CLER-B-169 PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE: FIRST ANNUAL REPORT 1977 -1978 by THE UNITED STATES DEPARTMENT OF ENERGY, ENERGY AND ENVIRONMENT RESEARCH

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE: FIRST ANNUAL REPORT 1977 -1978 by THE UNITED STATES DEPARTMENT OF ENERGY

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE: First Annual Report 1977-78, by The United States Department of Energy, Oak Ridge Operations Office, and the Division of Solar Energy Fuels From Biomass Branch, Washington, D.C. By The University of Puerto Rico, Center for Energy and Environment Research Through The Office of the President, University of Puerto Rico. CONTRACT NO.: EG-77-G-05-5422 (AES-UPR Project C481) PERIOD COVERED: June 1, 1977 - May 31, 1978 ENDORSEMENT: Leg B2 Cotssucle ‘Alex 6, Alexander Project Leader

Subject: ABSTRACT INTRODUCTION - PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE TABLE OF CONTENTS

(h) Sugarcane As A Short-Rotation Crop

Subject: Sudan 70-k And Napier Grass Trials (a)

Total Dry Matter: Napier Grass vs. Sordan 70-A. Rates of Dry Matter Accumulation. Tissue Expansion vs. Maturation. Moisture Content vs. Harvest Period. Relative Plant Densities.

Breeding Studies:
1. Evaluation of Local Germplasm Sources.
2. Flowering Control in S. spontaneum.
3. Evaluation of Local Breeding Progeny.

Project Outlook: Food and Energy Integration.
1. Categories of Biomass Candidates.
2. Minimum Tillage Candidates.
3. Production Targets.
4. Status of Candidate Screening.

Summary of First-Year Progress:
1. Greenhouse Studies.
2. Field-Plot Studies.

Revised Work Plan for Year 2.

References.
Tables 1-36.
Figures 1-10.

First Annual Report 1977-1978

Production of Sugarcane and Tropical Grasses as a Renewable Energy Source.

Authors: A. G. Alexander, O. Gonzalez-Molina, and J. Ortiz-Velez.
Affiliation: UPR Agricultural Experiment Station and Mayaguez Faculty, University of Puerto Rico.

Abstract: Varieties from Saccharum and related genera are being evaluated as candidates for intensive production of solar-dried biomass. Categories of candidate grasses include short-, intermediate-, and long-rotation species for intensive co-production with conventional food commodities. Minimum tillage candidates are also sought for extensive production on marginal lands. The hybrid forage grass Sordan 70-A (Northrup-King Company) is the outstanding short-rotation plant tested to date. It completes both the tissue-expansion and maturation phases within 10 weeks, yielding at least 4 tons of oven-dry biomass per acre. Napier grass (var. Common Merker) is a promising intermediate-rotation crop which possibly may be exceeded by several Napier grass hybrids. Interspecific Saccharum hybrids and the Saccharum species S. spontaneum and S. sinense are being evaluated for both long-rotation and minimum tillage cropping. Direct comparisons of sugarcane hybrids with Napier grass indicate that sugarcane is an inferior

candidate for short-term production of tropical forages. Sugarcane responded well to narrow spacing for.

About 6 months after seeding, Napier grass failed to respond to close spacing. Both species increased yields with decreasing frequency of harvest. Fertilization rates based on conventional sugar and forage production data were inadequate to sustain maximum biomass yields. Candidate grasses have shown two discrete biomass production phases, i.e., tissue expansion which is highly visible but consists mainly of water, and tissue saturation which has little visibility but yields the bulk of the plants' dry matter. Additional progress was made in sugarcane growth control with chemical growth regulators. Contract No. EG-T7-G-05-5422 (AES-UPR Project No. C-681)

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

Introduction

The biomass production studies herein reported were initiated June 1, 1977 as a contribution to the biomass energy program of the UPR Center for Energy and Environment Research (CEER). This research deals with sugarcane, tropical grasses related to sugarcane, and other tropical grasses having large growth potentials on a year-round basis. The basic premise is that such plant materials can be produced as a renewable, domestic source of fuels and chemical feedstocks that will substitute for imported fossil energy sources.

Project Objectives

Primary objectives include: (a) Determining the agronomic and economic feasibility of mechanized, year-round production of solar-dried biomass, through the intensive management of sugarcane and napier grass as tropical forages, and (b) examination of alternate tropical species as potential sources for intensive biomass production. A secondary objective concerns the selection and breeding of new sugarcane progeny having superior biomass productivity as their principal attribute.

Scope of the Project

Emphasis is directed towards a highly-intensive and mechanized production of tropical grasses as solar-dried forages. This is a deviation from AJ Contract No. EG-77-G-05-5422 (UPR-AES Project No. C-481).

Woe conventional cane and cattle feed production in that total dry matter rather than sugar and food components is the principal salable commodity. Management of production inputs, particularly water, nitrogen and candidate species, together with harvest frequency, will vary significantly from established procedures. On the other hand, advances in mechanized production and harvest operations within the sugar and cattle forage industries will be utilized to the maximum extent possible for dry biomass production. Optimized production operations require the identification of a few select clones and the conditions required for their management in an economically-realistic operation. This is being accomplished in three phases, including greenhouse, field-plot, and field-scale investigations. A fourth phase, commercial-industrial operations, follows logically but lies beyond the scope of the present project. The first year's work herein reported deals with the greenhouse phase and initial field-plot experiments.

The tropical grasses have never before been evaluated under conditions such that biomass energy would be the principal salable product. As a consequence, it is necessary to screen a broad range of candidate cultivars if the optimal yield capacity of these genera is to be realized. Under certain circumstances, existing sugar and fiber-producing varieties may excel also in total biomass yield, but it is generally recognized that the growth attributes have not been fully intensified in the hybridization programs that led to the present-day varieties of commerce. Screening studies have therefore included older hybrid varieties no longer produced commercially, “noble” or pure intraspecific clones, superior selections 1/ Numbers in parenthesis refer to relevant published literature, complete citations are listed on pages 54 to 56

-3 from wild populations, and more primitive forms bearing the germplasm from which modern genotypes have been assembled. A screening

The technique was adopted for this purpose in which botanical, physiological, and agronomic attributes are evaluated in a stepwise program involving greenhouse, field plot, and field-scale trials. In certain respects, this is a tropical application of the herbaceous species screening concept recently formulated by the DOE Fuels From Biomass Program (3). A breeding program designed to intensify the biomass-yielding attribute of Saccharum and related species lies beyond the scope of this project. Thorough breeding studies would require and justify a separate project. This would include the screening of candidate parental types, a physiological phase to synchronize flowering periods at the intergeneric level, and basic genetic research to break some serious constraints preventing the exchange of germplasm among Saccharum species and between Saccharum and allied genera (4). At a very modest level, some limited breeding is included in the present project. This work is confined to a few obviously desirable parent clones that have suitable flowering characteristics and which can be incorporated without inconvenience into an ongoing breeding program. Certain progeny originating with the AES-UPR sugarcane breeding program are also being considered for long-rotation biomass candidates. Under these circumstances, some prospect is created for the emergence of superior new progeny at very little expense. Categories of tropical grass candidates for biomass production are discussed in detail on pages 41-45.

This report covers the period June 1, 1977 through May 31, 1978. Some of the longer-term experiments were not initiated until after July 1, 1977. In these instances, final harvests were not complete at the close of Year 1. For example, the first major field-plot study, a 12-month experiment dealing with harvest frequency, varieties and row spacing, was completed only through the tenth month at the end of May, 1978. The compiled data thus include five of six 2-month harvests, two of three 4-month harvests.

Harvests, and one of two 6-month harvests. Similarly, statistical analyses are confined to "within harvest" variables, since the "between harvest" analyses would have little meaning if based on an incomplete set of data. The finalized data for Year 1 will appear in the first quarterly report of the project's second year. Certain of the results recorded in this report were presented in fragmentary form in earlier quarterly statements. In a few cases, these findings will be reiterated here as they were originally given. However, to the maximum extent possible, prior findings will be represented in the clearer perspective of one year's experience. From this point onward, earlier interpretations will be strengthened by the project's statistical analyses which begin to appear for the first time in this report.

TECHNICAL REPORT GREENHOUSE STUDIES

The project's greenhouse phase is concerned with the screening of candidate tropical grasses and the response of superior cultivars to growth input and management variables. Much information of this nature is obtained more rapidly and cheaply than is possible under field conditions. Greenhouse data are not definitive in the sense that direct field responses and cultural recommendations can be stated, but perhaps two-thirds of the total data package needed for a herbaceous candidate can be gathered in this way. For sunflowers and related species ordinarily propagated in populations of 30,000 to 300,000 plants per acre, the greenhouse offers a level of precision for control of the individual plant that is not remotely possible in the field. This method is currently used in Puerto Rico for its economy of project resources; under temperate climate conditions it offers an economy of time since field work is seasonally limited to four or five favorable months per year.

Greenhouse Method

All plants are propagated either by sand culture in glazed, 4-gallon pots, or in 1:1 or 2:1 mixtures of soil and cachaza contained in 10-gallon galvanized drums. Sand culture is used under certain conditions.

The following text has been corrected:

About 6% moisture, dry matter content (% DM), and water content (% moisture). Leaf samples, including the entire blades of Leaf ranks +1 and 42, are harvested for foliar mineral analyses. In some experiments leaf samples of Saccharum officinarum (9/16) x S. spontaneum (5/16) x S. sinense (2/16) are used. The uppermost leaf bearing a fully-emerged overlap is designated "+1". In sugarcane, this is the youngest fully developed leaf. Progressively older leaves are designated +2, +3, etc., while progressively younger leaves, still emerging from the spindle, are 0, -1, -2, etc.

Chlorophyll determinations. Biomass production characteristics evaluated during Year 1 are presented in Table 2. Both formally-replicated and non-replicated "observation" experiments are conducted in the greenhouse. The latter usually concern preliminary growth-potential measurements involving only a few hundred plants in an area covering roughly 1/200 acre. Replicated experiments deal with specific growth characteristics in previously-identified candidates. Ordinarily, these involve 3 to 5 replications of each treatment arranged in an incomplete randomized block design.

Total Growth Performance

Initial candidate evaluations for total growth included 25 Saccharum and two Erianthus clones in unreplicated trials (Table 3). Several commercial Saccharum species compared favorably with PR 980 under greenhouse conditions. Additional features under observation were germination (rate and percentages of planted cuttings), early growth rates, disease and insect tolerance, and erectness. The following clones were selected for seed expansion and further growth evaluation: Chunnee, Natal Uba, US S6~19-1, Tainan, NG 28-219, Saretha, and the SES clones 231, 317 and 327. The first clearly outstanding candidate to emerge during the first year is a sweet sorghum x Sudan grass hybrid produced by the Northrup-King Company. Marketed under the trade name "Sordan 70-A", this hybrid has shown excellent growth potential as a cattle forage on Puerto Rico's arid lands.

South Coast (7). Two observation trials were performed in the greenhouse. One was a direct comparison against the Saccharum standard, PR 980, and a second comparison against three sweet sorghum varieties of the "Meridian" series (Y71-5, Y72-2, and Y72-3). The sweet sorghum variety Rona and the noble sugarcane Badila, together with PR 980, were also included in the latter trial. In both experiments, Sordan 70-A easily out-produced PR 980. The sweet sorghum varieties similarly exceeded PR 980 in dry matter production over a time-course of 30 days (Table 4). Each of the sweet sorghum varieties have given good yield performances in an earlier AES project investigating their suitability as seasonal substitutes for sugarcane in Puerto Rico (8, 9). However, none of these varieties equalled Sordan 70-A in early green matter production or the rapidity of its conversion to dry matter.

In a subsequent greenhouse trial, Sordan 70-A was compared with Napier grass (var. Common Merker), two imported Napier grass hybrids (PI 7350 and PI 30086), and PR 980. Repeated harvests at 5-week intervals again emphasized the early growth potential of Sordan 70-A (Table 5). The Napier varieties excelled over longer periods of time. None of the candidates showed particularly favorable dry matter contents when harvested at 5-week intervals (Table 6). Dry matter values in excess of 20 percent would be desirable at this time. As discussed elsewhere (pp. 34-37), Sordan 70-A will convert rapidly to dry matter between 8 and 10 weeks after seeding, while Napier varieties require about 15 weeks for dry matter accumulation to accelerate appreciably.

The two Napier hybrids, PI 7350 and PI 30086, have shown excellent yield potentials in cattle forage experiments conducted in the mountainous interior of Puerto Rico (10). In those studies, they had out-produced Common Merker by up to 70 percent in annual dry matter yield. Greenhouse results were encouraging (Table 5); however, yields for PI 30086 compared quite favorably with.

Common Marker. Both hybrids were transferred to the arid Lajas Substation for field-plot evaluations (pp. 31-37).

3. Sudan Grass and Sorghum Hybrids

A series of Sudan grass and sorghum hybrids developed by the Northrup King Company (the "NK hybrids) are thought to have high productivity potentials for the SEEK-UPR terrestrial biomass program. These varieties were developed as cattle grazing and ensilage feed sources for hot, dry climates (©). From this series, the sorghum x Sudan grass hybrid Sordan 70-A has already shown exceptional promise for Puerto Rico's cattle forage industry on the Island's arid south coast (7, 11).

Sordan 70-A is technically a cross between a male sterile Kafir-milo sorghum and an R Sudan grass line produced by Northrup-King via a Piper x Sweet Sudan cross (12). Two other NK Candidates are presently being evaluated within the project's greenhouse phase; Trudan 7, a true hybrid Sudan grass, and Millex 23, a drought-resistant Pearl millet hybrid. The reference variety is Sordan 70-A. Data have not yet been completed from these trials. Additional candidates to be screened during the project's second year include Trudan 5 and the Northrup-King sorghum silage hybrids NK 300, NK 320, NK 326, and MK 367. Ordinarily the test variety would have to exceed Sordan 70-A in dry matter production by a significant factor to be retained for field evaluation. However, owing to the range of drought and pest resistances carried by the NK hybrids, it is conceivable that one or more varieties could extend the Puerto Rico habitat for this type of biomass candidate without having greater productivity than Sordan 70-A.

4. Growth Evaluations

Project emphasis is on candidate grasses suitable for frequent recutting and management as solar-dried forages using conventional forage-making machinery. A candidate's growth performance during the first 2 to 4 months of its

annual growth curve is of decisive importance. Growth performance time-course of 5 months have been measured for 16.

Varieties from the genera Saccharum, Erianthus, and Arundo (Table 7). Arundo donax is a tropical grass found in the wild along streams and irrigation canals on the island's south coast. Sordan 70-A was also included in this group. In terms of dry matter production per individual plant, Sordan 70-4 clearly exceeded PR 980 during the initial two months (Figure 1). This clone flowered heavily between 5 and 8 weeks and no reliable growth data were available after the second month. With reference to total yield per planted area (about 60 sq. ft.), the S. spontaneum clones SES 231 and SES 327, the S. sinense clone Chunnee, and Arundo donax all compared favorably with PR 960. Similarly, the thick-stemmed varieties Crystalina and # 37-1933, although exceeding PR 980 on an individual plant basis, produced less dry matter per planted area due to poorer plant densities. An unidentified wild clone thought to be a S. spontaneum hybrid also produced superior growth during the first two months. Moisture determinations for months 1-5 indicate a rapid dehydration of Sordan 70-A during the second month. It was rapidly becoming a mature plant within 8 weeks after seeding. This is an extremely positive factor in the search for fast-growing species requiring frequent cutting and drying. Such species should not only produce quick yield of green matter, which is largely water, but also convert rapidly to dry matter. Moisture values for thin and thick-stemmed varieties were comparable up to the fifth month (Figure 2). At this time, the more primitive thin-stemmed plants revealed greater dehydration than Saccharum hybrids and Crystalina (S. officinarum). The unidentified S. spontaneum hybrid produced a dehydration pattern intermediate between that of PR 980 and Sordan 70-A, a positive factor in this clone's favor. Growth curves encompassing a time-course of 3 months have been plotted for the sorghum varieties M71-5, M72+2, M72-3 and Roma, together with Sordan 70-A, Badilla, and the reference cane hybrid PR 960 (Figure 3).

The superiority of Sordan 70-A for rapid lines growth and an early conversion to dry matter is clearly evident. On an individual plant basis, Sordan 70-A had produced by 8 weeks as much dry matter as PR 980 could produce in 12 weeks. Roa is also a superior candidate in this respect.

5. Growth-Regulator Studies (a) Growth Inhibitor Responses: It has been shown that the plant growth inhibitor Polaris (Monsanto Agricultural Products Co.) produces growth increases in sugarcane when applied in low concentrations as an aqueous foliar spray (13). There is some likelihood that biomass yields from tropical grasses can be increased by this means at very little expense. Initial trials within the present project utilized juvenile sugarcane propagated by sand culture. The Monsanto products Polaris and CP 70139 were tested at sub-repressive concentrations on 6-weeks old plants of the variety PR 980. The objective of such trials is to produce a persistent increase in growth activity through a mild chemical "shock". Positive responses were obtained with Polaris administered as aqueous foliar sprays containing 50 to 300 ppm active ingredient (Table 8). These concentrations are roughly 1/10 to 1/50 of those required for optimal action as a chemical ripener on the IC variety. Internode measurements (Figure 4) suggest a greater persistence of the inhibitor's stimulatory effect than would be possible with a plant growth hormone such as gibberellic acid. This persistence is also affirmed by direct weight measurements taken at 6 and 12 weeks following chemical application (Table 8). The Monsanto compound CP 70139 produced growth repression rather than growth increases. Polaris was compared with several other plant growth inhibitors during the third quarter. These included Mon 6000 (Monsanto), ACR 1093 DA (Dr. Re Mang, Ltd., Düsseldorf, Switzerland), and Embark (3M Company). The test concentration was 109 ppm active material, the level at which Polaris appears to be most effective. Embark increased growth at a.

The following text has been corrected for spelling errors and clarity:

The level was comparable to Polaris for the first 6 weeks after treatment while the other candidate materials remained growth inhibitory (Table 9). The effects of each material similarly persisted through the subsequent 6 weeks. The extended duration of the growth-stimulatory effect is itself encouraging. Under identical conditions, growth stimulation in the same variety with the growth hormone gibberellic acid (Gig) seldom persists more than 4 or 5 weeks (15). When used as a chemical ripener, the action of Mon 8000 is identical to that of Polaris with the exception that Mon 8000 produces its effect at lower concentrations (13). Hence, it was thought that concentrations appreciably lower than 100 ppm might also produce growth increases. This seemed to be borne out in 2 subsequent trials where 10 and 25 ppm active Mon 8000 produced green weight increases of 17.6 and 27.9%, respectively (Table 10). Moreover, the number of harvested stems was also increased by the chemical when used at these levels.

Almost from the moment of germination, while others were reluctant ever to do so (16). A majority of clones increase tiller production roughly in proportion to the frequency of harvests. The use of chemical growth regulators that encourage tillering could be of value in several ways to biomass energy interests: (a) In any given planting the maximum stem population per acre could be attained earlier; (b) less seed would be needed; (c) where technical or engineering factors prohibit the narrowing of row centers the intra-row plant population could be increased as an alternative: and (d), superior biomass-producing candidates that are otherwise disqualified owing to an inability to tiller might be retained by chemical means. The latter example appears to be the case at present with a S. spontaneum hybrid having excellent growth potential but a persistent difficulty in establishing a satisfactory population.

Direct growth stimulation with plant hormones such as gibberellic acid have not given satisfactory results with sugarcane (14, chap. 12). Very pronounced growth increases occur as a temporary response which is lost after 2 or 3 joints are laid down. Gibberellin effects can be prolonged by multiple treatments or split applications of any given dosage (17, 15). However, this is followed by a slackening of growth until sub-normal levels are attained (18). The net effect is little or no increase in sugarcane tonnage, or increases too small to justify material and treatment costs.

Certain plant growth repressants used as chemical ripeners for sugarcane produce growth stimulation when administered in very low concentrations. Polaris and Babar will produce this effect as will 6-azauracil (19) and several other analogs of pyrimidine. The function of such responses is not clearly understood, but it is reasonably certain that the growth control mechanisms for sugarcane have sufficient flexibility to "command" increased growth activity when the presence of an inhibitory chemical is sensed by the plant.

Plant. This may be viewed as a compensation by the plant for "anticipated" growth stresses, or perhaps a more efficient usage of existing growth mechanisms and of growth resources already available to the plant. Whether plant growth increases of an appreciable magnitude can be produced by growth inhibitors remains to be determined. All of the Polaris concentrations used in the first experiment were too low to increase juice quality (Table 12). There is little likelihood that any ripener used in this concentration range would offer increased sugar as an added benefit. On the other hand, the Polaris concentration required for optimal biomass yield increases in sugarcane (100 ppm) is only about 1/30 of the level required for optimal ripening. Under field conditions, the quantity of Polaris needed to ripen one acre of sugarcane should suffice to increase growth in about 30 acres. Low material costs and the improved prospects of achieving adequate plant penetration operate in favor of using growth regulators in this manner for biomass production, if any appreciable yield improvement can be demonstrated. The possibilities for seasonal growth improvement or for the breaking of stresses imposed by adverse climate, moisture, or nutritional regimes also warrant consideration. An added advantage would derive from the co-administration of growth regulators with another material already required by the biomass crop. Under certain conditions, short-rotation tropical forages would require a foliar insecticide application some 3 or 4 weeks after planting, and overhead irrigations at about 4 and 8 weeks. Foliar urea is readily administered as a supplemental N source with overhead irrigation water (7). Accordingly, future experiments with growth regulatory materials on tropical grasses will include their co-administration with pesticides and urea.

6. Regrowth Studies

Initial data collection on plant regrowth rates was initiated during the second quarter. These measurements will determine: (a) The vigor and

Quality of ratoons (shoots) produced by established crowns whose tops have been harvested; (b) the number of new stems produced, i.e., the rate at which a single-eye cutting will expand into a multiple-stem crown; and (c) the persistence of vigorous regrowth over an extended period of time. Gibberellic acid is most effective as a growth stimulant in sugarcane when plants are undergoing some degree of physiological stress (22, 23).

 Many tropical grasses have a natural tendency to form "bushes" as they are repeatedly cut back. Exceptions to this may include the unidentified S. spontaneum hybrid discussed earlier in this report and the S. sinense clone Mandalay, both of which appear to produce only single shoots when the primary stem is harvested. Vigor of the regrowth is of equal concern. Even among hardy species such as B. pumila, a serious shock is experienced when the top/root ratio is drastically altered in this manner. The variety Camon Merker, for example, usually produces only weak and yellowed shoots for about two weeks after harvest before its vigorous growth habit and green color are reestablished (20). Persistence of vigorous regrowth is of even greater concern. Ideally, this project will identify candidate clones that will withstand frequent recutting for periods of several years duration. We will be fortunate to find two or three species that will do this. It may be necessary to establish the crowns and root systems very thoroughly over periods of 6 to 12 months before initiating a long series of repeated harvests. In this instance, the cutting height, harvest equipment to be employed, and use of growth-regulatory agents for improved crown development will all be contributing factors to successful long-term harvesting operations.

7. Mineral Nutrition

Two biomass nutrition experiments were initiated during the project's first year. One experiment relates to a nutritional disorder observed in Napier grass during the initial field-plot trials at the AES-Lajas Substation. It was

The text was tentatively identified as a manganese deficiency in a greenhouse experiment with the same variety (Common Merker) propagated by sand culture. All nutrient solutions were prepared with ACS-grade salts in once-distilled water.

Two non-replicated blocks of plants were propagated for 7 weeks, one block receiving a complete nutrient solution while manganese was withheld from the other. Leaf freckling symptoms characteristic of the field disorder began to appear in the leaves of the manganese-deficient plants at 4 weeks. Traces of the symptom also appeared in some plants of the control group (receiving 0.5 ppm manganese), suggesting that the manganese requirement of this plant is considerably higher than the norm for tropical grasses. It is also possible that the field symptoms were not purely the result of insufficient manganese in the soil. Manganese disorders quite commonly relate to soil pH and iron levels which affect the availability of native manganese to plants (21).

A second nutrition experiment was established during the fourth quarter using Sordan 70-A as the test species. Variable nitrate-N levels were provided to establish the project's first nitrogen-response curve. Plants were propagated in sand culture with water and all nutrient elements other than nitrogen held constant. The principal objective was to determine the slope of the plant's growth response when supplied with progressively higher levels of nitrogen. Accordingly, nitrogen supplies were increased in a geometric progression from 1.0 to 81.0 milliequivalents/liter of nitrogen. The low-nitrogen treatment was deficient while maintaining some limited growth; high nitrogen (81.0 meq/1) offered a vastly greater supply than most tropical grasses can utilize.

With sugarcane, for example, nitrogen levels in sand culture exceeding about 20.0 meq/1 are utilized only in the sense of "luxury consumption" (14). For sugarcane, 9.0 meq/l of nitrogen in sand culture are roughly comparable to a field treatment amounting to 100-150 pounds of elemental nitrogen per acre per year.

18 Growth data recorded at 4 and 8 weeks after seeding are.

The text can be corrected as follows:

As illustrated in Figure 5, at 4 weeks, there was little response to NO3 levels higher than 3.0 meq/l. This was partly due to the lack of a root system sufficiently developed in the young plants to make use of so much nitrogen. Large increases were obtained between 4 and 6 weeks with 9.0 meq/l of NO3 being optimal. Nitrogen levels higher than this appeared to be growth-repressive. The present data are incomplete as they pertain only to the rapid growth phase and exclude the main period of dry matter accumulation, i.e., from 8 to 12 weeks. Nutritional information gathered by the sand-culture technique is not directly applicable to field conditions; however, the type of the N-response curve is a characteristic feature of the candidate cultivar whether it is grown in sand under glass or in an open field. The response curve for Sordan Tora is in fact a very favorable one. It indicates that there is a fairly distinct point beyond which no further gain can be expected from increasing expenditures of nitrogen fertilizer. The situation would be much more complicated if the plant had continued to respond to higher N levels in a weakening first-order curve. In this case, a net-energy balance scenario for Sordan 70-A would require some elaborate field-plot work to pinpoint the correct cut-off level for applied N. It might never be determined with any appreciable precision.

Section 8. Importation and Quarantine of Candidate Tropical Grasses:

A number of Schauer clones and clones from both related and unrelated genera were available in Puerto Rico for screening as biomass candidates when the project was initiated on June 1, 1977. However, the vast majority of clones from these genera reside outside of Puerto Rico, both in the wild and in national and international collections. Mr. T. L. Chi, a project collaborator and a recognized authority on S. and allied species, traveled to the US mainland during December of 1977 to evaluate cultivars there as potential candidates for biomass screening in Puerto Rico. He...

[Continuation of the text]

Visited USDA collections at Canal Point, Florida, at Houma, Louisiana, and at Beltsville, Maryland. A total of 73 clones were identified as suitable candidates and arrangements were made for their shipment to Puerto Rico. An additional 379 clones from Indonesia (1976) and 25 from New Guinea (1977) were observed at Beltsville; however, these were still in quarantine and several years may pass before any of this material is available for export. The first fourteen clones were received from Houma during January, 1978, and at present are in quarantine at the AES-Gurabo Substation. This group significantly expands the germplasm selection for bio screening in Puerto Rico (Table 13). They are all intergeneric or interspecific hybrids representing parental material from the genera Saccharum, Eccoilopus, Sorjanthus, Ext, and Ripidium. Each of these clones Sclerostachya, Mfch, and those to arrive during 1978 have displayed an exceptionally robust growth habit and profuse tillering.

B. FIELD PLOT STUDIES

1. Saccharum Species Candidates at Gurabo Substation: The initial harvest was performed from an

observation field-plot trial with candidate Saccharum species. This group consists of S. spontaneum clones imported for conventional breeding purposes during 1976 and a series of S. spontaneum and S. ginense clones that had already shown desirable biomass properties under greenhouse conditions (Table 14). They were planted in non-replicated, 1/200 acre plots on a clay-loam soil at the Gurabo Substation. PR 980 served as the reference clone. All candidates were planted at standard row centers (150 cm) and received standard fertilization plus supplemental overhead irrigation when needed. The initial harvest, taken at 4 months, tended to favor the Saccharum hybrid PR 960 and other thick-stemmed candidates. At this stage of development, such plants already bear a 2 to 4-foot fleshy stem which would be difficult to dry for forage-making.

Operations, even though their advantages will be increasing more rapidly than those of the wiry-stemmed candidates more suited to forage production. Nonetheless, two of the S. spontaneum candidates equalled or surpassed the dry matter yield of PR 950 (Table 14, US 67-22-2 and US 72-70). Two other candidates, Tainan (S. sinense) and US 72-166 (S. spontaneum) also compared favorably with PR 980 while not quite equalling its yield. It should be noted that under conditions of maximized plant density, most of the chosen species would vastly exceed PR 980 in the number of plants produced per acre. An Erianthus clone included in this experiment gave an unremarkable yield owing largely to poor germination. Two additional harvests were completed during the project's first year, at 6 months and at 8 months (Table 14). Total yields for the 8-month interval show a very superior performance by two S. spontaneum clones (US 67-222 and US 72-70), each producing about 1/3 more dry matter than PR 980. An additional S. spontaneum clone, SES 231, had difficulty becoming established and produced very poor yields at 4 months, but it was clearly the superior biomass producer at 6 months and 8 months. This was largely the result of an excellent tillering performance following the initial harvest (Table 15). Each of the three S. spontaneum candidates has shown sufficient potential relative to PR 980 to warrant further evaluation at the field plot level.

2. Sugarcane and Napier Grass: The project's first replicated field-plot experiment was established at the Isle; Lajas Substation during July 1977, at the semi-arid AES-Lajas Substation. Controlled variables include varieties, row spacing, and harvest frequency (Table 16). There are three hybrid sugarcane varieties (PR 980, NCo 310, and PR 64-1791) and one Napier grass variety (common Merker). Each variety is recognized as a superior producer of biomass tonnage under Puerto Rico conditions.

(a) Field-Plot Methods: This experiment was planted on a moderately well-drained

The text should read:

The soil is clay in the Fraternidad region. The plot size is 1/50 acre and there are 'x' replications of each treatment, arranged in a randomized block design. All clones receive constant water and fertilizer levels, at roughly double the commercial rates for this region. Fertilizer was applied in three increments; 1/3 at planting, and 1/3 at 4 and 8 months after planting. Nitrogen in the form of ammonium sulfate was supplied at the rate of 200 pounds per acre per year for sugarcane and 600 pounds for Napier grass. Water was provided as needed by flood irrigation, delivering in the order of 2 acre inches per application. Whole plots, consisting of a 600 square foot area, are harvested at the appropriate interval, i.e., at 2 months (six times per year), at 4 months (three times per year), and at 6 months (two times per year). Two sub-samples of 10 plants each are harvested for dry matter determinations and for tissue samples used in various tissue-component analyses. These analyses include W, P, K, S, St, and ash for leaves, and invert, soluble protein, and sugars for meristem samples. Plans have been made to maintain this experiment for the duration of the project. This is the only study where long-term responses to biomass production variables can be measured over the course of several years.

In terms of establishing field-plot parameters, the project's field-plot phase is essentially an extension of the greenhouse screening studies. As biomass candidates will commonly vary at the genus level, certain decisions have to be made regarding the establishment and maintenance of controlled parameters. At a recent planning conference on herbaceous species screening held in Washington, D.C., there was a consensus that equal and constant production input parameters should be established for all species, at least at regional levels in the continental U.S. Candidate species for much of the screening work will have little or no history of intensive cultivation or genetic improvement. This is particularly true of wild plants and... [text cut off].

Arid-land species are being evaluated as energy sources for the first time. This is not true of sugarcane and Napier grass, both of which have long histories of intensive cultivation, genetic improvement, and advanced technologies for mechanized production and harvest. To apply equal production-input standards for the two groups would constitute an important step backward in the art of biomass production. The nitrogen (600 lbs/acre year) was set at three times the level for Napier grass, which is also higher than that of sugarcane, in accordance with the higher consumption rates known for Napier grass. Similarly, the standard and narrow row centers for Napier grass were set at 50 cm and 25 cm, rather than at 150 cm and 50 cm as was done with sugarcane. Harvest intervals of 2 and 4 months are a recognized advantage for Napier grass whereas intervals of 6 months or more are expected to favor sugarcane. Management practices that are equal for sugarcane and Napier grass include the level, method, and frequency of irrigation, the timing and method of multiple fertilizer applications, and all pest control procedures. Of greater concern was the location of Napier grass plots together with sugarcane within a single experimental design. The possibility exists that soluble nutrients may move laterally underground from areas of higher fertilizer application. Under semi-arid conditions, this could theoretically occur when soil water is replenished in stepwise flooding operations requiring two or three days to cross the experimental area. Moreover, the Lajas Sub-station canal system carries water continuously from one side of the Station to the other. The lateral movement of water from these canals to adjoining experiments is a recognized possibility, depending on the respective soil class and its water-receiving capacity at any given interval. This is also a contributing factor where soil drainage problems occur. These factors were considered when the first major field-plot experiment was established; however, no decisive compromises were expected by the cane.

The text is about a study involving Napier grass and sugarcane. Following the initial 2-month harvest, there were signs of possible nutrient deficiencies in some Napier grass plots. These were seen as foliar discolorations.

Similar symptoms, akin to manganese deficiency, appeared in nearly all Napier grass plots about 3 1/2 months in. No such symptoms were observed in the sugarcane plots, even though they had received only 1/3 of the fertilizer level given to Napier grass.

The symptoms in Napier grass significantly decreased or disappeared entirely after a second round of fertilization at 4 months. If the suspected deficiencies in Napier grass are confirmed by foliar diagnosis, it may be necessary to consider higher fertilizer rates and micronutrient additives in the fertilizer mix for Napier grass in the Lajas valley.

Production: By the end of Year 1, field-plot data had been collected for 10 months. This included five of six 2-month harvests, two of three 4-month harvests, and one of two 6-month harvests. The remaining first-year data will be summarized in the first quarterly report for Year 2.

Biomass yield data for the initial 10 months have shown the following trends:

(a) Napier grass is superior to sugarcane as a source of dry matter.
(b) Sugarcane responds more readily to narrow row centers than Napier grass, but this advantage decreases with age.
(c) Dry matter yields increase with less frequent harvesting.
(d) Early maturation of the candidate species, i.e., the capacity for rapid conversion of succulent new growth to dry matter, is a decisive factor in determining ultimate yields.
(e) Fertilization treatments based on conventional sugarcane and cattle forage production data are inadequate for optimal biomass yields.

Varietal Responses; Sugarcane vs Napier Grass: Over the first ten months, Napier grass has generally outperformed sugarcane as a biomass producer. Their differences were most evident at the first 2-month harvest when the

The ability to quickly establish a root system and to enter a zero-order growth phase overshadowed all other factors (Table 17). Total dry matter yields for the 1-month interval indicate a persistently higher yield capacity for Napier grass (Table 18). When harvested at 2-month intervals, sugarcane yields approached those of Napier grass only at the 4 and 5-month harvests (Table 20). These two periods coincide with the longest intervals following incremental fertilization, and hence reflect an inferior capacity of Napier grass to produce with a diminishing soil nutrient supply. Yield differences among individual sugarcane varieties at times remained statistically significant (Tables 19 and 21), but generally remained small in a quantitative sense. The sugarcane hybrid NCo 310 was moderately superior when harvested at 2-month intervals while PR 960 was the leading producer when harvested at 4- and 6-month intervals (Tables 22 and 23).

Close-Spacing Responses: The narrowing of row centers increased biomass yields for sugarcane but had little effect on Napier grass. Sugarcane juice quality was not appreciably affected as evidenced by hand refractometer values (Table 24). The sugarcane yield increases were most pronounced at 2 months (Table 17), and statistical significance was still attained at 4 and 6 months (Table 21 and 19, respectively). When harvested for the first time at 6 months, each of the cane varieties produced significant green tonnage increases at narrow row centers (Table 23). The magnitude of yield did not exceed 30% for green or dry weights. The highest green matter yield at 6 months was 48.5 tons/acre for sugarcane variety FR 980, and the highest dry matter yield was 13.6 tons/acre for Napier grass variety Common Mecker. There were no appreciable differences for sugarcane after 6 months from the time of planting or for Napier grass after 2 months.

DOE studies on cane row spacing in Louisiana and Florida have produced somewhat similar responses (26, 27). Yield.

In general, the spacing was larger in Louisiana (around 602) than in Florida (about 102), even though the experimental procedures had been carefully synchronized between the two regions. This is an important finding for Louisiana where the shorter growing season is restrictive against conventional cane production. Canopy closure does not appear to offer a complete explanation for the lack of narrow row responses at 8 months and later. Plants reharvested at 2-month intervals do not completely close their canopy but the narrow-row response was lost nonetheless. The time-consuming development of cane root systems is probably a contributing factor, since a far more vigorous crown development and tillering capacity was obtained at standard row centers with the passage of time for each of the three cane varieties. In the Puerto Rico experiment, all cane varieties had relatively weak and undeveloped crowns at the first 2-month harvest. At that time, the narrowing of row centers was the only real means available for these clones to increase their stem densities. From 4 months onward, the established crowns at standard row centers seemed to do this nearly as well as the more closely-spaced crowns. If this is correct, the best means of improving sugarcane density may be to plant a greater number of seed pieces within the row at standard row centers. Some evidence to this effect has been reported from intra-row seed density studies at Louisiana State University (26). Problems incident to cultural management and harvest operations would be eased considerably if standard row spacings can be retained for the intensive production of sugarcane biomass. Together with the varietal factor, the longer growing season in Puerto Rico (as compared with Florida and Louisiana) does not seem to offer a reasonable explanation for the loss of narrow-row responses after 6 months. However, in the event that two 6-month crops per year are contemplated for Puerto Rico's future, the island's 12-month growing season would...

Constitute a distinct advantage for intensive biomass production: (2) Harvest Frequency vs Maturation: In planning this project, the capacity of sugarcane to respond to frequent recutting was greatly overestimated. As indicated in Table 18, sugarcane harvested once at 6 months exceeded by more than 60 percent the combined yields of five 2-month harvests. High cane yields as they are known today require a massive stem which cannot be produced in 8 weeks. Napier grass was much more responsive to frequent recutting than was sugarcane (Table 18). However, due apparently to inadequate fertilizer, the superior growth potential for Napier grass was not fully utilized between months 2 and 4, and between months 6 and 8 (Table 19). During the course of the first year, a short-rotation candidate superior even to Napier grass was found in the sorghum x Sudan grass hybrid Sordan 70-A. Sugarcane yields increased progressively as the interval between harvests was lengthened from 2 to 6 months (Table 18). A single harvest at 6 months exceeded by 23 percent the combined yields of two 4-month harvests. Napier grass continued to produce more dry matter than sugarcane with lengthening harvest interval but the differences were becoming less pronounced. The goal at 10 months was that, to obtain maximum dry matter from sugarcane, the established cane stands should be left in place as long as possible before they are harvested. Hybrid sugarcanes are no longer regarded as a likely source of short-rotation candidates. More primitive saccharum species such as S. spontaneum and S. spontaneum hybrids might be suitable candidates for frequent recutting operations.

To a large extent, the optimal harvest interval for a given candidate will relate to its maturation profile, that is, its ability to convert sugarcane new growth to dry matter. This is a far more deceptive characteristic of candidate tropical grasses than was at first recognized. For example, the green weight data for the first 6-month harvest (Table 23).

The text indicates significantly greater tonnages of sugarcane than Napier grass, while dry weight tonnages show that Napier grass was significantly more productive than sugarcane. The explanation for this lies in a more rapid conversion of green matter to fiber by Napier grass. Once, while the sugarcane varieties ranged from 19.1 to 20.9 percent dry matter, Napier grass ranged from 31.5 to 32.9 percent (Table 25). Both sugarcane and Napier grass are quite succulent during their juvenile and early-adult growth phases. They yield in the order of 15 to 18 percent DM when harvested repeatedly at 2-month intervals (Table 26). When allowed to grow for 4 months between harvests, sugarcane retains a characteristic succulence while Napier grass increases DM by up to 90 percent (Tables 27 and 28). In 6-month old sugarcane, the dry matter content continued to lag behind that of Napier grass (20% vs 32%, Table 29). Napier grass shows little outward change during the 8 to 16-week interval save for the emergence of some tassels and a few yellowing leaves. In Jordan 70-A, the rapid conversion to dry matter begins 4 or 5 weeks earlier than in Napier grass and is accelerated by very heavy tasseling. A comparable maturation would not ordinarily begin in sugarcane until 8 or 9 months, or until forced by cultural practices (withholding N and water). Some cane varieties also tend to produce further as a consequence of a profuse tasseling habit, but many more varieties produce few or no tassels in the course of a year (14).

-29- On a future energy plantation producing solar-dried tropical forages, the principal salable product would be dry matter. Species designated for rapid growth and frequent recutting would need to change swiftly from an early vegetative growth phase to a fiber-accumulating maturation phase. Flower induction is a natural means of initiating this change, although it might also be accomplished by use of chemical growth regulators. However, the maturation phase in growing biomass (producing fiber in place of

Water is rarely mentioned in biomass-oriented literature. In some reports, dry matter is assumed as a constant percentage of green weight value. Such assumptions are still found in the ISSCT Proceedings and prestigious journals such as Plant Physiology and Plant Biochemistry. This is an erroneous concept and one especially to be avoided in biomass production projects dealing with herbaceous species. At this point in the present work on tropical grasses, the candidate's ability to terminate visible expansion and to get on with the accumulation of fiber seems equally important as the early rapid growth of succulent green tissues.

Responses to Incremental Fertilization: Nitrogen is the decisive growth-limiting nutrient for both sugarcane and Napier grass. Ammonium sulfate was the N source in the present experiment, with sugarcane and Napier grass receiving 200 and 600 pounds/acre year, respectively. For both species, 1/3 was applied at planting and 1/3 immediately following the 4 and 8-months harvests. These levels were thought to be adequate by current commercial standards in Puerto Rico, but yield data indicate that they were inadequate to sustain a consistent dry matter yield (Tables 18-20). This trend was particularly evident in the data from 2-month harvest increments where very poor yields were obtained from the 2 to 4 months and 6 to 8 months growth periods. The inadequate fertilization was generally marked in data from 4 and 6-month harvest intervals (Table 18). As depicted graphically in Figure 6, Napier grass was constrained far more than sugarcane even though its fertilization rates exceeded those of cane by a factor of three. Hence, at the 4 and 6-months harvests, Napier grass yield was not appreciably different than sugarcane. Putting this another way, the superior productive expertise of Napier grass was eliminated from about 4 months of the 10 months growth period. Since the late 1940s, such information has been gathered on foliar tissue analysis as a means of monitoring the health and productivity of these plants.

Macronutrient requirements of sugarcane are discussed in references 28 and 29. Unfortunately, this information is based on conventional sugarcane production where sucrose, rather than energy, is the principal salable product. Abundant growth is not necessarily a good thing when the cane planter has sucrose in mind. In Puerto Rico, for example, plantation managers have hesitated to apply nitrogen later than 8 weeks into the new ratoon crop because doing so can reduce recoverable sucrose some 8 to 10 months later (14). For the present experiment, foliar N data are available only through the 8-months harvest; however, the leaf nitrogen content ranged from about 1.5 to 2.0 percent among all varieties, a range that should have been adequate by traditional standards (29). Second-year plans for the same experiment include doubling the N fertilization levels for both sugarcane and napier grass and splitting the applications into six 2-month increments. At this point in time, it is suspected that a minimum foliar N level of 2.0 percent for sugarcane and 2.5 to 3.0 percent for napier grass should persist in an optimally-forced operation having dry matter as its principal objective.

(3) (h) Sugarcane Prospects as a Short-Rotation Crop: At present, hybrid sugarcanes are not regarded as prime candidates for frequent-recutting operations. Other candidates have emerged that seem more productive than sugarcane in short-term cropping situations. However, future investigations can do several things to improve upon the sugarcane responses presently reported. One obvious factor is the selection of better varieties. For example, a new Barbados polycross hybrid (B 70-701) recently obtained by the AES-UPR cane breeding program seems vastly superior to the canes used in this experiment (30). Use of more primitive Saccharum clones and increased fertilization are also valid considerations. Perhaps more importantly, a different handling of the crop establishment process should be considered. Rather than to initiate immediately the frequent recutting operations, a

A better response might be gained by first establishing mature crowns over 6 to 12-month intervals. Short rotation harvests might then be initiated in planned sequences that provide a periodic reestablishment of a normal top/root ratio. Whether or not sugarcane yields could be raised by these means to the levels of Napier grass or Sordan 70-A remains a matter of conjecture.

A second field-plot study was established during January of 1978 for direct evaluations of Sordan 70-A and Napier grass (Common Merker) as short rotation candidates. Two Napier hybrids (PI 7350 and PY 30086) were also tested for the first time as possible replacements for Common Merker. PR 960 was retained as a reference clone. This experiment is being conducted at the semi-arid Lajas Substation under soil and climatic conditions identical to those described earlier (31).

Common Merker, the Napier hybrids, and PR 980 were planted at 50 cm row centers, approximately the commercial spacing for Napier grass but about one-third the commercial distance for PR 960. Sordan 70-A was seeded at 25 cm row centers, slightly farther apart than the standard seed-drill setting of 22.5 cm for this crop. Harvest intervals are at 2, 4, and 6 months.

Overhead irrigation amounting to about 2 acre-inches was administered at planting and at 4 weeks, and by flooding at 10 weeks. Fertilizer was given in three increments; one-third at planting, one-third at 2 months, and one-third at 4 months. Harvests for this experiment are only partially complete. Data are reported for two of three 2-month harvests and one 4-month harvest. Final data will be tabulated in the first quarterly report of Year 2.

From the initial 2-month harvest, Sordan 70-A emerged as a superior short-rotation candidate, producing about 18 green.

An entirely different picture emerged when the plants were allowed to grow for 4 months before harvest (Table 30). Green-weight values for Sordan 70-A were lower than at either of the 2-month harvests. Meanwhile its dry matter content rose from roughly 20 percent to 32 percent; in effect, the plants had simply stood there accumulating fiber and producing no new visible growth from about the eighth week onward.

There were no significant yield differences between common Napier grass and the Napier hybrids at this time. The Napier hybrid PI 30086 retained a significantly greater dry matter content, approaching 22 percent as opposed to 19 percent for common Napier grass. This cultivar produced the highest yield to date, amounting to 9 dry tons and 42 green tons/acre over a time-course of four months.

The reference variety, PR 980, was unable to keep pace with any of the short-rotation candidates in terms of dry matter yields (Table 31). Sordan 70-A exceeded its production by more than 800 percent at 8 weeks, and at 16 weeks PR 980 still had not attained the production level reached by Sordan 70-A at 8 weeks. A comparison of total yields from two, 2-month harvests versus a single 4-month harvest indicates that two categories of candidates have emerged from the short-rotation experiment (Table 32).

It is evident that, given two harvests in a 4-month period, Sordan 70-A could exceed the Napier hybrids by a small margin and easily exceed common Napier grass. However, to delay harvest until 4 months would result in major losses for Sordan 70-A."

"Sordan 70-A,

Meanwhile, each of the chapter candidates would greatly benefit from this delay. The message here is that the chapter clones are not really short-rotation candidates at all but rather occupy an intermediate position between long-rotation plants such as sugarcane and a true short-rotation plant such as Sordan 70-A.

(®) Rates of Dry Matter Accumulation: Sordan 70-A plants revealed a superior dry matter content (percentage) at both the 2-month and 6-month harvests (Table 30). Actually, dry matter will tend to accumulate in conformation with a saturation curve that characterizes a given species. Dry matter accumulation was presently monitored for all candidates with plant samples harvested weekly from week 4 to 16. The moisture percentages for whole plants during the same interval are depicted graphically in Figure 7.

Several features are immediately evident from the plotted data: (a) The three chapter clones reveal essentially common moisture curves (and hence common dry matter trends); (b), the curves were variably sensitive to irrigations applied at weeks 4 and 10; (c), Sordan 70-A revealed a persistent and drastic moisture decline or maturation curve, which was insensitive to irrigation; and (d), the maturation curve appeared to initiate at week 5 or 6 for Sordan 70-A and at week 13 or 16 for the chapter clones.

The onset of maturation coincides very closely with the initiation of flower primordia in Sordan 70-A. By the eighth week, virtually all stems of this clone bear a maturing seed stalk. Flowering also appears to play some role in the maturation of Napier types. At least some scattered tasseling is evident in these clones from the twelfth week onward. Irrigation was not a controlled variable in this experiment; nonetheless, the moisture curves presented in Figure 7 indicate some distinct

235 water requirements for maximum growth among the candidate grasses. The Napier hybrids PI 7350 and PI 30086 were quite sensitive to applied water and probably did not receive enough."

Water is needed to sustain maximum growth during the first 12 weeks. Conversely, it would seem that the irrigation of Sordan 70-A after the sixth week is mainly a waste of water insofar as tissue expansion is concerned. However, some water is probably necessary to sustain a maximum dry matter accumulation. (©) Tissue Expansion vs Maturation: As previously noted, there are two important phases in the plant's production of herbaceous biomass, one being a rapid expansion of tissues which are highly visible but consist mostly of water, and a maturation phase in which much of the tissue space is occupied by fiber and various solids collectively termed "dry matter". Maturation has little outward visibility aside from a few symptoms characteristic of aging tissues. In the search for short-rotation candidates, it is necessary to find species that will perform both phases within a short period of time. For our present purposes, this is preferably within a 6 to 12-week interval. The two growth processes can be presented graphically by directly plotting both green and dry-matter increments against a common vertical axis. In this instance, two S-shaped curves would appear on the horizontal time axis, slightly overlapping but only separated in time. The dry matter curve would be the smaller of the two since it deals with only about 8 to 35% of the total plant composition. A more convenient method is to plot the individual green weight increments as percentages of the total green matter harvested during the sampling interval, and alternatively, the incremental percentages of the total dry matter produced over the same time-course.
The growth and maturation phases for Sordan 70-A are plotted in this manner in Figure 8. Plotted as incremental percentages, both phases appear in the same general order of magnitude. Because both processes are in fact occurring simultaneously but at different relative rates, both appear on an identical time-course with first the green matter curve and then the dry matter curve.

Predominating. An important feature is the abrupt break in the upward slope of both curves which occurred at the tenth week (Figure 8). This break coincides with the optimal point in time for harvesting the species, that is, the time period in which both the tissue expansion and maturation processes have exerted their maximum effect. Thereafter, each succeeding week's increment will be smaller, rather than larger, than that of the preceding week. From an agronomic and botanical point of view, the best course of action is to harvest at 10 weeks and either reseed the crop or produce a new 10-week stand from existing crops. Similar data plots for Napier grass and the Saccharum reference clone PR 960 were less conclusive. It appears that Napier grass may have reached its optimal period for harvest at 16 weeks, but several additional weeks of sampling would be needed to affirm this. For the sugarcane clone, both phases were accelerating rapidly at 16 weeks and its optimal harvest period may not have been reached for an additional 4 to 6 months.
(c) Moisture Content vs Harvest Period: From data illustrated in Figure 8, it was surmised that Sordan 70-A should not stand much longer than 10 weeks before it is harvested. It is equally important that this cultivar is not harvested too early if maximum production is to be realized. This

point is illustrated by the Sordan 70-A moisture curve presented in Figure 9.

-37- Respectively important is the rather slight loss of moisture (gain of dry matter) before the seventh week and after the eleventh week, and an almost linear loss of moisture from weeks 5 to 10. The minimum dry matter content possible for Sordan 70-A is about 10 percent, in newly-germinated seedlings, and this value roughly doubles by the eighth week (Figure 9). In the following two weeks, from weeks 8 to 10, the dry matter content more than doubles again. Because outwardly there is no visible growth increase after the eighth week, one must take care not to harvest when tissue expands, for there is much

There is little to be gained by waiting two or three weeks longer. After week 11, there is little to be gained by delaying harvest operations. Plant population counts reflect a more vigorous germination and tiller development for Napier hybrid no. 30086, among candidate grasses planted at 50 cm row centers (Table 33). There was a vastly greater population of Sordan 70-A plants at the 25 cm row spacing. However, when inspecting these plots, a persistent impression was that the Sordan 70-A population remained inadequate. There was considerable light penetration of the foliar canopies and there seemed to be excessive space between stems within the planted row. Second-year studies with Sordan 70-A will therefore include seeding rate increases from the present 60 pounds/acre up to 120.

Breeding studies: Some limited breeding work has been conducted during the project's first year. This includes:

(a) Evaluation of local germplasm sources,

38+

(b) Flowering control in a wild S. spontaneum hybrid;

(c) Evaluation of conventional sugarcane breeding progeny as possible biomass-producing sources;

and (d) Crossing a wild S. spontaneum hybrid with commercial canes.

(a) Evaluation of Local Germplasm Sources: Four local clones bearing pure S. spontaneum germplasm have been selected for further evaluation (Table 34). All have potential value as male parents, that is, under conditions such that their flowering stage can be synchronized with the flowering of a suitable male-sterile clone to serve as the female parent. All have shown the S. spontaneum characteristic of flowering some 6 to 8 weeks in advance of commercial hybrid sugarcanes. Two of the S. spontaneum clones are found in the wild in considerable abundance near Rio Piedras. No attempt is being made to formally cultivate these. A third wild clone, an unidentified S. spontaneum hybrid, is a very promising biomass producer in its own right and is to be propagated at the Gurabo and Lajas substations. The clone "Aegyptiacum" has been propagated in the greenhouse and at present is being grown.

Undergoing seed expansion at the AES | Garabe Substation, Flowering Control in S. spontaneum:

Efforts were made to synchronize the flowering of local S. spontaneum sources with the flowering of commercial hybrid canes suitable for female parents. The objective is to produce F1 progeny having dry matter production as their principal attribute. Synchronization studies included (a) Freezing of whole tassels from early-flowering; (b) Freezing of pollen collected from early tassels; and (c) Delay of early bud production by physical and chemical means. Pollen and whole tassels from four S. spontaneum clones were frozen during September and October, 1977. Pollen viability tested by the starch-iodine method indicated that from 20 to 50 percent of the frozen pollen could be viable. Initial attempts were made to delay early tasseling with the unidentified spontaneum hybrid at two sites near Rio Piedras. This consisted of cutting the S. spontaneum stalks back to ground level on June 1, 1977. The regrowth material was still in the juvenile (non-flowering) stage when the clone's normal floral induction period passed in July. The new plants were intended to become adults (capable of flowering) at about the time that floral initiation occurs in commercial sugarcanes, i.e., during early September. A few buds did emerge on one of the test sites, however, they were still relatively early, emerging from October 20 to 28, and we were unprepared to attempt crosses at that time. The same method will be tested in 1978 with some modifications in the time that S. spontaneum plants are cut back. Efforts will also be made to delay flowering by treatment of cuttable S. spontaneum stands with the growth hormone gibberellic acid. In this instance, the objective will be to delay the shift from a vegetative to reproductive status, without totally eliminating the plant's capability to flower. (d) Evaluation of Local Breeding Progeny: For many years the AES cane breeding program has screened its new progeny with a view towards increased

Sugar and tonnage yields, suitability for mechanical harvest, disease resistance, and regional ability (32, 33, 34). Total biomass per se has not been a decisive parameter in the selection of new sugarcane hybrids. Nonetheless, a number of new canes have emerged that do have exceptional promise as biomass energy producers, at least on the basis of regional trials.

Plans have been made to establish some 12 to 15 of these in an observation "nursery" at the AES Lajas Substation. Depending on the availability of seed, these plots will range from about 1/50 to 1/2 acre in size. They will not be replicated but will enable us to make preliminary evaluations of the clones' productivity potentials under semi-arid conditions. They will also provide seed for those candidates warranting formal study under replicated field-plot conditions.

(A) S. spontaneum Crosses: Two crosses were performed during December of 1977. Two male-sterile hybrids were used as female parents; one hybrid, F-106, originated in Taiwan and the other, PR 63-227, is a local sugarcane (35). Both crosses utilized frozen pollen from the early-flowering spontaneum hybrid noted above. Although pollen tests by the starch-iodine method had indicated a probable viability, only 5 seedlings were obtained from these crosses. This suggests that freezing is almost totally destructive of the pollen. It is also possible that the S. spontaneum hybrid is itself nearly male-sterile. In any case, a few hybrid progeny are available for evaluation.

PROJECT OUTLOOK: FOOD AND ENERGY INTEGRATION

A number of distinct types of candidate tropical grasses have already emerged in accordance with their management and timeframe requirements for optimal production. Several of these categories are also compatible with an eventual integration of energy planting with the production of traditional food commodities. The need for establishing such categories is evident from data trends and from the claims that biomass energy production will take on land and water.

Resources from the mid 1980's onward (36).

1. Categories of Bioware

At least three broad categories are required based on the candidate's suitability for rotation with food crops or other energy crops. Cultivars from the first group would have only a brief occupation of land otherwise committed to conventional food or fiber crops. Ordinarily, such plants would occupy a truck-crop site to prevent leaching, erosion, and weed development until it is replanted with the more valuable commodity. In sugar cane land rotations, they would serve as ground cover between the harvest of a final ratoon and the seeding of a new plant crop. The biomass candidate should be directly seeded and have a rapid tissue expansion phase followed by an equally rapid conversion to dry matter. It should be a good "scavenger" crop utilizing residual fertilizer and it should quickly shade out the native weed species. Potential sources of such candidates include the hybrid forage grasses. Among these, the tropical forage Sordan 70k (Northrup-King Company), has shown very excellent promise in greenhouse and field-plot trials.

It seems highly improbable at this point that a short-rotation candidate appreciably superior to Sordan 70-A will be found during the course of this project. It is the fastest-growing candidate examined to the present time. This hybrid is propagated from true seed and hence can be sown with a commercial seed drill. This alone is an important advantage over plants such as sugarcane and napier grass that are propagated through a cumbersome and costly processing of stem cuttings. Sordan 70-A germinates very quickly—within about 3 or 4 days—and this is followed by a very rapid tissue-expansion phase lasting about 5 weeks. During this interval, the daily growth increases are quite visibly evident each evening.

Native weed species are quickly shaded out. Another positive feature is the plant's early shift from a vegetative to reproductive regime, possibly occurring as early as the fourth week. By the sixth week, immature tassels begin to emerge. This enables the plant to reduce its water content and accumulate dry matter much earlier than the sugarcane and Napier grass candidates examined thus far. With optimized management, Sordan 70-A appears capable of producing in the order of 8 to 10 dry tons per acre over the course of four months.

A second category includes forage grasses that will establish quickly and withstand frequent recutting for a year or preferably 18 months before reseeding is necessary. A sufficient number of harvests is needed to cover establishment costs and to bring an acceptable return for the energy planter's investment. Energy is the predominant agricultural commodity in this instance. It constitutes the principal claim on land, water, and other production resources in the cropping sequence. Napier grass (Pennisetum purpureum, var. Merker) is the outstanding candidate in this category at the moment. At least one Napier grass hybrid has similarly shown promise in field-plot trials.

 A third category consists of the very durable grasses that must withstand repeated harvests over a period of 2 1/2 to 5 years. For this classification, candidates are needed that are suited both for intensive cultivation and for minimum tillage regimes where plant productivity is too low to justify reseeding at more frequent intervals. This long-term capacity for growth will be difficult to maintain in commercial forages. Napier grass might possibly succeed if sufficient water and fertilizer is expended and if occasional "rest" periods of 4 to 6 months duration are allowed for the crowns to reestablish at full top. Within this category, a series of Saccharum hybrids bearing a large dosage of S. spontaneum germplasm is being evaluated. These plants are similar to sugarcane in outward appearance but...

The text is characterized by a more robust growth habit and higher fiber contents than the sugarcanes of commerce. It is also possible that certain high-tonnage Saccharum hybrids, previously thought too fibrous for cultivation, will contribute to this category. In this case, at least some sugar would be recovered as a co-product of fiber.

2. Minimum Tillage Candidates
In addition to the biomass categories noted above, there is a need for species that will produce at least moderate yields with the bare minimum of production inputs. This requirement is underscored by two factors: (a) Puerto Rico's water resources, even when fully developed, would supply only about half the water needed for highly intensive production throughout the island; and (b) economic considerations will not always permit maximum expenditure of production resources even where such resources are otherwise available. Hence, the decisive requirement of a minimum tillage candidate is a relatively large yield capability over a period of at least 3 or 4 years with only a marginal input of water, fertilizers, and pesticides.

This is the most difficult candidate to identify. Plant survival and prolonged productivity in a semi-wild state become important attributes not generally found in commercial forages and forage hybrids. More primitive grasses, such as the wild forms of Saccharum, are the principal candidates at this time. Many such clones have survived in the wild and improved themselves over several geologic ages, and it would seem likely that this toughness can be harnessed for service in energy agriculture.

Under Puerto Rico conditions, minimum tillage would mainly involve the preparation of a seedbed followed by irrigation and fertilization just sufficient to establish the forage crops. Natural rainfall would be the only water source.

EQUIPMENT AND INFRASTRUCTURE FOR TROPICAL FORAGE CANDIDATES IN PUERTO RICO

Anticipated Annual Requirements for Harvest Crop Area:
- Cultivation
- Fertilization
- Pesticides
- Interval(s)
- Duration (Years) only

Roots bird at planting at the onset is one source of water thereafter under humid conditions. In arid to semi-arid regions, only subsistence irrigation amounting to about 2 acre-feet/year would be given. Harvest frequency would be reduced to about 6 months.

This would allow more time for dry matter accumulation than is possible under intensive production regimes with 2-3 month harvest intervals. Limited fertilization would be administered after the 6-month harvest, and under dryland conditions, one of the infrequent irrigations would be given at this time. No pesticide usage is anticipated within either humid or arid growth regions.

3. Production Targets

From project data gathered to the present time, and from prior experience in biomass production, the optimal yield and production-cost values for tropical forages can be stated in at least general terms. Under intensive propagation regimes, it appears that 40 dry tons per acre year might be produced at a cost of roughly $22 per ton. A higher heating value in the order of 15,000,000 BTU's per ton is assumed on the basis of published BTU values for other biomass sources. A solar-dried ton in this case would consist of about 18 to 20% moisture.

That is, about 6% more moisture than is present in conventional dry cattle forages and about 12% more moisture than is contained in the oven-dried materials presently reported in these studies. The production cost estimate of $22 per dry ton includes delivery of baled material to a hypothetical thermoconversion facility at Naguabo, about 15 miles from the production site. This cost figure would be unattainable without the 40-ton yield. With a conventional yield of 10-12 dry tons, the production input costs presently anticipated would raise the product value to the order of 80-90 dollars per ton. Yield estimates would be scaled accordingly.

Down for short-rotation energy crops and for minimum tillage operations. Short rotation crops are seen as essentially a periodic filler for lands otherwise committed to food commodities of higher value. Minimum tillage operations would be directed towards low to moderate productivity from marginal lands that otherwise would remain out of production. Such operations, if properly managed, might be equally profitable to the energy planter.

4. Status of Candidate Screening

First-year screening of tropical grasses has made good progress. Categories of tropical grass sources have been defined both in terms of the source groups that will be required by future energy planters and the groups that are realistically available in a botanical and agronomic sense. The four principal categories together with present candidates for each category are illustrated graphically in Figure 10.

Jordan 70A is believed to be the definitive candidate for short rotation cropping. On this basis, Jordan 70-A will be carried into mechanized field-scale operations that begin during the project's second year. The final source selection for the intermediate rotation category could well be any one (or all) of the Napier grass clones examined to date. The Napier grass hybrid PR 7350 appears to be the superior source under Lajas conditions but only by a modest margin of productivity.

There does not appear to be any other Napier grass hybrid available to Puerto Rico at this time that will seriously challenge the present Napier candidates (37). One development we would like to see is the emergence of a true-seeded candidate for intermediate-rotations that can be planted mechanically with a seed drill. The collection and handling of Napier grass stem cuttings is at best a job. In this connection, the failure of cumbersome and expensive operations of Napier grass to respond to close spacing is seen as a highly positive factor. The establishment of this plant at narrow row centers would be attended with logistic difficulties.

Excessive expense in a commercial-scale operation. There remains some possibility that one of the directly-seeded KK hybrids may replace or supplement the Napier clones in this category. At this point in time, the long-rotation category is quite clearly the realm of the commercial Saccharum hybrids. Although shown to be totally inappropriate as short-rotation sources, there is no reason to believe that they would not exceed all other tropical grasses if allowed a year or more to express fully their tissue-expansion and maturation phases. In this respect, the technical problems inherent to their harvest may be as decisive as the selection of specific clones. For instance, it will be necessary to harvest standing biomass in excess of 80 green tons per acre. Also, at this time it appears that the minimum tillage category belongs to the wild tropical grasses, or possibly to the semi-wild and primitive forms of Saccharum. Here, the main interest lies in species that will literally manage themselves. In Puerto Rico's humid regions, certain commercial species such as Napier grass (Var. Merker) seem as content in the wild state as they are under cultivation. In semi-arid regions, the clone ‘Arundo donax' performs well in a totally wild state. Under arid conditions, a series of Panicum bunch grasses are extremely durable with little or no management following their initial seeding. The ultimate minimum tillage source could quite possibly derive from the primitive species of Saccharum, particularly forms of S. spontaneum. Some of these have survived over several geologic ages involving extensive climatic changes and almost continuous competition from other herbaceous species (14). This genus is not native to the western hemisphere, however, and early explorers and botanists brought to Puerto Rico only "noble" or S. officinarum clones that had experienced some prior domestication. Even in very recent times, certain island officials ignorant of the genetic value of S. spontaneus hesitated to import clones of it.

This species were feared that they would establish themselves as noxious weeds. The local "villa" §. spontaneum forms, described earlier in this report, were found in the humid zone near Rio Piedras where they probably escaped from ABS breeding stock collections during the 1930's and early 1940's. Their performance under arid conditions will be studied for the first time during the project's second year. Additional Saccharum and related species will be imported for screening as biomass sources during 1978. Among these, there will be several inter-generic hybrids. One clone incorporates Saccharum, Miscanthus, and Erianthus germplasm, and has aroused considerable interest among authorities in Houma, Louisiana (38).

49 - SUMMARY OF FIRST-YEAR PROGRESS

1. Greenhouse Studies

Greenhouse experiments dealt with the rapid screening of commercial Saccharum hybrids, primitive Saccharum species, and species from the genera Pennisetum, Sorghum, Erianthus, Arundo, and Panicum. Principal test parameters included total biomass-producing capability, characteristic growth curves, recutting tolerance, maturation profiles (conversion of green tissues to dry matter), response to chemical growth regulators, and response to variable nitrogen supplies.

Progress was made in the following areas:

(a) Total biomass production capability was examined in over 60 clones from the genera Saccharum, Sorghum, Pennisetum, Erianthus, and Arundo. All were evaluated against a high-tonnage Saccharum hybrid, PR 980, serving as the standard or reference clone. Superior performances were obtained with the Saccharum spontaneum clones US 67-22-2, US 72-70, and SES 231, an unidentified wild S. spontaneus hybrid, the sorghum variety Rona, and a commercial hybrid originating from a Sudan grass x sorghum cross (Sordan 70-A; Northup-King Co.)

(b) Sordan 70-A was identified as an authentic short-rotation source of biomass. Its tissue expansion phase proceeds rapidly for about 6 weeks from the time of seeding. This is followed by an equally rapid maturation.

Phase terminating at 10 to 11 weeks. Its dry matter potential is at least 20 oven-dry tons/acre per year. A very favourable nitrogen response curve was established for Sordan 70-A plants propagated by sand culture.

50- (2) Chasteal growth regulator experiments with PR 980 confirmed that the Monsanto product, Polaris, produces growth increases in the order of 25 to 50% when administered as an aqueous foliar spray. Its effective concentration range is 50 to 300 ppm. The stimulatory action persists for at least 12 weeks following chemical application. A nutritional disorder observed in Napier grass field plots was tentatively identified as manganese deficiency. This work was performed with the same variety propagated by sand culture.

2. Field plot experiments were established at the semi-arid AES Lajas Sub-station. Controlled variables included varieties (3 sugarcane, 3 Napier grass, and Sordan 70-A), row centers (150, 50, and 25 cm), and harvest frequency (2, 4, 6, and 12 month intervals). The following observations are based on partially-complete data obtained over a time-course of 10 months.

Napier grass (var, common Merker) is superior to commercial sugarcane hybrids as a biomass source under conditions of short and intermediate rotation cropping. Sugarcane responds well to close spacing for approximately 6 months after planting; thereafter the response virtually disappears in each variety. Napier grass does not respond to close spacing. Fertilization levels based on conventional sugar and forage production practices are totally inadequate to sustain maximum biomass production. Dry matter yields for both cane and Napier grass are increased by lengthening the interval between harvests. For example, a single harvest at 6 months exceeds the combined yield of five 2-month harvests.

For all field plot candidates (sugarcane, Napier grass, Sordan 70-A), biomass yield was a function of two growth phases, i.e., tissue expansion and tissue maturation.

The candidate's yield potential is heavily dependent on the maturation phase. For Sordan 70-A (short-rotation source), maturation is complete by 10 or 11 weeks after seeding; more than half of the dry matter is produced between weeks 8 and 10. Complete maturation requires at least 16 weeks in Napier grass and probably up to 12 months in sugarcane. For optimal yields, sugarcane should stand at least 6 months between harvests. The Napier grass hybrids, PI 30086 and PI 7350, appear to have significantly larger biomass-production potentials than common Napier grass (var.

Morker).

REVISED WORK PLAN FOR YEAR 2:

Funding constraints will not permit second-year research to proceed at the level originally proposed. These reductions relate to a DOE cutback of about 30% from the original second-year budget, plus a UPR doubling of the project's overhead deductions. The Year 2 work plan will retain the original objectives and as many features of the original work plan as can be retained with reduced funding. Cutbacks and modifications will be made in the following areas:

1. Personnel: The project will not hire an Agricultural Engineer and a Plant Physiologist as originally intended. Certain of the physiological analyses will be conducted by the project leader if time can be made available. Student participation will be reduced to one graduate plus one or two undergraduates.

2. Candidate Screening: Screening objectives will be modified to obtain one or two superior clones per category of biomass candidates. This will ultimately have the effect of confining the project's findings to the main production site, i.e., the Lajas Valley. It will eliminate about half of the repetitive field plot work. However, response curves for water, nitrogen, row spacing, and harvest frequency will have to be retained for the few candidate clones identified for the respective categories.

3. Yield Plot Tests: These experiments will be reduced in number to about 2/3 of those originally planned. Duration

The number of experiments will also be reduced whenever the incoming data is judged to be sufficient for the experiment's objectives. Several test parameters will be eliminated, including nitrogen-source variables, moving heights, and season of planting. It should be possible to rationalize these factors to some degree insofar as prior data is available on the biomass candidates. In those field plot experiments that have to be performed, it may be possible under certain conditions to reduce the number of replications from 6 to 4.

4. Field-Scale Experiments: Field-scale work will begin earlier but will be confined to fewer biomass candidates. Harvest frequency, total yield, and performance of harvest equipment with variably-aged candidates will be the primary variables for evaluation. The initial field-scale candidate will be Jordan 70-A. The earliest field trials are planned for the second quarter of Year 2.

5. Breeding: Breeding studies will be confined to a few crosses with a few existing parents that can be incorporated at little expense into the existing AES cane breeding program. This will enable us to attempt some important corrections in otherwise desirable candidates for the long-rotation and minimum-tillage categories.

REFERENCES:

1. Artechwager, B., and Brandes, E.W. Sugarcane. Agricultural Handbook No. 122. U.S. Government Printing Office, Washington, D.C., 1958.

2. Brandes, B.W., and Sartoris, G.B., Sugarcane: Its Origin and Improvement, USDA Yearbook of Agriculture, U.S. Government Printing Office, Washington, D.C., pp. 561-611, 1936.

3. Anon., Request For Proposal For Establishment of Herbaceous Species Screening Program-RFP No. ET-78-R-2-0014. DOE Chicago Operations Office, May 19, 1978.

4. Stevenson, C. Genetics and Breeding of Sugarcane, Longmans, Green and Co., Publishers. London, 1963.

5. Alexander, A.G., The potential of sugarcane to produce sucrose, Proc. Int. Soc. Sugar Cane Technol., 13:1-24, 1969.

6. Anon., Amazing Grazing: Tefdan-5, Millex-23, and Jordan.

"Miniature Sugarcane", J. Agr. Univ. P. R. 53(2): 61-92, 1969. Personal communication with Mr. Vélez Santiago, Agronomist in charge of tropical forage grass studies, AES-Corozal Substation, December 1977. Gauch, I. G., "Inorganic Plant Nutrition", Dowden, Hutchinson, and Ross, Inc. (Publishers), Stroudsburg, Pa, 1972. Alexander, A. ., "Interrelationships of gibberellic acid and nitrate in sugar production and enzyme activity of sugarcane", J. Agr. Univ. P-R. 52(1): 15-28, 1968. Bull, T. A., "The effects of temperature, variety, and age on the response of Saccharum species to applied gibberellic acid", Aust. J. Agr Res. 15: 77-84, 1964. Vicente-Chandler, J., Silva, S., and J. Figarella, "Effects of nitrogen fertilization and frequency of cutting on the yield and composition of napier grass in Puerto Rico", J. Agr. Univ. P.R, 43(4): 215-227, 1959. Personal communication with Mr. W. Allison, Agricultural Engineer, ABS-UPR and UPR-Mayaguez Faculty, December, 1977. Lipinsky, E. S., Kresovich, S., McClure, T. A., and W. T. Layton, "Third Quarterly Report on Fuels From Sugar Crops", Battelle Columbus Division, Columbus, Ohio, January 31, 1978. Personal communication with Dr. James E. Irvine (US Sugarcane Field Station, Houma, La.), ASSCT Annual Meeting, Orlando, Florida, June, 1978. Humbert, R., "The Growing of Sugarcane", Elsevier Scientific Publishing Co., Amsterdam, 1968.

2. 3. 32. 34. 36. 37. 38. Senewiratne, G., "Foliar Diagnosis for Sugarcane", Agricultural Research Publications, Rio Piedras, P. R., 1969. Personal observations by A. G. Alexander, and personal communication with Mr. L. Cha, AES Sugarcane Breeding Program, Curabo, P. R., 1978. Alexander, A. G., "Production of sugarcane and tropical grasses as a renewable energy source", Second quarterly report to the United States Department of Energy, December, 1977, Corozal, Puerto Rico. You, P., "Patudio sobre Las variedades de caña de azúcar en Boletin No. 199", AES, 1966. Gotticatirolina, E. L., "Regional Evaluation of new sugarcane varieties", Ann. Repts., AES-UPR.

1969, 1972, 1973, 1974. GonadlorNoline, C. "Performance of commercial sugarcane varieties in the Aguierre clay soil of the Tajas Valley," J. Agr. Univ. P. R., 61(2), 1126-136, 1977. Two communications with Mr. T.L. Chu, Sugarcane Breeder, AES- Sugarcane Breeding Program, Gurabo Substation, December 1977. Anon., Report and recommendation of the CEER-UPR Senior Advisory Committee to the President, University of Puerto Rico, January, 1978. Personal communication with Mr. J. VélezeSantiago, Assistant Agronomist and forage grass specialist,

AES-UPR Corozal Substation, July, 1978. Personal communication with Mr. T. L. Chu, AES Sugarcane Breeding Program, Gurabo Substation, July, 1978.

TABLE 1. RESEARCH PHASES FOR BIOMASS PRODUCTION STUDIES WITH TROPICAL GRASSES
Research phase, Class of objectives
Greenhouse, Physiological-Botanical
Field plot, Botanical-Agronomic
Field Scale, Agronomic-Economic
Commercial-Industrial, Economic

TABLE 2. BIOMASS PRODUCTIVITY PARAMETERS BEING EVALUATED DURING THE PROJECT'S GREENHOUSE PHASE
Performance (Relative to Reference Clone Parameter PR 980) Required For Field Plot Phase
Total Biomass, Superior
Growth Curve, Superior
Regrowth Rate, Superior
N Response, Equal Or Superior
Water Response, Equal Or Superior
Recutting Tolerance, Superior
Insect Tolerance, Equal
Disease Resistance, Equal
Tissue Composition 1/, Equal Or Superior
Tillering Density, Superior
A/ Total Ash, Silicate, Sulfur

TABLE 3. CUMULATIVE CASE WEIGHT PRODUCTION BY CANDIDATE TROPICAL GRASSES OVER A TIME COURSE OF 7 MONTHS
Total Green Weight as % of Sector Chose Reference Clone (PR 980)

TABLE 4. INITIAL GREENHOUSE GROWTH RESPONSES OF EIGHT SPECIES

Text:

Teotomt, Grasses' total growth (g/10 pages) since close green VI. Dry Me. Moisture exchanges range from 980 to 105, 15 for 287680 with ails, 70 ns) sours - Serdan TOA 330, 22.0 each 20 5 xs or 206 Nine Ho 22 330 days after planting.

Whole 5, Dry Matter Silos for Napier Grass, Napier Hybrids, and Sordas 70-4 proposed 16 times in the greenhouse and harvested at intervals of several months.

For Production Interval - Week 7-12, Napier race 0.75, Napier hybrid 7350 0.65, Napier hybrid 20086 0.0, Sorden 70-8 0.88.

Unreplicated greenhouse trial: Week 135 0.38 0.50, cost 0.63 02.

Table 6. Dry Matter Content (%) for Napier Grass, Napier Hybrids, and Sordas, harvested at intervals of six weeks.

For production, the measurement scale varies from week 1-6, week 7-12 to week 13-18. PR 980 (Reference) 16.0 na 18.3 approx. Green 10.3, Napier hybrid 7350, Napier hybrid soos ne 37 BA, as Sorden 70-4 no 5.5 19.8 38.7.

Table 8, Green weight responses of mature sugarcane to the growth of muneon powanns.

Response at 6 weeks: Response at 12 weeks. Polaris (oye) _g/plant _% Change a/Pane 1 Change ° 263 ° as ° %0 2410 a4? 100 a4 28 a1.

AY variety 980, applied as aqueous foliar sprays at 4 weeks of age.

Table 9, Growth responses of mature sugarcane to plant growth stimulators.

Green wt (g/plant) deviation from the compound 1/6 weeks after treatment control (2) control 40.6 °, rolarts ea +28.0 on 5000 = 40.7 cx 1099 0 455.

AY administered as aqueous foliar sprays containing 100 pa active ingredient.

Ladoke Fefbgte CP Nox Goo OM Muller (6HC7) production by mature sugarcane at KP Dates Green.

I'm sorry, but the text you provided is incoherent and seems to have a lot of typographical errors as well as missing context. It would be helpful if you could provide more context or a clearer version of the text.

I'm sorry, but the provided text seems to be highly garbled and corrupted. It's not possible to fix it without knowing the original context or meaning. Please provide a clearer version of the text or provide context so I can assist you better.

The text appears to be incoherent and scrambled, making it difficult to understand or correct. It seems to contain several different topics and segments, including tables, page breaks, and a mixture of random words and numbers. To help you, I would need more context or a clearer version of the text.

The text appears to be scrambled and filled with typos, making it challenging to correct without any context. Could you provide more information or context?