventional spacing, in south Florida. These data were then modified by Battelle to obtain estimated costs for producing close-spaced sugarcane on muck soils in south Florida (Table V-4).

TABLE V-4. ESTIMATED COSTS OF PRODUCING, HARVESTING, AND TRANSPORTING CONVENTIONAL AND CLOSE-SPACED SUGARCANE IN FLORIDA, 1978/79

	Muck Soils, Conventional Spacing, $/Ha.	Muck Soils, Close-Spacing, $/Ha.	
Preharvest Cash Operating Expenses			
Labor	269	295	
Seed cane purchased	4	8	
Fertilizer	68	(175) 102[a]	
Other chemicals	65	15	
Other materials & supplies	16	16	
Fuel & other petroleum products	30	35	
Water & electricity	2	3	
Repairs & maintenance	98	108	
Machine hire	27	27	
Interest on operating capital	53	62	
Total	632	(744) 671	
Harvesting Cash Operating Expenses		System A[b]	System B[c]
Labor	459	165	225
Supplies & materials	12	21	21
Fuel & other petroleum products	26	47	47
Repair & maintenance	142	178	249
Interest on operating capital	23	14	19
Total	662	425	561
Ownership & Overhead Costs (Preharvest & Harvest)			
Depreciation	109	125	142
Taxes (personal property & real estate)	82	94	107
Insurance	23	26	30
Interest on investment capital	43	49	56
Administration expenses	114	114	114
Total	371	408	449
Cane Transportation	139	231	196
Total costs, excluding land charge	1,804	1,808	1,877
Land Charge	330	330	330
Total costs, including land charge	2,134	2,138	2,207
Harvested yields, metric tons fresh weight	78[e]	130[d]	110[e]
Total costs per metric ton sugarcane	$27.36	$16.44	$20.06

Source: Estimated by Battelle's Columbus Division.

(a) $175 per hectare fertilizer cost if all crop residues removed from the soil; $102 per hectare if only millable cane harvested.

(b) Utilizing heavy duty forage harvester similar to that used for harvesting corn silage.

(c) Utilizing combine or mat-type harvester.

(d) Total plant biomass, including tops and leaves.

(e) Millable cane.

Some of the major differences assumed between costs of close-spaced sugarcane on muck soils versus conventionally spaced cane on muck soils are discussed below:

- Brooke's data indicated a relatively high proportion of hand labor utilized in sugarcane harvesting. Production of close-spaced cane on muck soils presumably would be fully mechanized, utilizing combine or mat-type harvesters. Heavy duty forage harvesters possibly could be used if total plant biomass was to be removed. Harvesting costs were estimated under each system. System "A" in Table V-4 refers to use of a modified heavy-duty forage harvester and the removal of all plant biomass. System "B" assumes use of a combine harvester in which only millable cane would be harvested, and tops and leaves would remain in the field. Harvesting labor under System "A" is estimated to cost $165 per hectare (33 hours times $5.00 per hour, including benefits), while harvesting labor in System "B" is $225 per hectare (45 hours times $5.00 per hour).

- Costs of repairs and maintenance associated with harvesting will increase for close-spaced cane due to more mechanization, higher yields, and more wear-and-tear on the machinery. It was assumed that repairs and maintenance costs would increase 75 percent utilizing a combine harvester and 25 percent utilizing a heavy-duty forage harvester, compared to conventional muck soil harvesting with more hand labor.

- Ownership and overhead costs are slightly higher for close-spacing cane, assuming that more investment capital would be associated with the higher degree of mechanized harvesting.

- The main difference in preharvest cash operating expenses is associated with fertilizer usage. For conventionally spaced cane on muck soils, it was assumed that no nitrogen would be applied, approximately 55 kg/ha of P_2O_5 (phosphate) and 275 kg/ha of K_2O (potash). By comparison, with complete removal of all plant biomass, close-spaced cane on muck soils would receive no nitrogen, 165 kg of P_2O_5, and 650 kg/ha of K_2O. Lower amounts of these nutrients (100 bag P_2O_5 and 370 kg K_2O) would be required if the tops and leaves were left on the field. At current prices for primary plant nutrients, total fertilizer costs for close-spaced cane on muck soils amounts to $175 and $102 per hectare, depending upon whether or not total removal of plant biomass is practiced. Fertilizer costs for conventionally spaced cane on muck soils is estimated to be only $68 per hectare.

- The use of other chemicals for weed control should be significantly less when close-spacing is practiced. In fact, no herbicides may be necessary for close-spaced cane. On the other hand, insecticides still will be required in some instances for borer control. Total cost for other chemicals is estimated at $65 per hectare for conventionally spaced cane, versus $15 per hectare for close-spaced cane.

- The land charge on muck soils is calculated to be $330 per hectare, based on a land value of $3,880 multiplied by an interest rate of 8.5 percent.

- Sugarcane yields were estimated at 78 metric tons per hectare millable cane on muck soils, utilizing conventional spacing. For close-spaced cane, yields were estimated to be 110 metric tons per hectare millable cane, and 130 metric tons of total plant biomass based on the 1977/78 experimental yields.

Total sugarcane costs, including the land charge, were estimated at $2,134 per hectare utilizing conventional spacing on muck soils. By comparison, total costs of close-spaced cane utilizing a heavy-duty forage harvester is $2,138 and $2,207 utilizing a combine harvester. Based on the yields stated above, the costs per metric ton of sugarcane are $27.36 for conventional practices, versus $20.06 per metric ton using combine harvesters for close-spaced cane on muck soils. With total removal of all plant biomass, the cost per metric ton is $16.44.

These costs are about $4-$5 per ton higher than those estimated for Louisiana, noted below. The main reason for the disparity is the greater increase in yields achieved with close-spacing (compared to conventional practice) in Louisiana compared to Florida in a single experiment. (The comparison is being repeated in the 1978/79 crop year). Also, there are many unknown factors affecting estimated harvesting costs associated with close-spaced cane. These uncertainties are compounded when going from a labor-intensive harvesting system, such as currently predominates in Florida, to a completely mechanized harvesting system that presumably would be necessary when producing sugarcane as a renewable resource for energy production. Finally, it should be noted that the costs shown here represent "average" performance in terms of crop management. Costs would certainily be less for the more efficient sugarcane growers exercising better overall management of their crop.

Even though the costs should be regarded as "rough estimates" due to the aforementioned uncertainties, they provide a reasonable basis for estimating costs of fermentable sugars and combustible organic material from close-spaced sugarcane. These data are presented beginning on page 152 of this report.

Louisiana. Costs for conventional sugarcane production in Louisiana were based upon data developed by Louisiana State University (Campbell, 1977). These data, indicating 1975 costs incurred by large sugarcane farms in Louisiana, indicated net costs equal to approximately $985 per hectare. This cost did not include cane transportation costs from the field to the mill.

The 1975 Louisiana data were updated to 1978 (Table V-5), based on discussions with Louisiana costs analysts (Campbell, 1978, and Warner, 1978).* 1978 costs for conventionally spaced cane in Louisiana were estimated at approximately $865 per hectare, before adjustments by Battelle to include cane transportation charges and a higher land charge. Battelle has estimated 1978 costs, including a land charge of $210 per hectare and a transportation charge of $95 per hectare, equal to $1,135 per hectare. Based on a millable cane yield of 54 metric tons per hectare, total costs for sugarcane delivered to the mill is approximately $21 per metric ton.**

As with the Florida cost estimates, two different harvesting systems and their associated costs were assumed in Table V-5. System "A" refers to the use of a modified heavy-duty forage harvester to

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* After preparation of the BCD cost estimates, data were published by Campbell (June, 1978) indicating total production, harvesting, and transportation costs to be approximately $19.23 per metric ton for an efficient 500-acre Louisiana sugarcane farm. This cost is adjusted slightly to reflect yields comparable to the 24 metric tons per hectare estimated by BCD. The difference between this estimate and BCD's estimate of $21.02 per metric ton shown in the first column of Table V-5 is considered within the range of normal variation.

** Many individual cost items in Tables V-4 and V-5 are not comparable due to different accounting methods and financial reporting procedures. No attempt has been made to standardize the data, only to ensure that the same general items are included in deriving total production costs.

TABLE V-5. ESTIMATED COSTS OF PRODUCING, HARVESTING, AND TRANSPORTING CONVENTIONAL AND CLOSE-SPACED SUGARCANE IN LOUISIANA, 1978 CROP

	Dollars Per Hectare		
	Conventional Spacing	Close-Spacing	
Planting & Cultivating			
Labor	82	106	
Seed cane	46	92	
Fertilizer	48	(245) 120[a]	
Other	60	78	
Total	236	(521) 396	
Harvesting & Transportation		System A[b]	System B[c]
Labor	55	68	91
Transportation	95	260	197
Other	7	17	17
Total	157	345	305
General Overhead			
Labor	153	170	225
Lubricants	27	40	40
Insurance	45	55	65
Depreciation	77	102	114
Taxes	14	14	14
Interest on Operating Capital	30	55	52
Other materials	146	200	215
Miscellaneous	40	55	60
Total	532	691	785
Total costs, excluding land charge	925	1,557	1,486
Land charge	210	210	210
Total costs, including land charge	1,135	1,767	1,696
Harvested yield, metric tons fresh weight	54[e]	148[d]	112[e]
Total costs per metric ton sugarcane	$21.02	$11.94	$15.14

Source: Estimated by Battelle's Columbus Division.

(a) $245 per hectare fertilizer cost if all crop residues removed from soil; $120 per hectare if only millable cane harvested.

(b) Utilizing heavy duty forage harvester similar to that used for harvesting corn silage.

(c) Utilizing combine or mat-type harvester.

(d) Total plant biomass including tops and leaves.

(e) Millable cane.

remove all plant biomass. System "B" assumes use of a combine harvester in which only millable cane would be harvested, with tops and leaves remaining in the field.

A major item to note in Table V-5 is the difference in fertilizer costs between conventional sugarcane spacing and close-spaced sugarcane, as well as the difference between complete removal of all biomass versus harvesting only millable cane. Under conventional practices, fertilizer costs are estimated at $48 per hectare. For close-spacing, with millable cane yields approximately twice those obtained under conventional practices, fertilizer costs become $120 per hectare. If all plant biomass is removed, fertilizer costs are estimated at $245 per hectare. The large increase in fertilizer requirements for whole-plant harvesting is based on the hgin percentage of nitrogen and potash in the tops and leaves portion of the plant (Golden and Ricaud, 1963). When the tops and leaves are left in the soil, nitrogen fertilization is estimated at 225 kg per hectare, P_2O_5 requirements are 56 kg per hectare, and K_2O is 112 kg per hectare. Under whole-plant harvesting, nitrogen and requirements based on replacement of materials contained in the tops and leaves, are estimated at 488 kg per hectare, P_2O_5 at 90 kg per hectare, and K_2O at 202 kg per hectare.

Transportation costs are assumed to be $1.75 per metric ton in all instances. Therefore, higher yields per hectare results in proportionatley greater transportation costs.

A land charge of $210 per hectare was assigned, based on an assumed land value of $2,470 per hectare ($1,000 per acre) multiplied by an interest rate of 8.5 percent.

Louisiana close-spaced cane yields in Table V-5 are based on the approximate average of experimental yields obtained in 1977 at Houma and Baton Rouge. At Houma, experimental yields for close-spaced cane on non-irrigated land were approximatly 176 metric tons (fresh weight) total plant material and 134 metric tons per hectare of millable cane. At Baton Rouge, average yields for various types of close spacing were approximately 125 metric tons per hectare total plant material and 95 metric tons of millable cane. For the purposes of estimating production costs per metric ton, Battelle assumed yields of 148 metric tons total plant material and 112 metric tons millable cane per hectare.

Under the above assumptions, total costs per metric ton of sugarcane under conventional cultural practices and harvesting is approximately $21 per metric ton. For close-spaced cane, utilizing only the stalks, production costs are approximately $15 per metric ton. If total plant biomass is removed, costs per metric ton of sugarcane delivered to a processing plant fall to slightly less than $12 per metric ton.

Based on these estimates, there is approximately a 28 percent cost reduction obtained with close-spaced sugarcane, compared to standard practices, assuming that only millable cane is utilized. This change is comparable with independent estimates developed in 1975, where cost per metric ton of sugarcane, excluding a land charge, for close-spaced cane were $11.04, compared to $16.09 per metric ton for standard production practices (Irvine, 1977).*

Projected Costs of Fermentable Sugars From Close-Spaced Sugarcane

Projected costs of fermentable sugars from close-spaced sugarcane utilizing only millable cane or the stalk portion of the plant is shown in Table V-6. Estimates are presented at 5-year intervals from 1980 through 2000 for the muck soils of Florida and for Louisiana, without drip irrigation or "fertigation".

The first column of Table V-6 shows total sugarcane costs, including a $100-per-hectare management charge for the growers over and above fixed and variable costs. Estimated close-spaced sugarcane costs for 1980 were assumed to be approximately 10 percent over 1978 levels noted in Tables V-4 and V-5, due to inflation. Also, slight adjustments in

* Allowing for a 15 percent incerease in costs from 1975 to 1978 due to inflation, plus a land charge of $210 per hectare, results in total costs for close-spaced cane of $14.84 per metric ton and $22.25 per metric ton of conventionally spaced cane.

TABLE V-6. PROJECTED COSTS OF FERMENTABLE SUGARS FROM CLOSE-SPACED SUGARCANE, UTILIZING STALK PORTION OF PLANT, FLORIDA AND LOUISIANA, 1980 DOLLARS[(a)]

	Dollars Per Hectare			Net Cost of Fermentable Sugars		
	Total Sugarcane Costs, Inc. Grower[(b)] Management Charge	Value of Fibrous By-Products[(c)]	Fuel Value of Residual Combustible Material[(d)]	$/Ha.	$/Metric Ton	¢/Lb.
Florida, Muck Soils						
1980	2,400	166	83	2,153	152	6.9
1985	2,447	178	89	2,180	142	6.4
1990	2,505	192	96	2,217	134	6.1
1995	2,560	208	104	2,248	126	5.6
2000	2,617	224	112	2,281	119	5.2
Louisiana, No "Fertigation"						
1980	1,867	148	74	1,645	121	5.5
1985	1,903	160	80	1,663	113	5.1
1990	1,946	172	86	1,688	107	4.9
1995	1,987	186	93	1,708	100	4.6
2000	2,033	200	100	1,733	95	4.3

Source: Estimates by Battelle's Columbus Division.

(a) Cost of fermentable sugars in sugarcane stalks delivered to a mill, before juice extraction.

(b) Includes $100 per hectare management charge over total fixed and variable costs.

(c) Assumes that 50 percent of combustible organic material in the stalks is marketable fibrous by-product, with an average value of $40 per metric ton.

(d) Residual combustible material equals total combustible organic material in stalks, less marketable fibrous by-products. Value of residual combustible material estimated to be $20 per metric ton, dry weight basis.

harvesting and transportation costs were made to reflect anticipated lower yields obtained under commercial conditions.

The second and third columns of Table V-6 indicate the value of fibrous by-products and the fuel value of residual combustible organic material contained in the sugarcane. These values represent credits against the total cost of production. Assuming that the Tilby process is utilized, approximately 50 percent of the combustible organic material in the stalks would be marketable at an average value of $40 per metric ton. The remainder of the combustible organic material is assumed to have a fuel value of $20 per metric ton on a dry weight basis, ($1.21 per million Btu or $1.15 per gigajoule).

The net cost of fermentable sugars represents the difference between total sugarcane costs, less the credits obtained for fibrous by-products and residual combustible material. In 1980, the net cost of fermentable sugars on Florida muck soils is estimated at $2,153 per hectare, which amounts to approximately $152 per metric ton, assuming a fermentable sugars yield of 14.2 metric tons per hectare (from Table V-3). This is equivalent to approximately $0.069 per pound. With increasing yields, the net cost of fermentable sugars would decrease to approximately $0.052 per pound by the year 2000 on Florida much soils.

By going through the same procedure for Louisiana, the net cost of fermentable sugars is $0.55 per pound in 1980, decreasing to $0.043 per pound by the year 2000.*

The cost of fermentable sugars from close-spaced sugarcane utilizing the entire plant is shown in Table V-7. There is very little difference in total delivered sugarcane costs compared to utilizing only millable cane. The decreased harvesting costs are offset by higher fertilizer and transportation charges. The major difference is that more combustible material would be available from the tops and leaves. If this additional biomass can be marketed for a fuel value of $20 per per metric ton, a larger credit against sugarcane production costs can be realized. Under this assumption, the net cost of fermentable

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* The cost of fermentable sugars in Louisiana utilizing drip irrigation and the application of fertilizer nutrients through such a system is not included in this study due to lack of reliable data. Such analysis should be included in future investigations.

TABLE V-7. PROJECTED COSTS OF FERMENTABLE SUGARS FROM CLOSE-SPACED SUGARCANE, UTILIZING ENTIRE PLANT, FLORIDA AND LOUISIANA, 1980 DOLLARS[(a)]

	Dollars Per Hectare			Net Cost of Fermentable Sugars		
	Total Sugarcane Costs, Inc. Grower[(b)] Management Charge	Value of Fibrous By-Products[(c)]	Fuel Value of Residual Combustible Material[(d)]	$/Ha.	$/Metric Ton	¢/Lb.
Florida, Muck Soils						
1980	2,330	166	167	1,997	141	6.4
1985	2,370	178	181	2,011	131	6.0
1990	2,416	192	194	2,030	123	5.6
1995	2,462	208	208	2,046	115	5.2
2000	2,508	224	224	2,060	108	4.9
Louisiana, No "Fertigation"						
1980	1,930	148	178	1,604	118	5.4
1985	1,965	160	192	1,613	110	5.0
1990	2,003	172	206	1,625	103	4.7
1995	2,042	186	223	1,633	96	4.4
2000	2,088	200	240	1,648	90	4.1

Source: Estimates by Battelle's Columbus Division.

(a) Cost of fermentable sugars in sugarcane biomass delivered to a mill, before separation of stalks from tops and leaves and before juice extraction.

(b) Includes $100 per hectare management charge over total fixed and variable costs.

(c) Assumes that 50 percent of combustible organic material in the stalk portion of the biomass is marketable fibrous by-product, with an average value of $40 per metric ton.

(d) Residual combustible material equals total combustible organic material in stalks, less fibrous by-products, plus combustible organic material in tops and leaves. Value of residual combustible material estimated to be $20 per metric ton, dry weight basis.

sugars on Florida muck soils is $0.064 per pound in 1980, decreasing to $0.049 per pound by the year 2000. Louisiana costs are $0.054 per pound in 1980 and $0.041 per pound by the year 2000.

Florida Sandy Soils. This report does not include any detailed cost of production estimates for close-spaced sugarcane on sandy soils of Florida, because no experiments were conducted on sandy soils in 1977/78. If substantial additional sugarcane production is to occur in Florida, either for food or fuel purposes, the only land available would be sandy soils, primarily south and west of the current sugarcane-producing region (See Chapter IV on cropland development). This land would have to be acquired, at an estimated price of $2000 per hectare, and developed for sugarcane production, which would cost an additional $500-$600 per hectare. Installation of a drip irrigation system would cost anywhere from $1500-$3000 per hectare (Chemical Week, 1976). Therefore, assuming a mid-point of the above ranges, the total development costs for new sugarcane land on sandy soils would be approximately $2800 per hectare.* If this amount were amortized over a 30-year period at an interest rate of 9.0 percent, the annual cost would be approximately $270 per hectare (including repayment of principal plus interest).

Another additional cost incurred on sandy soils would be additional fertilization, particularly nitrogen. Additional fertilizer costs might range from $40-$60 per hectare, depending upon whether whole-plant harvesting was practiced.

Compared to estimated sugarcane production costs of $2100-$2200 per hectare on muck soils, close-spaced sugarcane costs on sandy soils (including annualized land development and irrigation installation costs) might approach $2400-$2500 per hectare.

The yield for fermentable sugars on sandy soils can only be estimated at this time. Gascho (1978) estimates that the cane tonnage would be approximately 75 percent of that obtained on muck soils, with

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* The $2800 does not include the purchase price of the land, which is already accounted for in the cost analyses under "land charge".

about 85 percent of the sucrose production obtained on muck soils. LeGrand (1976) reports one commercial grower has been experimenting with sugarcane on the sandy soils of Hendry County, Florida. Yields of approximately 13.5 metric tons of sucrose per hectare have been consistently achieved. This would be equal to approximately 16 metric tons per hectare fermentable sugars. These yields presumably have been achieved without the benefits of close-spacing and drip irrigation. If these new practices were assumed to increase yields by 25 percent, the yield of fermentable sugars could exceed 20 metric tons per hectare on Florida's sandy soils. With total production costs of $2500-$2600 per hectare, the cost per pound of fermentable sugars would be approximately $0.056-$0.059 per pound in 1980.

The above cost estimates are intended to provide a rough indicator of potential sugarcane costs on sandy soils, utilizing new technology. Again, it is emphasized that they are based on the sketchy information that is available at this time. Much better information on this subject will be forthcoming after the 1978-79 Florida experiments on sandy soils have been completed.

Economic Analysis of Sweet Sorghum as an Energy Crop

Yield and Composition Assumptions

Detailed data on the yield and composition of sweet sorghum as evidenced by the 1977 experimental results is found elsewhere in this report. These data are summarized in this section as a basis for estimating the raw materials costs for feedstocks for ethanol production.

Table V-8 shows fresh and dry weight yields obtained for specified sweet sorghum varieties at Weslaco, Texas; St. Gabriel, Louisiana; and Columbus, Ohio. The planting and harvest dates for each variety also are indicated, so that the growing period length can be calculated.

TABLE V-8. 1977 EXPERIMENTAL SWEET SORGHUM BIOMASS YIELDS
(Metric tons per hectare)

Location Plant-Harvest Dates	Variety	Total	Stalks	Leaves	Heads	Dry Weight Total	Dry Weight Stalks	Dry Weight Leaves	Dry Weight Heads
Weslaco, TX[a]									
4/27-8/9	Rio	61.9	36.5	18.8	6.6	22.2	12.5	6.6	3.1
4/27-10/17	MN 1500	119.5	83.1	27.8	8.6	44.0	29.3	11.7	3.0
St. Gabriel, LA									
5/2-8/23	Rio (DD)[b]	83.6	61.9	21.7[c]	--	30.0	22.2	7.8[c]	--
5/2-8/23	69-13 (DD)	91.9	73.1	18.8[c]	--	31.4	25.4	6.0[c]	--
Columbus, OH[d]									
6/13-10/24	Rio	51.7	27.8	14.4	9.5	15.3	8.3	4.4	2.6
6/13-10/24	Sart	87.9	58.5	14.3	15.1	25.7	17.6	4.7	3.4
6/13-10/24	Ramada	57.4	40.7	8.6	8.2	18.1	12.2	3.1	2.8

Source: Experimental test results conducted at specified locations.

(a) 68.6 cm row spacing, yields on 8/9/77 for Rio and 10/17/77 for MN 1500.

(b) DD signifies double-drilled, 4 plants per hill and hills 12 inches apart in drills 18 inches apart on 6-feet rows.

(c) Includes both leaves and heads; separate measurements not taken.

(d) 50.8 cm row spacing.

It should be noted that the data for Columbus, Ohio, are not representative for optimum cultural practices. The sorghum was not planted until June 13, when a planting date of around May 15 would be closer to optimum. Therefore, the crop did not derive the benefit of the longer day length in late May and early June. Also, the growing season was drier than normal, which also inhibited crop yields.

Dry weight yields for sweet sorghum are roughly 30 to 35 percent of fresh weight when the crop is mature. In Texas, the dry yield of total plant material for the MN 1500 variety was 44 metric tons per hectare, which was approximately double the yields obtained from the Rio variety. In St. Gabriel, Louisiana, yields of the Rio and 69-13 varieties were roughly equal, at 30-31 metric tons per hectare. In Columbus, total biomass yields ranged from 15-26 metric tons per hectare.

Table V-9 shows experimental yields of fermentable sugars and combustible organic material on the basis of 1977 experimental results. Note the footnotes at the bottom of Table V-9 for an explanation of these data. Sweet sorghum composition analyses are extremely variable, due to the physiology of individual plants and can be affected by such factors as the degree of ripening, disease damage, water stress, etc. Sweet sorghum reacts more quickly than sugarcane to changes in environmental conditions, and therefore, requires more careful management than does sugarcane. For example, water stress at certain times during the growing season can have a much more detrimental effect on sweet sorghum than on sugarcane (Reeves, 1977).

The amount of material in the seedheads is highly variable and affected to some degree by the amount of seed that is eaten by birds before harvesting.

The main factor to note in Table V-9 is the high percentage of fermentable sugars contained in the stalks, as compared to the leaves and seedheads. The relatively low percentage of fermentable sugars in leaves and seedheads makes these plant components unlikely direct contributors to ethanol production. Their value, if collected, primarily would be in supplying combustible energy to run the processing plant to

TABLE V-9. 1977 EXPERIMENTAL YIELDS OF SWEET SORGHUM FERMENTABLE SUGARS AND COMBUSTIBLE ORGANIC MATERIAL
(Metric tons per hectare)

Location Plant-Harvest Dates	Variety	Fermentable Sugars				Combustible Organic Material			
		Total	Stalks	Leaves	Heads	Total	Stalks	Leaves	Heads
Weslaco, TX									
4/27-8/9	Rio	6.3	5.3	0.7	0.3	14.3[a]	6.5	5.2	2.6
4/27-10/17	MN 1500	9.8	8.3	1.1	0.4	30.5[a]	19.4	9.0	2.1
St. Gabriel, LA									
5/2-8/23	Rio (DD)	9.1	8.3[e]	0.8[b]	--	18.9	12.6	6.3	--
5/2-8/23	69-13 (DD)	11.6	11.0[e]	0.6[b]	--	17.5	12.8	4.7	--
Columbus, OH									
6/13-10/24	Rio	(c)	(c)	(c)	(c)	10.0[d]	4.3	3.5	2.2
6/13-10/24	Sart	(c)	(c)	(c)	(c)	17.7[d]	11.7	3.6	2.4
6/13-10/24	Ramada	(c)	(c)	(c)	(c)	12.2[d]	7.6	2.4	2.2

Source: Experimental test results conducted at specified locations, and Battelle Columbus Division estimates as indicated.

(a) Total dry matter less fermentable sugars, ash, nitrogen, phosphorus, and potassium.

(b) Estimated on basis of Weslaco test results; includes both leaves and heads.

(c) Not calculated since crop did not mature properly due to late planting.

(d) Estimated yields of combustible organic matter.

(e) Brix content multiplied by 84% to obtain estimate of fermentable sugars content.

allow for other higher valued uses for the fibrous material found in sweet sorghum stalks. Seedhead starch might be used as cattle feed or as input to a starch-based ethanol facility.

Table V-10 shows sweet sorghum yields obtained commercially in Iowa. These data are based upon discussions with personnel at Waconia Sorghum Company in Cedar Rapids, Iowa. Waconia is the single largest producer of sweet sorghum syrup in the United States, and harvests from 1,000-1,500 acres of sweet sorghum annually.

The dry weight yields of approximately 21 metric tons total biomass and 14 metric tons per hectare of stalks are relatively low, compared to the experimental results noted in Tables V-8 and V-9. However, it should be noted that no attempt was made to optimize the crop for biomass production, because the purpose was to produce sweet sorghum syrup. The crop was planted on rows spaced 96.5 centimeters apart, utilizing a variety which was known to produce a high quality syrup with the desired taste characteristics.

The estimated fermentable sugar yield per hectare shown in Table V-10 of 2.4 metric tons is a rough approximation based upon the yield of syrup per ton of stalks. Syrup yields reportedly can range anywhere from 40 to 65 liters per ton of stalks. (1 liter of syrup weights approximately 1.4 kilograms, with a dry solids content of approximately 82 percent.)

Projected Commercial Sweet Sorghum Yields. Projecting commercial yields of a relatively unknown crop such as sweet sorghum is a subjective task at best. However, some projections are necessary in order to derive a rough estimate of the potential raw material costs of this crop as an enregy feedstock.

One important factor influencing future yields will be the extent to which sweet sorghum is grown on prime agricultural land. If sweet sorghum is substituted for corn and soybeans in the Midwest, yields will be considerably higher than if the crop is grown as a supplementary crop on lower value land currently used for pasture or woodland.

TABLE V-10. APPROXIMATE COMMERCIAL SWEET SORGHUM YIELDS CURRENTLY OBTAINED IN IOWA
(Metric tons per hectare)

Fresh Weight		Dry Weight		Fermentable Sugars,[b]	Combustible Organic Material	
Total	Stalks	Total	Stalks	Stalks Only	Total	Stalks Only
59	41	20.7	14.4	2.4	16.1	10.8

Source: Based on information supplied by D. Brunius, Waconia Sorghum Co., Cedar Rapids, Iowa (January, 1978).

(a) "Waconia Orange" seed planted on 96.5 rows with approximately 5-6 cm between seeds within the row; planting date approximately May 15-June 15, with harvesting from August 20-October 20.

(b) Estimated.

Another important factor will be the degree to which increased research emphasis can be translated into higher yields. Sweet sorghum, although it is an old crop, may be in the same stage of development as corn was in the 1930's and 1940's. In 1940, average U.S. corn yields were approximately 30 bushels per acre; U.S. corn yields in the late 1970's averaged approximately 90 bushels per acre. On the other hand, there has been very little change in Louisiana sugarcane yields over the past 35-40 years, averaging about 19 tons per acre in the early 1940's versus about 23 tons per acre in the mid-1970's.

Table V-11 indicates goals for commerical yields of sweet sorghum biomass production in the southern and midwestern United States. Yields are expressed in fresh and dry weights of stalks and total plant materials. In deriving these statistics, it was conservatively assumed that 1980 commerical yields would be equal to approximately two-thirds of the highest experimental yeilds obtained in 1977 as part of this study.* Projections for 1985 through the year 2000 assume a 2 percent average annual growth rate from the 1980 base. This growth rate is equal to the average annual growth rate of all U.S. crop production per hectare over the period 1949-1953 through 1972-1976. It is substantially lower than the 3.5 percent per annum growth rate of U.S. corn yields over this time period.

Using this procedure, total sweet sorghum biomass production goals in the southern United States are 25 metric tons per hectare in 1980, 30 tons per hectare in 1990, and 37 metric tons by the year 2000. In the midwestern United States, the projections are 21, 25, and 31 metric tons per hectare for 1980, 1990, and 2000, respectively.

Projected commercial yields of fermentable sugars and combustible organic material in sweet sorghum grown in the southern United States is shown in Table V-12. Insufficient data on midwestern sweet sorghum fermentable sugars production are available to make any meaningful future projections on a commercial scale.

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* Discussions with various agronomic and sugar crop production specialists indicated that commercial crop yields normally range from 65-80 percent of experimental yeilds within the same geographical area.

TABLE V-11. GOALS FOR COMMERCIAL YIELDS OF SWEET SORGHUM-FOR-BIOMASS PRODUCTION[a]

	Fresh Weight		Dry Weight	
	Stalks	Total Plant	Stalks	Total Biomass
	- - - - Metric tons per hectare - - - - - -			
Southern United States				
1980	52	71	18	25
1985	57	78	20	27
1990	63	87	22	30
1995	70	96	25	34
2000	77	106	27	37
Midwestern United States				
1980	40	59	14	21
1985	44	65	15	23
1990	49	72	17	25
1995	54	79	19	28
2000	59	88	21	31

Source: Projected by Battelle's Columbus Division.

(a) Assumes that 1980 commercial yields equal two-thirds 1977 experimental yields obtained in Louisiana, Texas, and Ohio. Projections beyond 1980 assume a 2% average annual growth rate.

TABLE V-12. GOALS FOR COMMERCIAL YIELDS OF FERMENTABLE SUGARS AND COMBUSTIBLE ORGANIC MATERIAL IN SWEET SORGHUM IN THE SOUTHERN UNITED STATES
(Metric tons per hectare)

Year	Fermentable Sugars in Stalks(a)	Combustible Organic Material	
		Stalks(b)	Total Biomass(c)
1980	6.8	9.9	17.2
1985	7.4	10.8	18.4
1990	8.2	12.0	20.6
1995	9.1	13.3	23.5
2000	10.0	14.6	25.5

Source: Projected by Battelle's Columbus Division.

(a) Based on projected fresh stalk yields (Table V-11) times 13%.

(b) Based on projected fresh stalk yields (Table V-11) times 19%.

(c) Estimated as residual; i.e., total dry weight biomass minus fermentable sugars in stalks, minus ash content of tops and leaves, plus combustible organic material in stalks, equals combustible material in total biomass.

The projected productivity of fermentable sugars includes only those sugars in the stalk portion of the plant. Projected combustible organic material is shown for the entire plant, as well as the stalk portion. The basis of these projections is explained in the footnotes.

In 1980, commercial production of fermentable sugars from sweet sorghum is projected at approximately 6.8 metric tons per hectare; in 1990, projected levels are 8.2 metric tons; and for the year 2000 are 10.0 metric tons per hectare.

As previously indicated, these yields are used in the following section of this report as a basis for estimating future raw material costs of sweet sorghum as an energy feedstock.

Production, Harvesting, and Transportation Costs

As with sugarcane, it is necessary to estimate the production costs of sweet sorghum in order to (1) derive the cost of fermentable sugars used in producing ethanol or other fuels and (2) determine the potential returns to growers compared to other crops and alternative land uses. However, there are several reasons that sweet sorghum costs cannot be well defined at this time. First, very little sweet sorghum is grown commercially in the United States. No sweet sorghum is grown for crystalline sugar and only several thousand acres are grown by relatively small entrepreneurs for syrup production. The single largest sweet sorghum producer in the United States, Waconia Sorghum Company in Cedar Rapids, Iowa, grew only 450 hectares in 1977. Another Iowa producer interviewed by Battelle grew approximately 32 hectares in 1977. Other producers of comparable size are located in Arkansas, Alabama, Indiana, Florida, and other southeastern states. Therefore, unlike sugarcane, no statistical base of production cost information has yet been developed for sweet sorghum.

Another factor limiting the usefulness of current sweet sorghum cost estimates is that technology used to grow sweet sorghum for energy purposes will undoubtedly differ from current practices. Currently, most commercial operations are extremely labor intensive, which would not be possible on large-scale operations. Also, no suitable equipment is now available to harvest sweet sorghum. Where hand labor is not utilized, growers have modified ensilage harvesters to harvest their crops. This equipment must necessarily operate at relatively slow speeds to produce stalks suitable for syrup production. Therefore, the development of heavy-duty equipment capable of operating at production rates comparable to existing harvesters is required.

An optimum harvesting system for sweet sorghum can be developed after it is determined whether or not the processing plant should receive only "millable" stalks or the total plant biomass, including systems that are found to be most desirable and cost effective.

Input requirements and their costs also will be altered as growers gradually move up the learning curve for this new crop. As new varieties are developed for biomass production, modifications in present cultural requirements may be necessary.

Given the above reservations, Battelle assembled estimates of 1978 sweet sorghum production costs for three regions, including Louisiana, the Texas Rio Grande Valley, and Iowa (Table V-13).

The cost estimates in Table V-13 are based upon personal interviews with existing commercial producers (Iowa) and with agronomists and agricultural engineers who have grown sweet sorghum under experimental conditions (Louisiana, Mississippi, and Texas). Another important source of information were crop production budgets developed by the U. S. Department of Agriculture and individual state experiment stations for analogous crops such as grain sorghum, corn, and sugarcane.

Total costs are estimated under two different harvesting systems, since it is uncertain at this time what type of harvesting system will be most desirable for sweet sorghum. System "A" in Table V-13 provides estimated costs utilizing an ensilage harvester similar to that used for harvesting corn silage. Under this system, the entire plant would be harvested, including seedhead, tops, and leaves. Stalks would be cut off near the base at the ground and cut into 6-to 10-inch lengths after modification of the harvester, i.e., removal of several blades from the cutter and reduction of blade speed. Also, gearing adjustments are necessary to increase the speed of the stalks' movement through the machine.

TABLE V-13. ESTIMATED 1978 SWEET SORGHUM PRODUCTION COSTS, BY REGION
(Dollars/hectare)

Item	Louisiana[a]		Texas Rio Grande Valley[a]		Iowa[a]	
Preharvest Variable Costs						
Seed (5.6 kg/Ha @ $3.30/lb)	18		18		18	
Fertilizer	(187)[d] 107		(98)[d] 46		(138)[d] 79	
Herbicide	13		15		25	
Insecticide	43		43		--	
Labor:						
Tractor & machinery	27		36		17	
Irrigation	--		20		--	
Machinery operating expense:						
Tractor & machinery	26		46		15	
Irrigation, inc. water charge	--		32		--	
Custom pesticide application	15		15		6	
Interest on operating capital	10		9		7	
Subtotal, preharvest variable costs	260		282		168	
Harvest Variable Costs	System A[b]	System B[c]	System A[b]	System B[c]	System A[b]	System B[c]
Labor	51	76	59	87	47	67
Machinery operating expense:						
Fuel & lubricants	37	42	42	45	34	40
Repairs	36	82	42	88	33	79
Hauling (20 km avg hauling radius)	104	91	130	104	96	75
Subtotal, harvest variable costs	227	291	274	323	211	242
Fixed Costs						
Machinery ownership	118	162	112	172	123	178
Land	198	198	235	235	272	272
Miscellaneous	16	18	17	20	20	22
Subtotal, fixed costs	331	378	363	427	415	472
Total Costs	899	929	969	1,032	852	882

Source: Estimates by Battelle's Columbus Division.

(a) Assumed fresh weight yields per hectare are: Louisiana, 63 metric tons total biomass and 49 metric tons stalks; Texas, 78 metric tons total biomass and 56 metric tons stalks; Iowa, 58 metric tons total biomass and 40 metric tons stalks.

(b) Utilizing ensilage harvester similar to that used for harvesting corn silage.

(c) Utilizing harvesting system similar to that used for sugarcane.

(d) Number in parenthesis indicates estimated fertilizer cost if top and leaves removed from field.

With this type of system, it would be possible to make another trip over the field before the forage harvester to remove the seedheads with a special cutting device that would "top" the stalks. The seedheads could be collected or discarded back onto the field. The costs/benefits of this additional step are not included in any of the estimates shown in Table V-13.

System "B" estimates costs utilizing a harvesting system similar to that currently used for sugarcane. This system, utilizing a larger and more costly machine, would harvest primarily the stalk portion of the plant, and separation of leaves and seedheads would be done in the field, as is now the case, or collected for transfer to the processing plant. The cost estimates in Table V-13 under System B include only the stalk portion of the plant. In other words, under System "B" it is assumed that all material other than millable stalks would be left in the field.*

Costs included in Table V-13 include preharvest variable costs, harvesting variable costs, and fixed costs, including machinery ownership and land. They do not include any grower management charge. Total costs, utilizing an ensilage harvesting system range from approximately $850 to $970 per hectare. Costs utilizing a harvesting system analogous to that used for sugarcane range from approximately $880 to $1,030 per hectare. The fresh weight yields per hectare assumed in deriving these costs are as follows:**

Louisiana -- 63 metric tons total biomass; 49 metric tons stalks

Texas -- 78 metric tons total biomass; 56 metric tons stalks

Iowa -- 58 metric tons total biomass; 40 metric tons stalks.

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* A more detailed discussion of some of the key issues involved in harvesting sugar crops as an energy source are discussed in another section, beginning on Page 102.

** Estimated by Battelle, based on a percentage of 1977 experimental crop yields obtained in Louisiana and Texas, and discussions with commercial sweet sorghum growers in Iowa.

The single largest preharvest variable cost is fertilizer. Fertilizer application rates in Louisiana, with tops and leaves left on the field, were assumed to be 180 kg/ha nitrogen, 45 kg/ha P_2O_5, and 90 kg/ha K_2O. These rates were increased by 75 percent if tops and leaves were removed from the field. In the Texas Rio Grande Valley, it was assumed that only 112 kg/ha of nitrogen would be applied, at a cost of approximately \$0.41 per kg. No P_2O_5 and K_2O are necessary in this region if tops and leaves are not removed. If tops and leaves are removed, an application of 250 kg/ha nitrogen, plus 90 kg/ha K_2O, is assumed. In Iowa, Waconia Sorghum Company utilizes a plow-down application of fertilizer of about 55 kg/ha each of nitrogen, P_2O_5, and K_2O for sweet sorghum following soybeans in a crop rotation. If sweet sorghum follows corn, approximately 67 kg/ha of nitrogen is recommended, along with 35 kg/ha each of P_2O_5 and K_2O. Also, a "starter" fertilizer of ammonium phosphate is applied at the time of planting, in a quantity equal to approximately 9 kg/ha nitrogen, 36 kg/ha P_2O_5, and 18 kg/ha K_2O.

In the Texas Rio Grande Valley, a charge for irrigation, including labor and machinery operating expense of approximately \$52 per hectare,is included. No irrigation is assumed to be necessary in Louisiana or Iowa.

Harvesting costs, as previously indicated, are based upon the principles associated with either harvesting corn silage (System "A") or sugarcane (System "B"). A major item included in harvesting costs is that of hauling material from the field to a processing plant. In all cases, a 20-kilometer (12-mile) average hauling radius is assumed. Hauling costs per metric ton kilometer are estimated at \$0.083, when the entire plant biomass is transported, and \$0.093 per ton kilometer when only the stalks are transported. The higher bulk density of hauling the entire plant versus only the stalk portion results in this slight cost differential.

The fixed costs of machinery ownership include such items as depreciation, insurance, interest, etc. Machinery ownership is another major cost item, ranging from \$112-\$123 per hectare under an ensilage harvesting system, and roughly \$160-180 per hectare utilizing sugarcane harvesting machinery.

The land costs indicated in Table V-13 might be expected to vary considerably, depending upon the estimation procedure. In Iowa, it was indicated that farmers were paid $272 per hectare ($110 per acre) for the use of their land on which sweet sorghum was grown. Comparable "cash rents" in Louisiana and the Texas Rio Grande Valley were estimated at $198 per hectare and $235 per hectare, respectively.

As indicated in the beginning of this section, the production costs associated with sweet sorghum are far from precise. Therefore, the total costs indicated in Table V-13, ranging from approximately $850-$1,030 per hectare, should be regarded as being within plus or minus 20-25 percent of actual costs.

Projected Costs of Fermentable Sugars From Sweet Sorghum

There are several steps involved in estimating the potential cost of fermentable sugars from sweet sorghum. Basically, the procedure was to deduct the market value of sweet sorghum by-products from the total production, harvesting, and transportation costs associated with the crop. The difference was the net cost of sweet sorghum, expressed in terms of the estimated fermentable sugar content. Two sets of estimates were prepared, including one in which only the stalk portion of the plant was utilized, and the second in which the entire plant biomass was harvested and transported to a processing facility.

The projected costs of fermentable sugars from sweet sorghum in the southern United States, utilizing only the millable stalk portion of the plant, is indicated in Table V-14 at 5-year intervals from 1980 through the year 2000. The total costs of sweet sorghum shown in the first column of this table represent the average total costs for Louisiana and Texas shown in Table V-13. These costs, utilizing the harvesting system similar to that used for sugarcane, averaged $981 per hectare in 1978, excluding management fee. Adding a management charge of $100 brought 1978 costs up to $1.081 per hectare. Adjustment of this cost upward at a 5 percent annual rate resulted in 1980 costs of $1.191 per hectare.

TABLE V-14. COST GOALS FOR FERMENTABLE SUGARS FROM SWEET SORGHUM IN THE SOUTHERN UNITED STATES, UTILIZING STALK PORTION OF PLANT, IN 1980 DOLLARS[a]

Year	$/Hectare			Net Cost of Fermentable Sugars		
	Total Cost of Sweet Sorghum[b]	Value of Fibrous By-Products[c]	Fuel Value of Residual Combustible Material[d]	$/Ha	$/M. Ton	¢/lb
Based on Yield Projections in Year:						
1980	1,191	198	99	894	131	6.0
1985	1,216	216	108	892	121	5.5
1990	1,241	240	120	881	107	4.9
1995	1,279	266	133	880	97	4.4
2000	1,304	292	146	866	87	3.9

Source: Estimated by Battelle's Columbus Division.

(a) Cost of fermentable sugars in sweet sorghum stalks delivered to a mill, before juice extraction.

(b) Includes $100 per hectare grower management charge over total fixed and variable costs.

(c) Assumes that 50% of combustible organic material is marketable fibrous by-product with an average value of $40 per metric ton.

(d) Residual combustible material equals total dry matter less 4% ash, less fermentable sugar content, less fibrous by-products. Value of residual combustible material estimated at $20 per metric ton, dry weight basis.

Estimates of combustible organic material obtained from commercial production of sweet sorghum were previously noted in Table V-12. Based on the composition of various types of sorghum, corn, and sugarcane (National Academy of Sciences, 1971),it was estimated that approximately 50 percent of the combustible organic material contained in the sweet sorghum stalks would be recoverable as fibrous by-products for use in pulp, paper and composition board, and cattle feeds. This fibrous material is assumed to have a value of $40 per dry metric ton (Atchison, 1978). Therefore, using the 1980 yield estimates of 9.9 metric tons combustible organic material, multiplied by 50 percent and multiplied again by $40 per metric ton, results in a value per hectare of $198.

The residual combustible material, not strictly classified as fiber, is estimated to have a fuel value of approximately $20 per metric ton, dry weight basis. The residual combustible material equals the total dry matter content, less 4 percent ash, less the fermentable sugars content, less the fibrous by-products noted above. In 1980, the estimated fuel value of the residual combustible material is estimated at $99 per hectare.

After deducting the value of fibrous by-products and the fuel value of the residual combustible material from the total costs of sweet sorghum, the net cost of fermentable sugars in sweet sorghum is obtained. This amount, or $894 per hectare, divided by the estimated quantity of fermentable sugars obtained (6.8 metric tons per hectare "low" yield in 1980) results in a net cost of fermentable sugars of about $131 per metric ton, which is equivalent to $0.06 per pound.

Projected total costs of sweet sorghum, in real terms, were assumed to increase as a result of higher variable harvest costs associated with increasing crop yields. In other words, it was assumed that variable harvest costs per acre would increase one-half as fast as the percentage increase in crop yields. For example, under the low yield projection assumption, dry stalk yields increase from 18 metric tons per hectare in 1980 to 20 metric tons per hectare in 1985. This was approximately an 11.1 percent increase, so variable harvesting costs per hectare were increased by half this amount, or 5.6 percent. All other costs per hectare were assumed to remain constant. This assumption may be subject to further examination in that some inputs, such as fertilizer and water may need to be increased as yields are projected to increase. For example, if fertilizer costs were to increase at the same annual rate as yield (2 percent per year), the net cost of fermentable sugar would be approximately \$0.040-\$0.042 per pound per year by the year 2000, instead of \$0.039, as shown in Table V-14.

The basis of the yield projections should be repeated here, since they are an important factor affecting the projected net costs of fermentable sugars. After estimating commercial yield goals for sweet sorghum stalks and total biomass, as noted in Table V-II, estimated fermentable sugars and combustible organic material content was projected based on a percentage of fresh stalk yield goals. These estimates assumed a projected fresh stalk yield multiplied by 13 percent fermentable sugars. Similarly, projections of combustible organic material were based on the projected stalk yields times 19 percent. These assumptions imply that the dry matter content of sweet sorghum, excluding ash content,will be approximately 32 percent of fresh weight. These estimates are based upon the experimental results obtained in Texas and Louisiana during the 1977 growing season.

The net cost of fermentable sugars declines from 1980 through the year 2000 as crop yields increase. Utilizing just the stalk portion of the plant, the net cost of fermentable sugars under the assumptions noted above is projected to decline from \$0.06 per pound in 1980 to \$0.039 per pound in the year 2000.

The same estimation procedure was employed in Table V-15 to estimate the cost of fermentable sugars of sweet sorghum when the entire plant was harvested and transported from the field. There are two reasons that the net cost of fermentable sugars is lower under this assumption. First, the total production costs are lower since a lower cost forage harvesting system would be utilized. Second, since all of the biomass is removed from the field, a higher fuel value of residual combustible organic material is realized. The value of fibrous by-products such as fiberboard and animal feed remains the same, since these are all derived from the stalk portion of the plant.

TABLE V-15. COST GOALS FOR FERMENTABLE SUGARS FROM SWEET SORGHUM IN THE SOUTHERN UNITED STATES, UTILIZING ENTIRE PLANT[a]

Year	$/Hectare			Net Cost of Fermentable Sugars		
	Total Cost of Sweet Sorghum[b]	Value of Fibrous By-Products[c]	Fuel Value of Residual Combustible Material[d]	$/Ha	$/M. Ton	¢/lb
Based on Yield Projections in Year:						
1980	1,141	198	245	698	103	4.7
1985	1,152	216	260	676	91	4.1
1990	1,169	240	292	637	78	3.5
1995	1,191	266	334	591	65	3.0
2000	1,201	292	364	545	55	2.5

Source: Estimated by Battelle's Columbus Division.

(a) Cost of fermentable sugars in sweet sorghum biomass delivered to a mill, before separation of stalks from tops and leaves, and before juice extraction.

(b) Includes $100 per hectare management charge over total fixed and variable costs.

(c) Assumes that 50% of combustible organic material in stalk portion of biomass is marketable fibrous by-product, with an average value of $40 per metric ton.

(d) Residual combustible material equals total dry matter, less 6.7% ash, less fermentable sugar content of stalks, less fibrous by-products. Value of residual combustible material estimated at $20 per metric ton, dry weight basis.

Under the whole-plant harvesting system, estimated net costs of fermentable sugars are $0.047 per pound in 1980, and $0.025 per pound in the year 2000.

Qualifications

The cost of $0.025 per pound (in 1980 dollars) of fermentable sugars by the year 2000 is really a mathematical artifact, based on the assumptions contained in the stated estimation procedure. Obviously, a reduction in by-product credits obtained for fibrous by-products would result in higher costs for fermentable sugars. It is beyond the scope of the current study to conduct a market and price analysis for these by-products, especially if large volumes are produced. The values chosen are believed to be realistic in light of current knowledge and conditions.

It is also important to note that these fermentable sugars costs are "as contained in the sweet sorghum plant". In other words, these costs do not include any juice extraction, processing, storage, etc., necessary to get the fermentable sugars into a suitable state for conversion into ethanol or other fuels. Also, no allowance has been made for drying charges that undoubtedly would be necessary if the combustible organic material is to be stored for any length of time before utilization for fuel. Processing seasonality is another factor significantly affecting the commercial feasibility of this type of venture (See Chapters VI and VII in Volume II for more detail).

Also, the fact that the cost of fermentable sugars is lower under whole-plant harvesting as compared to utilizing only the stalk portion of the plant does not mean that this method is necessarily preferred. Undoubtedly, higher processing costs would be incurred at the plant site if the biomass material brought in was a conglomerate mixture of stalks, leaves, seeds, and other trash. In other words, if only millable stalks were to be processed, the whole processing step would be less complicated than if the trash had to be separated from the millable stalks at the plant site. Whether processing facilities should receive millable stalks or total biomass is an issue that needs more investigation.

Grower Income Comparisons

If renewable resources are to be successfully utilized as energy feedstocks, the potential returns (profits) to growers must be comparable with alternative land uses. Insofar as sweet sorghum and sugarcane are concerned, alternative land uses depend upon the geographic region being considered. In Louisiana, alternative cropland uses might be for cotton or soybeans, in addition to conventional sugarcane for sugar production. In the Texas Rio Grande Valley, cotton, vegetables, citrus, and conventional sugarcane production would be alternative crops. In the midwestern United States, corn for grain and soybeans are the major crops currently grown on existing cropland.

Other land uses might include pasture, recreation, and urban development in certain areas. Land values for recreation and industrial and urban development would almost certainly outweigh any demand for land being considered for production of renewable resources for biomass production.

Table V-16 indicates potential returns to growers for various crops grown in U.S. mainland sugarcane regions and the midwestern United States. The data indicate how a hypothetical sweet sorghum and/or sugarcane for biomass production operation would compare to other crops grown in a particular region. The data for "conventional" crops represent approximate averages based on the period 1975-77 (U.S. Department of Agriculture). It should be noted that averages may be misleading in that individual growers may achieve much higher or lower yields per acre. Also, prices for commodities may fluctuate as much as 50-100 percent within a year's time.

In estimating the potential returns to a grower, only out-of-pocket costs were considered in the comparisons noted in Table V-16. Land and management charges are not included in the total costs per hectare. Land charges are an important item in overall production costs; however, for the sake of comparing alternative crops, they may be excluded from the analysis. Also, transportation charges from the field to a mill are not included for sugarcane and sweet sorghum, since these costs are usually paid by the mill operator.

TABLE V-16. ESTIMATED GROWER INCOME COMPARISONS FOR SELECTED CROPS, 1978

	Average Yield Per Hectare (Fresh Weight)	Average Price Per Unit Yield — With By-Product Credits	Average Price Per Unit Yield — Without By-Product Credits	Total Revenue Per Hectare[a] — With By-Product Credits	Total Revenue Per Hectare[a] — Without By-Product Credits	Total Costs Per Hectare[b]	Net Income Per Hectare — With By-Product Credits	Net Income Per Hectare — Without By-Product Credits
Sweet Sorghum for Ethanol[c]								
Southern U.S.--Stalks Utilized	52 MT	$ 18.70	13.08	$ 972	680	$ 735	$ 237	(55)
Southern U.S.--Whole Plant Utilized	71 MT	15.75	9.58	1,118	680	663	455	17
Midwest U.S.--Stalks Utilized	40 MT	18.70	13.00	748	520	591	157	(71)
Midwest U.S.--Whole Plant Utilized	58 MT	15.75	8.97	914	520	534	380	(14)
Close-Spaced Sugarcane for Ethanol[c]								
Florida - Stalks Utilized	93 MT	17.95	15.27	1,669	1,420	1,853	(184)	(433)
Florida - Whole Plant Utilized	108 MT	16.39	13.15	1,770	1,420	1,739	31	(319)
Louisiana - Stalks Utilized	92 MT	17.20	14.78	1,582	1,360	1,357	225	3
Louisiana - Whole Plant Utilized	117 MT	14.41	11.62	1,686	1,360	1,372	314	(12)
Sugarcane for Sugar[d]								
Florida	78 MT	17.60		1,373		1,328	45	
Louisiana	54 MT	15.25		824		830	(6)	
Soybeans[d]								
Louisiana	1,751 kg	0.209		366		210	156	
Midwest U.S.	2,290 kg	0.211		483		170	313	
Cotton[d]								
Louisiana	596 kg	1.232		826[e]		578	248	
Midwest U.S.	730 kg	1.166		952[f]		647	305	
Corn for Grain[d]								
Midwest U.S.	6,287 kg	0.088		553		296	257	

(a) Excluding government payments.
(b) Excluding land, management, and transportation charges.
(c) Hypothetical estimate based on 1977 experimental results and assuming successful implementation of Tilby processing technology.
(d) Yields, prices, and costs based on 1975-77 averages, and currently utilized and cultural practices, harvesting technologies, and recovered by-products, such as molasses from sugarcane, cottonseed, etc.
(e) Includes $91 per hectare for value of cottonseed.
(f) Includes $101 per hectare for value of cottonseed.

The hypothetical estimates for sweet sorghum assume that the new Tilby processing technique will be successfully utilized. This means that part of the fiber in the stalks will be extracted and utilized for industrial markets at an average value of $40.00 per ton. Sweet sorghum and sugarcane for ethanol yields were based upon the anticipated commercial yields previously noted in Tables V-11 and V-12. It was assumed that the fermentable sugars content of fresh stalk weight would be 14 percent, and that fermentable sugars would be sold at a value of $0.045 per pound, or $100 per metric ton. The combustible material other than the fiber is estimated to have a value of $20 per dry metric ton when used for fuel. These assumptions form the basis for an estimated total revenue per hectare which was then divided by the yield per hectare to obtain an average price per ton.

Total revenue per hectare was estimated both with and without by-product credits obtained from the fiber or combustible organic material contained in the plant. These two sets of data are presented to indicate the importance of biomass producers being compensated for this nonsugar material. Without the by-product credits, it does not appear that either sweet sorghum or sugarcane could effectively compete with alternative crops in the southern or midwestern United States. However, with the by-product credits, sweet sorghum compares favorably with other crops, particularly under the concept of whole-plant utilization. On the other hand, sugarcane for ethanol production appears to be more favorable for growers in Louisiana than for growers in Florida. An important question to be resolved is whether or not such yield differentials could be maintained year-after-year under commercial operations. Based solely on these results, it would appear more desirable for growers in Louisiana to produce sugarcane and/or sweet sorghum for ethanol, while Florida producers would continue to produce sugarcane for sucrose. Seasonability considerations in operating, processing, and fermentation facilities favor the Florida location.

Sweet sorghum for ethanol production in the Midwest, including by-product credits, would appear to lie somewhere between corn and soybeans in terms of grower income. However, this does not consider the secondary effects of corn and soybean prices when switching acreage from those crops over to sweet sorghum.

An important factor to note is the degree of "risk" associated with producing ethanol (or other chemicals) from sweet sorghum or sugarcane. In other words, the risk factor associated with a new venture is greater than growing conventional crops with conventional technology for conventional uses. Growers may desire additional compensation for assuming such risks. The degree to which this additional compensation would have to exceed current income is not known at this time.

In the long run, however, if the above estimates are reasonably indicative of actual costs and returns, it appears that sweet sorghum for ethanol could be an alternative crop for American farmers. Upward or downward adjustments in yields and prices for commodities could change the relative income rankings, but there would seem to be enough potential return from sweet sorghum to justify future investigation of this crop as a renewable resource for energy production. Sugarcane for ethanol production could be competitive for growers in those regions where close-spacing can achieve significantly higher crop yields. However, the sugar crop-to-fuel system has several non-agricultural segments with requirements that also must be satisfied. See Chapters VI and VII of Volume of this report.

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AGRICULTURAL RESEARCH AND DEVELOPMENT IMPLICATIONS

The agricultural technology development program for sweet sorghum and sugarcane consists of work in three major categories: variety development, cultural practices, and agricultural engineering. Sweet sorghum and sugarcane have been bred exclusively for edible uses and for processing by conventional sugarcane milling equipment. The varieties have been selected for their composition and yield at conventional row spacings. As described in this and previous Battelle reports, virtually all of these ground rules are changed to a considerable degree when the goal is fuels from biomass. Therefore, a variety development program for each crop is needed to achieve the potential of these species.

The cultural practices associated with sugarcane and sweet sorghum have been directed to use of equipment now in growers' hands. The practice of cane burning and the existence (until recently) of cheap energy sources at mills has led the mainland U.S. industry to adopt cultural practices that are far from meeting biomass prediction goals. As was demonstrated at the 1978 Harvesting Field Day in Belle Glade, Florida, all of the major harvesting equipment is designed for harvesting burned cane planted at conventional row spacings. A major deterrent to narrow-row spacing development has been the lack of harvesting equipment.

Sugarcane production technology is very site specific. There is a very clear distinction between mainland subtropical sugarcane conditions and tropical Hawaiian and Puerto Rican conditions. Also, Florida muck soil conditions differ greatly from those found in the Texas Rio Grande Valley and Louisiana.

The outcome of the 1977/78 fuels from sugar crops research had led to a major restructuring of research and development goals and priorities. This restructuring arises primarily from the impact of three events:

(1) Emergence of sweet sorghum as the leading sugar crop for production of fuels by fermentation

(2) Emergence of the Tilby process as a means of juice extraction that does not require low fiber stalks

(3) Verification of the narrow-row spacing hypothesis in Louisiana but not on Florida muck soil.

These considerations alter the desirability of variety improvement, cultural practices, and harvesting techniques. This chapter is designed to present the research and development implications and opportunities as they exist in mid-1978.

Sweet Sorghum

Sweet sorghum research and development has been carried out on limited budgets by a few dedicated research organizations in the southern states for many years. Especially notable are the efforts of the USDA Sugar Crops Field Station in Meridian, Mississippi, the Texas A&M Agricultural Experiment Station at Weslaco, and the Louisiana State University Department of Agronomy. Except for a few demonstration plantings coordinated by the USDA Meridian Laboratory with Battelle's Columbus Division, northern U.S. research and development on sweet sorghum has been negligible.

The USDA Sugar Crop Field Station at Meridian, Mississippi, presently is the principal organization in the United States undertaking varietal and cultural development of sweet sorghum. It is the repository of over 4,600 varieties. However, it is engaged in a relatively low level of effort with a research staff composed of only a breeder, an agronomist, and a pathologist. Present objectives primarily concern improving varietal disease and pest resistance and fine-tuning the composition of the plant to make it more suitable for edible products. Due to the limited staff, hybridization work has been held to a minimum and no genetic engineering program has been initiated.

Sweet sorghum apparently is capable of cultivation wherever corn or soybeans are grown. This enormous geographical range, high dry matter content for a sugar crop (35 percent versus 28 percent for commercial sugarcane), and degree of fit with the corn/soybean crop rotation cycle promote sweet sorghum to a high level of priority.

Cultural practices development for sweet sorghum would be concentrated in the midwestern states where the large corn/soybean acreage could be rotated with sweet sorghum, thereby leading to the production of billions of gallons of ethanol or other fuels based on fermentation. Specific varieties developed for midwestern conditions would be evaluated at various row spacings, dates of planting, and fertility levels. Material and energy balances, resistance to pests, sensitivity to drought conditions, and many other factors would be measured. It is imperative to obtain a quick start in sweet sorghum development in the midwest. The effort would be spearheaded by Battelle's Columbus Division, a group currently investigating the potential of sweet sorghum as an energy crop in the midwest. From this foundation, the intent is to immediately obtain several collaborators throughout the midwest who would seize upon the initial results to progress at a more rapid rate. If initial results proved successful, funding levels would need to be increased to approach the goals of commercialized production of sweet sorghum for fuels applications.

Sweet sorghum cultural practices in the South would be spearheaded by the Meridian station which would use its field plots to help screen new varieties for the locations. In other areas where the weather permits, multiple crops of sweet sorghum could be investigated. In Louisiana, sweet sorghum technology development would be directed to problems associated with close integration with existing sugarcane mills.

The major aspects of sweet sorghum agricultural technology that need to be subjected to intensive research and development efforts are:

(1) Development of varieties that are suitable for manufacture of fuels

- (a) Achievement of large-diameter stalks suitable for Tilby cane separator process
- (b) Varieties suitable for planting in the relevant regions of the United States with respect to temperature, day length, and precipitation
- (c) Genetic protection against diseases and pests
- (d) High fermentable sugars content regardless of ratio of sucrose to invert sugar

(e) Minimum extraction of nutrients during growth.

(2) Cultural practices that are tailored to the geographical, climatic, and institutional factors

(a) Planting and harvesting dates as a function of variety, spacing, fertilization, and stress factors

(b) Reduction of the incidence and extent of damage to sweet sorghum by insects, weeds, and diseases

(c) Spacing of plants to achieve high yields while still inhibiting weed competition and facilitating mechanical harvesting.

(3) Development of harvesting and beneficiation practices that leave on the field plant parts beneficial for maintaining soil productivity while collecting those parts most useful for fuels and fiber productions. For example, topping of seedheads is necessary with sweet sorghum, in contrast to sugarcane.

Experimentation with sweet sorghum varieties, cultural practices, and harvesting practices provide information on yield, composition, suitability for downstream processing, and the economics of the crop in terms of the cost per usable unit delivered to the processing facility. Accordingly, an integrated approach involving breeding, agronomy, agricultural engineering, chemical evaluation, processing evaluation, and economic evaluation is required.

As shown in Figure VI-1, sweet sorghum research and development activities should be directed to a go/no-go decision to be made by Fuels from Biomass Systems Branch of DOE in the early 1980's. What is needed are the following:

(1) An estimate of the total quantity of liquid motor fuel (or other high priority energy output) that could be generated from production of sweet sorghum on acreage that is agronomically and economically suitable for this crop, using yields for sweet sorghum that are matched to the quality of land to be used for this purpose

(2) An estimate of the cost of the sweet sorghum biomass in terms that are useful for those developing benefication processes and conversion processes

(3) An estimate of the length of the harvesting season for sweet sorghum

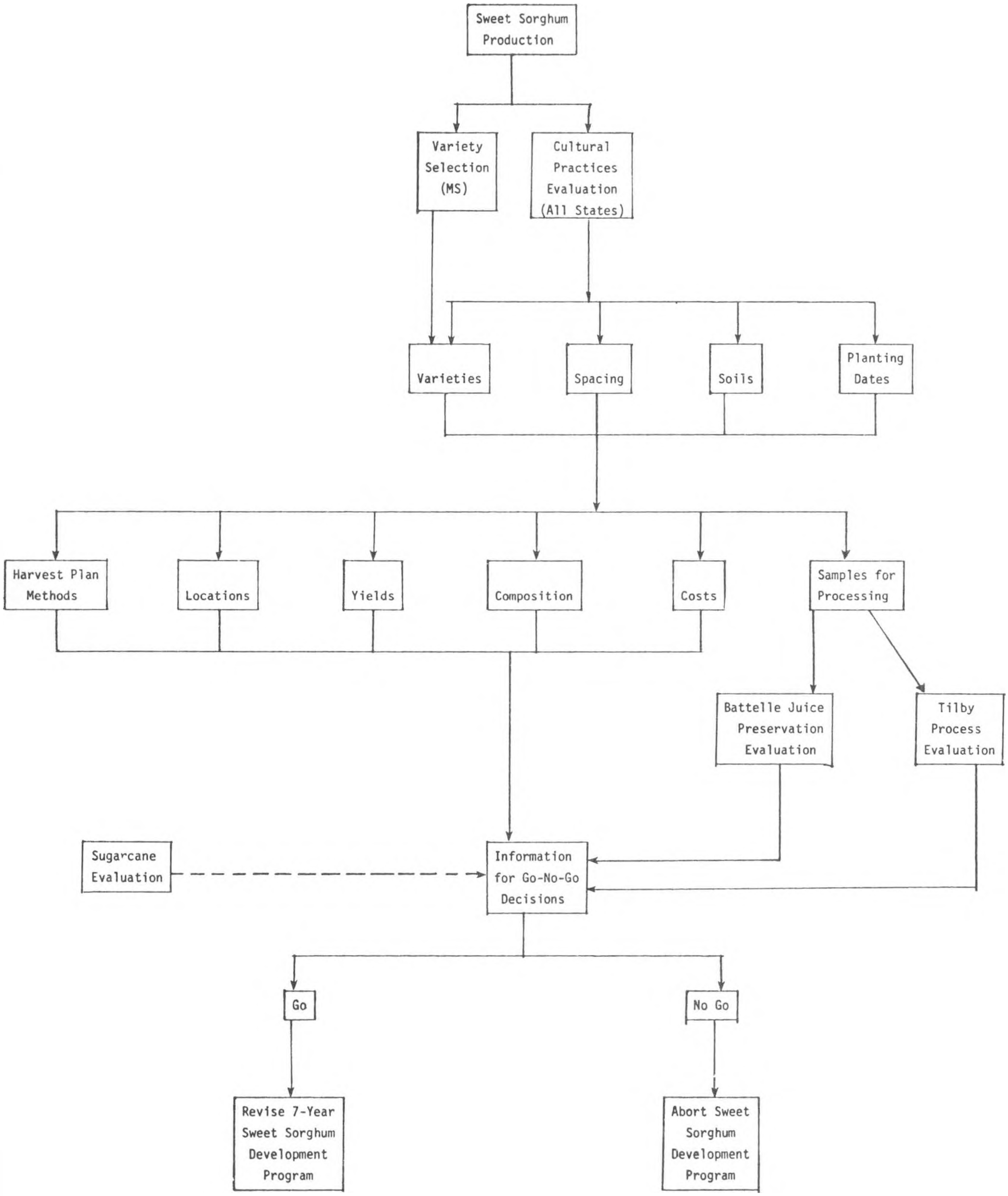

FIGURE VI-1. OVERVIEW OF SWEET SORGHUM ACTIVITIES

(4) An estimate of the probability that the quantity and cost goals can be achieved.

Research and development on sweet sorghum thus serves to put this crop into perspective versus competitive fuel sources, rather than to optimize the crop for immediate fuels production. It follows that it is more important to sample the yields in different geographical regions and soil types and to firm up the economics of production than it is to fine-tune the crop for any specific location.

Sugarcane

The strengths and weaknesses of sugarcane need to be appreciated lest the crop be dropped when it should be retained in the fuels from biomass program or retained when it should be dropped. In Battelle's opinion, the strengths and weaknesses of sugarcane are as shown in Table VI-1 (See Page 190).

The fate of sugarcane is not independent from that of sweet sorghum because sweet sorghum can be employed to further extend the processing season of sugarcane in the South, with advantage to both crops. As shown in Figure VI-2, variety selection and ratoon cropping performance are extremely important in sugarcane production research and development. The introduction of the Tilby cane separator process changes the ground rules for selection of varieties. The hardier, more lodging, and insect-resistant varieties that contain high fiber have been rejected previously because conventional milling practices could not tolerate the reduced throughput. Results of the 1977/1978 experiments in Florida indicate that the commercial sugarcane variety CP 65-357 has relatively little to recommend it as a fuels-from-biomass crop and needs to be replaced with a high fiber variety capable of growing well on Florida's sandy soils over the more extended growing season that Florida offers. As Drs. Alexander and Irvine have both pointed out, the problem of obtaining desired fuels from biomass sugarcane varieties goes deeply into the methodology by which the large collections in Florida and Hawaii were obtained.

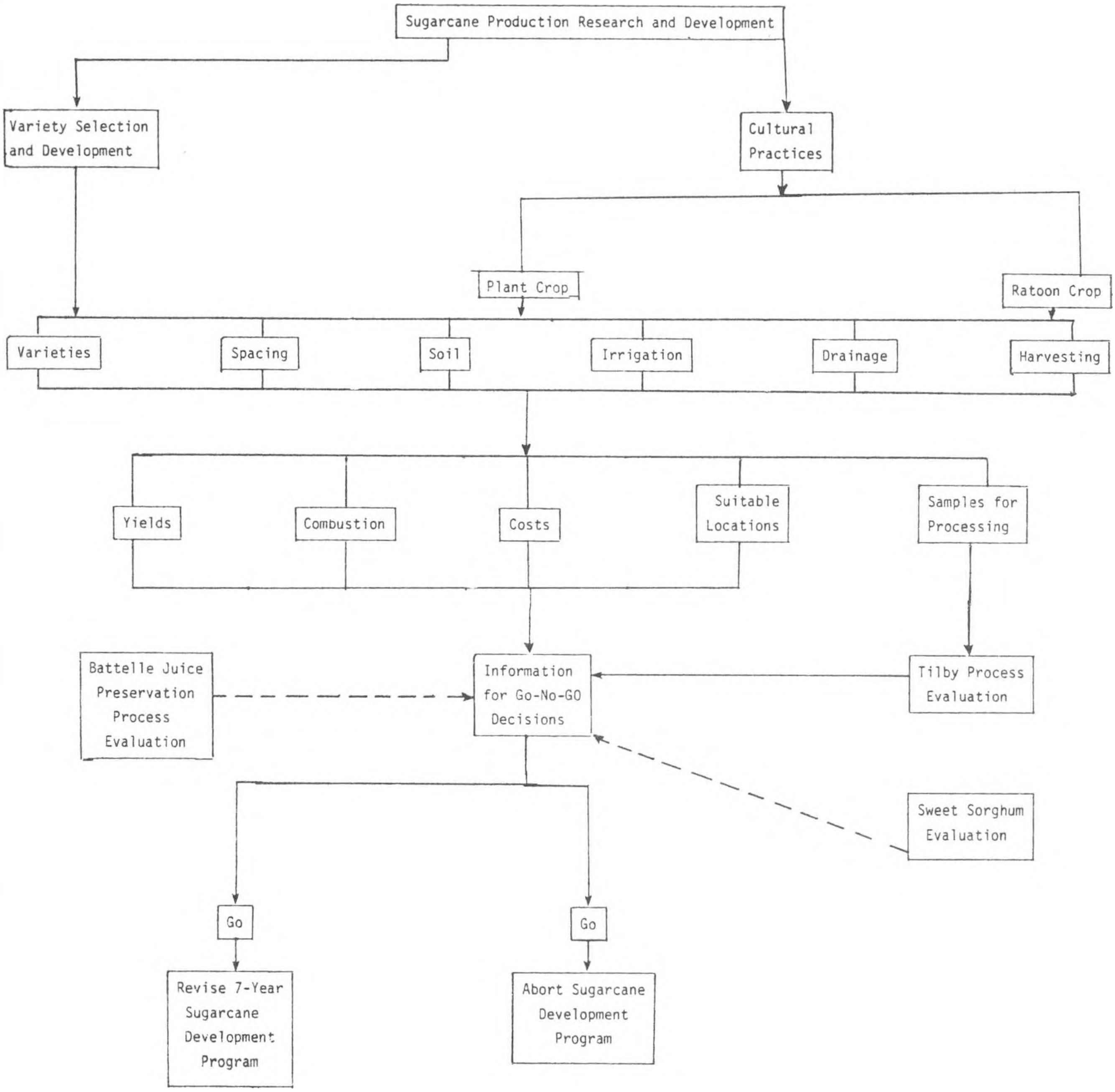

FIGURE VI-2. OVERVIEW OF SUGARCANE ACTIVITIES

TABLE VI-1. STRENGTHS AND WEAKNESSES OF SUGARCANE AS AN ENERGY CROP

Strengths	Weaknesses
(1) Sugarcane is harvested over a long season which has a highly advantageous impact on both processing and conversion to fuel (see Chapter VIII).	(1) By U.S. fuels needs standards, sugarcane has a limited geographical range such that it can have only a localized impact.
(2) Sugarcane produces high yields compared with other U.S. crops.	(2) In Battelle's opinion, the U.S. price support program on sugar for food use represents a powerful disincentive for the type of revolution that is needed to attain profits at low selling prices needed to penetrate fuel markets.
(3) The ratooning crop system in which one planting suffices for 3 or 4 years' production by means of regrowth has desirable economic implications and stabilizes production because the farmer is not shifting to other crops.	(3) A major increase to sugarcane production generally will require development of new croplands, frequently with expensive irrigation or drainage projects; whereas, such crops as sweet sorghum can be rotated with corn or soybeans on land that already is in production

The germ-plasm base on which these superficially extensive collections are based is much too narrow for the purposes at hand. Correction of this germplasm problem is not a matter of a few years' effort--it may take decades. It is not clear yet that sugarcane has such a high priority that the long lead time and great expense should be undertaken. However, the opportunity is there and needs evaluation.

The success of narrow-row spacing in the Louisiana environment raises this cultural practice from the research stage into the development phase. Alternative means to plant, cultivate, harvest, and ratoon narrow-row spaced sugarcane need to be evaluated and the best procedures brought to a development stage suitable for transfer to farm equipment manufacturers and sugarcane growers. The harvesting of narrow-row spaced sugarcane is especially critical because yield maximization presently leads to relatively impenetrable stands at harvest time. If sufficiently rugged equipment is used, the sugar crop can be harvested, but the damage done to the terrain and the plants in the field would cause a very low yield in the ratooned crop. Dr. B. J. Cochran of the Louisiana State University is spearheading a group that is studying this problem and suggestions would be welcomed.

Favorable sugarcane economics are derived from ratooning practices in which yields in subsequent crops are important. This consideration tends to stretch out the time required to determine whether a new cultural practice or variety is worthwhile.

Agricultural Engineering

The amount of agricultural engineering in sugarcane technology development will depend on the cultural practices that are selected as providing the best fuels from biomass system. The agricultural equipment companies have proved to be very cooperative in providing and testing equipment. However, modification of equipment frequently is done by outsiders with subsequent commercialization of the modification by the equipment companies. The foundation of the agricultural engineering technology development will be a state-of-the-art report concerning harvesting equipment which will be coordinated by the Louisiana State University in cooperation with equipment experts from Florida, Louisiana, Texas, Hawaii, Puerto Rico, and other affiliated organizations. This effort will be followed by the development and testing of a prototype harvester(s) built specifically for the utilization of sugarcane as an energy crop. Specific site-harvesting problems will be considered individually by the participating groups.

No satisfactory sweet sorghum harvesting system is available now. Texas A&M has been studying the problem but not from a fuels from biomass viewpoint. The major uncertainty is the breakdown between in-field benefici ation and beneficiation at the processing facility. For example, the Tilby process may be modified to remove leaves and sheaths from the stalk in the same manner it now removes the dirt and cuticles from the stalk.

Agricultural Economics

There are several types of agricultural economics research that are needed for sugar crops. These can be summarized under the following five categories:

(1) Extension of current production cost regarding effects of alternative environments and cultural practices upon sweet sorghum and sugarcane production costs and grower income
(2) Examination of the economic potential for irrigating additional sugarcane land in specific areas of Florida and Texas Rio Grande Valley
(3) In-depth analysis of alternative policies for stimulating the production of sugar crops for fuels purposes
(4) Analysis of alternative market structures and marketing practices necessary to insure an orderly flow of sugar crops for fuels use
(5) A preliminary systems study of a means for extending the length of the annual season for processing sweet sorghum via integration with sugar beet processing.

A summary description of the type of research conducted under each of the above areas follows.

Production Costs

Changes in economic or harvesting practices have an associated cost component. The basic objective of changing cultural practices such as close-spacing, drip irrigation, use of growth regulators, new varieties, etc., is to increase yield of sugar crops biomass per unit area, either in the form of fermentable sugars or combustible organic material. However, it is necessary to make some assessment of whether the increased yield will offset the potentially higher costs incurred through modified environments or cultural practices. The energy input/output ratios associated with new technology also are of paramount importance in utilizing sugar crops as an energy source.

Examples of cost/benefit studies include conventional irrigation versus drip irrigation, conventional harvesting versus multiple harvests within a single growing period, usage of growth regulators and ripeners, costs of modified equipment for harvesting close-spaced sugarcane and sweet sorghum, potential returns from utilizing subsurface drainage, and production costs on Florida's sandy soils.

Irrigation Potential

If sugarcane production is to be expanded in Florida or in the Texas Rio Grande Valley, the "true potential" for irrigating large volumes of additional land must be determined. These types of studies would include projections of water availability for various uses in these areas, the cost of developing irrigation systems on a large-scale basis, alternative uses of water that would cause it to be diverted away from crop irrigation, and associated environmental cost effects of irrigating additional cropland. This study is of particular importance in Florida and Texas because of suspected problems surrounding water availability. If there are insufficient supplies or excessive costs of irrigation, the contribution of these areas to biomass production would be significantly affected.

Agricultural/Energy Policy Studies

Currently, BCD is initiating agricultural/energy policy studies as part of its 1978/79 research. This preliminary work is designed to assess the implications of current agricultural policy legislation regarding its effect on potential utilization of carbohydrate crops as an energy resource. It also will identify and examine, in preliminary fashion, alternative policies for stimulating energy production from carbohydrate crops. This work should be continued to provide a more comprehensive and in-depth analysis. This is particularly true with respect to a crop such as sweet sorghum, which can be grown on a wide geographic area. If sweet sorghum is found to be an economically advantageous substitute crop, interchangeable with corn, soybeans, and small grains, it could result in significant shifts in land use within the U.S. agricultural sector. This, in turn, could present significant impacts on the volume and nature of U.S. food production. If at some point in the future, biomass is a major source of energy for the United States, it is essential that an integrated agricultural/energy policy be adopted. The nature of such research cannot be specified in detail at this time; however, it is essential that alternative programs be conceptualized and evaluated regarding their potential impact on the U.S. population.

Marketing Alternatives

Up to this point, little consideration has been given to the marketing aspect of utilizing sugar crops for fuels. The objective of such studies would be to evaluate growers' willingness to produce and sell biomass, along with various means to which adequate supplies could be ensured at equitable prices for all parties. The research might include consideration of organizational alternatives (i. e., open market, corporation, cooperative, etc.), various types of contractual arrangements between buyers and sellers of biomass, pricing arrangements, grading systems, etc.

Integration of Sweet Sorghum with Sugarcane or Sugar Beet Processing

In developing a new crop such as sweet sorghum as a potential energy source, it is logical to consider it as an extension of existing sugar crops, i.e., sugarcane and sugar beets. This is particularly true because sweet sorghum is a short season crop and would be harvested over a 60- to 90-day period, whereas it is desirable to operate an alchohol manufacturing facility throughout the year. When coordinated into a production scheme with either sugarcane or sugar beets, sweet sorghum has a potential for supplementing the output of existing factories since it is harvested in the summer or fall when the factory is idle. In addition, in warmer, longer season areas, it may be possible to double-crop sweet sorghum with grain or vegetable crops -- with the food crop going into the food market and the sweet sorghum into the energy market. Research in this area would be directed at determining the economic implications for existing growers and processors of sugar crops of integrating sweet sorghum into their current operations. Separate analysis would be made for the sugarcane and sugar beet industries. The work could involve development of a conceptual model for an integrated sweet sorghum/sugar beet or sweet sorghum/sugarcane operation. The model could have separate components for each segment, i.e., a grower model and also a processor model.

If the integration concept looked attractive at the grower and processor levels, estimates would be made of the potential volume of energy produced by integrating sweet sorghum with sugarcane and sugar beets on a large scale. Such estimates might be based on the amount of fallow sugarcane area, and the amount of additional land that might be brought into production in the vicinity of existing sugarcane and sugar beet mills, current mill capacities, economies of scale, the ability to coordinate harvesting both crops, and other factors.

APPENDIX A

LAND RESOURCE INFORMATION FOR NINE SELECTED REGIONS

Nine land resource areas in the mainland United States area of sugarcane production are described in this Appendix, based on information presented by the U. S. Department of Agriculture (Austin, 1965).

Rio Grande Plain, Texas

Land Use

Nearly all the land is in farms and ranches. About 80 percent of it is in range of native shrubs and grasses grazed by beef cattle. Nearly 10 percent of the area, mainly along the Rio Grande and Nueces Rivers, is irrigated. Cotton, seed corn, citrus fruit, sweet corn, melons, and many kinds of vegetables and sugarcane are grown. About the same amount of land in the north and the east is used for crops without irrigation or with only supplemental irrigation. Cotton, grain sorghum, flax, and hay are the principal crops.

Elevation and Topography

Sea level in the southeast to 304.8 meters in the northwest. This plain is nearly level to gently undulating. Valleys are few, widely spaced, and shallow. Local relief is mainly in a meter or so to several meters.

Climate

Average annual precipitation--508-889 millimeters; highest in spring and autumn. Average annual temperature--about 21.1^{o} C. Average freeze-free period--280 to 320 days.

Water

The high summer temperatures reduce the effectiveness of the relatively low to moderate rainfall. The Rio Grande and Nueces Rivers provide water for irrigation, but the smaller streams have a small and intermittent flow and are little used for irrigation. Ground water is abundant throughout the area, and wells provide water for livestock, domestic use, and some irrigation.

Southern Mississippi Valley Alluvium

Land Use

This entire area covers parts of Arkansas, Mississippi, Louisiana, Missouri, and Tennessee. Nearly all the area is in farms. For the area as a whole, about 10 percent is in woodland and the remainder is evenly divided between cropland and pasture. But the proportion of cropland is nearly three-fourths in the north and less than one-fourth in the south. The amount of land on forest varies inversely with that in crops; the amount in pasture is a little higher in the south. This is an important cash-crop area. Cotton, corn, and soybeans grown by highly mechanized methods are major crops throughout the area. Rice is an important crop in Arkansas and Louisiana and sugarcane in southern Louisiana.

Elevation and Topography

Sea level in the south, increasing gradually to about 152.4 meters in the north. The area consists of nearly level to gently sloping broad flood plains and low terraces. Most of the area is flat. The only noticeable slopes are sharp terrace scarps and natural levees that rise sharply a meter to several meters above adjacent bottom lands or stream channels.

Climate

Average annual precipitation--1,143-1,651 millimeters, increasing from north to south; over most of the area highest in winter and early spring, decreasing gradually to a minimum in autumn; along the Gulf Coast highest in midsummer and early autumn. Average annual temperature--14.4^{o} to 21.1^{o} C, increasing from north to south. Average freeze-free period--200 to 280 days, increasing from north to south.

Water

Rainfall, streamflow, and ground water supply an abundance of water. Surplus water is a serious problem on many of the soils and artificial drainage is required before they can be used successfully for crops. The Mississippi River crosses the area from north to south, and many of its tributaries also cross the area. Oxbow lakes and bayous are extensive throughout.

Southern Coastal Plain

Land Use

The Southern Coastal Plain area covers some 375,550 square kilometers in 12 states. A small portion of this area in southwestern Louisiana lies within the region of potential sugarcane production. Nearly all the area is in farms. A small acreage is owned by the Federal Government, and additional small areas are urban or in other uses. Between one-half and three-fourths is woodland, nearly all in small holdings but some in large tracts. The proportion of woodland is greatest in the west. Lumber, pulpwood, and naval stores are the major forest products. Between one-tenth and one-third is cropland; the largest acreage is in the east. Less than one-tenth is in pasture. This is a cash-crop area, and cotton is a major crop. Peanuts, tobacco, melons, various vegetable crops, and corn are also important.

Elevation and Topography

Elevation is 30.48-182.88 meters, increasing gradually from the lower coastal plain to the Piedmont. The gently to strongly sloping dissected coastal plain is underlain by unconsolidated sands, silts, and clays. In their upper reaches, stream valleys are narrow, but the lower parts of the valleys are broad and have widely meandering stream channels. Local relief is mainly in a few meters, but some of the more deeply dissected parts have relief of 30.48 to 60.96 meters.

Climate

Average annual precipitation--1,016-1,524 millimeters; lowest in autumn throughout the area and highest in midsummer in the east and in winter and spring in the west. Average annual temperature--15.5-20.0^{0} C, increasing from north to south. Average freeze-free period--260 to 280 days in Southwestern Louisiana.

Water

Rainfall, many perennial streams, and ground water provide an abundance of water. Even though summer rainfall is fairly high, droughts are common, and then good returns are obtained from irrigation on all but the wettest soils. Drainage is necessary before the wet lowlands can be used for crops. Domestic water supplies are obtained mainly from shallow wells and water for livestock from perennial streams and small farm ponds. The many perennial streams are potential water sources that have been little used in most of the area.

Southern Mississippi Valley Silty Uplands

Land Use

A small portion of this area lies in south central Louisiana. Most of the land is in farms, a small amount is Federally owned, and other small areas are urban or in other uses. About a third of the whole area is cropland but the amount of cropland varies greatly from county to county, depending on soils and topography. This is largely a cash-crop area. Cotton, corn, and soybeans are major crops. Feed grains and forage are grown on dairy farms, mainly near the larger towns and cities. Only about a tenth of the area is in pasture, but the present trend is to a moderate increase in land in pasture. About one-fourth is in forest. Lumber is the major forest product and some pulpwood is harvested.

Elevation and Topography

Elevation is 30.48 to 182.88 meters. The sharply dissected plains have a thick loess mantle, which is underlain by unconsolidated sands, silts, and clays, mainly of marine origin. Valley sides are hilly to steep, especially in the west. The intervening ridges are mostly narrow and rolling, but some of the interfluves between the upper reaches of the valleys are broad and flat. Stream valleys are narrow in their upper reaches but broaden rapidly downstream and have wide flat flood plains and meandering stream channels. Local relief is mainly in several meters to 30.48 to 182.88 meters.

Climate

Average annual precipitation--1,169-1,524 millimeters, increasing from north to south; highest in winter and spring, decreasing gradually through summer to autumn except for a moderate increase in midsummer. Average annual temperature--15.5^{o}-20.0^{o} C, increasing from north to south.

Water

Rainfall and ground water are abundant. In the uplands shallow wells, cisterns, and ponds are the main water sources for domestic use and livestock. Shallow wells provide only small amounts of water but deep wells in the underlying sands and gravels yield large amounts. Most streams in the area are small and flow intermittently. They flow most of the time in winter and spring but only during and immediately after storms in summer and autumn.

Gulf Coast Prairies

Land Use

This area in Texas and Louisiana covers about 41,181 square kilometers. Nearly all the area is in farms. Rice, cotton, corn, grain sorghum, and alfalfa and other hay are the major crops; a large hectareage is in pasture or range of native grasses, tame grasses, and legumes. Bottomland hardwood forests border several streams that cross the area.

Elevation and Topography

Sea level to about 60.96 meters along the interior margin. The level low coastal plain has local relief of only a meter or so.

Climate

Average annual precipitation--635-1,397 millimeters, increasing from west to east; evenly distributed except somewhat higher in midsummer and late summer. Average annual temperature--20.0-21.1^{o} C. Average freeze-free period--280 to 320 days.

Water

The moderate to high rainfall and many perennial streams provide abundant water. Water for irrigating rice is obtained from streams. Ground water is abundant. Much of the land must be drained before it can be successfully used for the general farm crops.

Gulf Coast Marsh

Land Use

Only a small part of the area in Texas and Louisiana is in farms, and little or none is cropped. The drier parts are grazed seasonally, but hunting, fishing, and trapping are the principal uses. Oil wells and sulfur wells are important in some places. Reeds, cattails, bulrush, freshwater marsh grasses, and salt grasses occupy most of the area. Mangrove is prominent in places near the coast, and forests of cypress, tupeol gum, and other wetland hardwoods border the area on the landward side.

Elevation and Topography

Sea level to less than 1.52 meters above sea level. Marshes and swamps are broken by shallow lakes and bayous and are crossed by many stream channels. Except for narrow bands of gentle slopes on natural levees, the area is flat.

Climate

Average annual precipitation--1,397-1,651 millimeters; highest in midsummer and early autumn and lowest in midautumn. Average annual temperature--about 21.1^{o} C. Average freeze-free period--280 days to more than 300 days.

Water

Much of the area is periodically covered either by tide flow or by stream overflow. Flooding and salinity preclude use of most of the area for agriculture.

South Central Florida Ridge

Land Use

About four-fifths of the area is privately owned, but only a small part is organized into farms. About two-fifths is in forest, partly in national forests and game refuges, but mostly in other large holdings. Pulpwood and naval stores are the chief forest products. The forests are grazed extensively. About one-tenth of the area is in crops. This is the major citrus-producing area of Florida. Other subtropical fruits and many kinds of winter vegetables are grown also. More than one-fourth of the area is in pasture. About one-fifth of the pasture is improved and is intensively managed; the trend is to more pastures of this kind. Beef cattle are the principal livestock and dairying is important near some of the large cities. Phosphate mines are a prominent feature in the northern part of the area, and in a few places, they are encroaching on farmland.

Elevation and Topography

Elevation is 15.24 to 45.72 meters, some hills 76.20 meters, and a narrow strip along the western edge at sea level. The nearly level to gently rolling coastal plain has a sandy mantle of varying thickness over limestone. The land surface is very irregular because of the many sinkholes that dot the area. Local relief is mainly a few meters but in places is 30.48 meters or more.

Climate

Average annual precipitation--1,270-1,448 millimeters; highest in summer and early autumn and lowest in late autumn and winter. Average annual temperature--21.1^{o}-23.3^{o} C. Average freeze-free period--300 to 350 days.

Water

Rainfall and ground water supply an abundance of water. Wells in the cavernous limestone that underlies much of the area yield large amounts of water that is highly mineralized but of good quality otherwise. There are many lakes in the sinkholes throughout the area but few perennial streams.

Southern Florida Flatwoods

Land Use

About nine-tenths of the area is privately owned. Most of the remainder is in state and national forests, parks, game refuges, and military facilities. Most of the privately owned land is in large holdings and only a small part is organized into operating farm units. Slightly more than one-fourth of the total area is in forest, mostly of longleaf and slash pine and also some hardwoods. The forests are grazed extensively. About one-half of the area is in pasture. One-fourth to one-fifth of the pastures have adequate water-control systems and have a high carrying capacity. Recently, the trend is to more improved pastures. About 5 percent is cropped, principally to many kinds of winter vegetables. Citrus fruits and some other subtropical fruits are increasing in importance.

Elevation and Topography

Sea level to 30.48 meters, increasing gradually from the coast inland. The nearly level coastal plain is mantled by sand of varying thickness over limestone. The many swamps, marshes, lakes, and streams are prominent landscape features. Most of the area is flat but some hammocks rise up to a meter above the general level.

Climate

Average annual precipitation--1,270-1,524 millimeters; highest in summer through early autumn and much lower in late autumn and winter. Average annual temperature--21.1-23.9^{0} C. Average freeze-free period--300 to 365 days.

Water

Rainfall, surface water, and ground water provide an abundance of water. On much of the cropland ground-water levels are controlled by canals and ditches. Excess water is pumped out during the rainy season and irrigation is provided during the growing season. Domestic and municipal water supplies are obtained mainly from wells in the underlying limestone. Water from this source is highly mineralized.

Florida Everglades and Associated Areas

Land Use

Slightly more than one-half of the area is in Indian reservations, national parks, game refuges, and other large holdings. About one-fifth is forested. Cypress forests are most extensive but mangrove is widespread along the eastern and southern coasts. A large part of the area is open marsh covered by water-loving grasses, reeds, sedges, and other aquatic herbaceous plants. Hunting, fishing, and other recreational activities are major uses of much of the area. Only 5 percent is cropland and about 15 percent is in pasture. Winter vegetables constitute the main crop but some citrus fruits, avocado, and papaya are grown on better drained sites. Sugarcane has become increasingly important on the bog soils south of Lake Okeechobee.The hectareage of improved pasture has been increasing. Beef cattle are the principal livestock and dairying is important locally.

Elevation and Topography

Sea level to 7.62 meters. The level low coastal plain contains large areas of swamps and marshes. Poorly defined broad streams, canals, and ditches drain the area to the ocean. Most of the area is flat, but in the interior hammocks rise a few meters above the general level. Low beach ridges and dunes, mainly in the east, rise several meters above the adjoining swamps and marshes.

Climate

Average annual precipitation--1,270-1,626 millimeters; highest from late spring through midautumn and much lower in late autumn and winter. Average annual temperature--22.2^{o}-23.9^{o} C. Average freeze-free period--335 to 365 days.

Water

Rainfall, surface water, and ground water provide an abundance of water. Near the coast both surface water and ground water may contain salts. A large part of the area is flooded during the rainy season. Canals and ditches are used to control the ground water level for crops and pasture. Excess water is removed by pumping during the rainy season and irrigation water is applied during the dry season. Domestic and municipal water supplies are obtained from wells in the underlying limestones. The water is highly mineralized.

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APPENDIX B

LAND CLEARING METHODS AND EQUIPMENT

Machinery and job requirements are matched for each specific land clearing job. Track-type tractors are used in almost every phase of land development. Approximately six different size track-type tractors are well suited in various stages of land clearing operations. Generally, the use of larger tractors will reduce land clearing costs if the amount of clearing involved is sufficient to merit a greater investment in the bigger machines. Tractor horsepower ranges from 75 hp for the D4D model up to 385 hp for the D9G model manufactured by Caterpillar Tractor Company.*

A brief description of some of the major activities necessary to prepare new land for sugarcane production is described below. As noted above and in the previous quarterly report, specific methods will vary according to location, type of vegetation, soil type, etc.

Cutting or Shearing

A widely used tool for clearing medium and large vegetation (over 5 cm in diameter) in large areas is a shearing blade on a track-type tractor. The shearing blade principle results in the total tractor horsepower being applied to a sharp cutting edge. The shearing blades are usually equipped with a wedge-like projection, which allows larger trees to be split in one or more passes before the trees are actually felled.

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* Mention of specific commercially available machinery is not a recommendation over comparable products of other manufacturers.

Chaining

Chaining involves the use of two tractors to pull a heavy chain which uproots the vegetation. Chain clearing is most economical in arid or semi-arid type vegetation where only limited or no undergrowth occurs. Chaining can be used in almost all size vegetation, with the upper limit in size and density varying according to the size of tractor used and the width of the area chained. Chaining is difficult under extremely heavy undergrowth conditions, which inhibit operator visibility. Also, the terrain should be well drained, level to gently sloping without large gullies, stone outcroppings, or other obstructions preventing tractor maneuverability.

Root Plowing

The root plow removes vegetation below the soil surface by undercutting it at the crown, or bud ring. Large roots are forced to the surface by fins welded to the horizontal blade. Root plows also shatter hard surface crusts and hard pan which results in better water retention and seed bed preparation.

Piling

If vegetation is not disposed of in place, it is normally piled for burning or left to decay. Angled shearing blades and clearing rakes are often used for piling. Rakes are highly satisfactory in extremely sandy soils such as that encountered in northern Florida. Rakes are almost universally recommended for repiling burned or burning materials, since the ash residue sifts through the teeth and more efficient burns can be achieved.

Disking

Tractor drawn disk piles can be used in covering small brush or as the final step in a land clearing operation involving larger vegetation. It can be used on dry, hard, rocky soils where moldboard piles are generally not recommended.

Land Forming

Land forming or land levelling involves reshaping field surfaces to a constant grade and slope (Doane's, 1976). It is used as an irrigation aid and is also utilized in humid areas to improve drainage. A variety of scrapers and land planes are used in making the cuts in fields associated with land forming.

Drainage and Irrigation Ditches

A drag line is typically used to construct the major canals and field ditches used to irrigate and drain sugarcane fields. This is basically an earth moving job in which productivity and cost is based on the number of bank cubic yards to be moved. One bank cubic yard (BCY) consists of a cubic yard of earth material as it lies in the natural state. A 640-acre farm producing sugarcane (1 square mile) is assumed to have 12 miles of ditches (Walker, 1972).

Subsurface Drainage

Subsurface drainage is used on soils that are permeable enough for economical spacing of the drains and that are sufficiently productive to justify the investment. Subsurface drainage is not widely utilized in Florida and Louisiana at the present time. However, it is being utilized to some extent in the newly developed sugarcane lands in the Texas Rio Grande Valley. Installation of subsurface drainage basically involves utilizing some type of trenching machine which cuts the trench and lays the pipe or tile, along with a backfiller to cover the trench. There are several types of trenching machines available, but North American trenching equipment has traditionally centered around the wheel-type trencher. Wheel-type trenchers are less costly to operate than chain- or ladder-type machines, and are generally accepted as being the best all-purpose trencher (Big 'O' Drain Tile Co., Ltd., undated).

Corrugated plastic drainage tubing is widely used in the United States, having been introduced commercially in 1966. Tubing is manufactured in continuous lengths and in diameters ranging from 7.6 to 30.5 cm. Plastic tubing has revolutionized the land drainage industry and daily installation rates of 6,000 meters or more have been achieved, although a typical rate of operation would be 1,500 meters per day (Palmer, 1977).

Construction of Access Roads

Access roads for production, harvesting, and transportation equipment are a necessary part of sugarcane land development. Walker indicates that out of a 260-hectare sugarcane plantation, approximately 28 hectares would be devoted to ditches, canals, and access roads. It is assumed that a track-type tractor plus a grader would be the primary fuel-burning equipment used in constructing these roads.

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