CEER-B-169

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

FIRST ANNUAL REPORT
1977—1978

TO

THE UNITED STATES DEPARTMENT OF ENERGY

CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO · U.S. DEPARTMENT OF ENERGY

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First Annual Report
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To

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

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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

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FIRST ANNUAL REPORT
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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE [1]

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ABSTRACT

Tropical grasses 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 investigated 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, ie, tissue expansion which is highly visible but consists mainly of water, and tissue maturation 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.

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[1] Contract No. EG-77-G-05-5422 (AES-UPR Project No. C-481)

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE [1]

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. Its 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.

1. 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 grasses 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.

2. Scope of the Project

Emphasis is directed toward a highly-intensive and mechanized production of tropical grasses as solar-dried forages. This is a deviation from

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[1] Contract No. EG-77-G-05-5422 (UPR-AES Project No. C-481).

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 (Table 1). 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 attribute has not been fully intensified in the hybridization programs that led to the present-day varieties of commerce (1,2) [1/]. Screening studies have therefore included older hybrid varieties no longer produced commercially, "noble" or pure intraspecific clones, superior selections

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[1/] Numbers in parenthesis refer to relevant published literature. Complete citations are listed on pages 54 to 56.

from wild populations, and more primitive forms bearing the germplasm from which modern genotypes have been assembled. A screening 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 operating to prevent 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 on-going breeding program. Certain progeny originating with the AES-UPR sugarcane breeding program are also being considered as long-rotation [1/] biomass candidates. Under these circumstances some prospect is created for the emergence of superior new progeny at very little expense.

[1/] Categories of tropical-grass candidates for biomass production are discussed in detail on pages 41-45.

3. Statement on the Presentation of First-Year Data

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 date thus include five of six 2-month harvests, two of three 4-month 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

A. 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 Saccharum 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 (5). 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.

1. Greenhouse Methods

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 offers precise control of water and nutrient variables. Soil-cachaza mixtures are convenient media for determining relative growth rates, growth curves from germination to the young-adult stage, responses to chemical growth regulators, and tolerance to frequent recutting of candidates having superior growth potentials. Most candidates to date have been established with stem cuttings of uniform size, age, and vigor. A few candidates such as sweet sorghum varieties and the sorghum x sudan grass hybrids are established with true seed. Insects are controlled with weekly applications of Malathion. All plants receive controlled water and nutrient supplies that are not rate-limiting for growth.

All first-year experiments employed the interspecific[1] sugarcane hybrid PR 980 as a reference clone having recognized excellence as a high tonnage producer. In this capacity PR 980 has not been very satisfactory. Its major dry matter accumulation begins after 6 months and the project requires some cultivars that will do this as early as 2 to 3 months after planting. Also, several *Saccharum* imports and AES cane breeding progeny have been identified already as tonnage producers superior to PR 980. Future reference clones will be selected from the specific category of candidates under scrutiny, ie, Sordan 70-A for short-rotation candidates, napier grass (var. Merker) for intermediate rotations, and a suitable *S. spontaneum* hybrid for the long-rotation category.

Harvest intervals have varied in accordance with the stage of screening and biomass parameters under investigation. Preliminary production tests may involve only a single harvest at a convenient point in the species' grand period of growth. Definitive growth curves require multiple harvests during the plant's initial 3 or 4 months after seeding. Growth-regulator trials require sampling at precise intervals following chemical penetration.

The principal biomass parameters measured during the first year included total green weight, dry weight (oven dried to about 6% moisture), dry matter content (% DM), and water content (% moisture). Leaf samples, including the entire blades of leaf ranks +1 and +2,[1] are harvested for foliar mineral analyses. In some experiments leaf samples are harvested for blade-area and

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[1] *Saccharum officinarum* (9/16) x *S. spontaneum* (5/16) x *S. sinense* (2/16).

[2] The uppermost leaf bearing a fully-emerged dewlap 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.

2. Total Growth Performance

Initial candidate evaluations for total growth included 25 *Saccharum* and two *Erianthus* clones in unreplicated trials (Table 3). Several commercial hybrids and *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 56-19-1, 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 (6). Marketed under the trade name "Sordan 70-A", this hybrid had shown excellent growth potential as a cattle forage on Puerto Rico's arid south coast (7). Two observation trials were performed in the greenhouse; one a direct comparison against the *Saccharum* standard, PR 980, and a second comparison against three sweet sorghum varieties of the "Meridian" series (M71-5, M72-2, and M72-3). The sweet sorghum variety Roma and the noble sugarcane Badilla, 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 6-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 6-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 less encouraging (Table 5); however, yields for PI 30086 compared quite favorably with Common Merker. 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 CEER-UPR terrestrial biomass program. These varieties were developed as cattle grazing and ensilage feed sources for hot, dry climates (6). 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 drouth-resistant Pearl millet hybrid. The reference variety is Sordan 70-A. Data are not yet complete 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 NK 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 drouth 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 Curve 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 performances over a 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-A 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 980. Similarly, the thick-stemmed varieties Crystalina and H 37-1933, although exceeding PR 980 on an individual plant basis, produced less dry matter per planted area owing 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 a 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 980 (Figure 3). The superiority of Sordan 70-A for rapid initial 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 would produce in 12 weeks. Roma 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 of 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 same 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 8000 (Monsanto), ACR 1093 DA (Dr. R. Maag, Ltd., Dielsdorf, Switzerland), and Embark (3M Company). The test concentration was 100 ppm active material, the level at which Polaris appears to be most effective. Embark increased growth at a level 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 (GA_3) 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 a subsequent trial 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.

(b) Tillering Responses: The effects of Mon 8000 on increased stem production were relatively small; however, the growth inhibitor Embark (3M

Company) has a pronounced capacity to increase tillering in sugarcane. These effects were noted in earlier trials where the material was tested as a chemical ripener and during the present project when Embark was compared with Polaris as a growth stimulant. Embark was further evaluated for its tillering effects at concentrations ranging from 25 to 300 ppm active material (Table 11). Shoot production was increased by all Embark treatments, the maximum effect being recorded at 50 ppm. This concentration virtually doubled the number of shoots per plot.

The ability to tiller, ie, to produce a large number of stems from a single crown, is probably a genetically-controlled factor in the tropical grasses. Within the genus Zea, field corn varieties rarely produce a second stem while sweet corn varieties usually retain the tillering feature. In Saccharum, some clones tiller heavily almost from the moment of germination while others are 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 planters: (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.

(c) Theoretical Role of Plant Growth Regulators: 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 Embark 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. 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 [1/] also warrant consideration.

An added advantage would derive from the coadministration of growth regulators with another material already required by the biomass crop. Under PR 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 already administered as a supplemental N source with overhead irrigation water (7). Accordingly, future experiments with growth regulatory materials on tropical grasses will include their coadministration 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, ie, 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.

[1/] 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 *P. purpureum* a serious shock is experienced when the top/root ratio is drastically altered in this manner. The variety Common 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 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 Mn was withheld from the other. Leaf freckling symptoms characteristic of the field disorder began to appear in spindle leaves of the minus-Mn plants at 4 weeks.

Traces of the symptom also appeared in some plants of the control group (receiving 0.5 ppm Mn), suggesting that the Mn 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 Mn in the soil. Manganese disorders quite commonly relate to soil pH and iron levels which affect the availability of native Mn 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 N held constant. The principal objective was to determine the slope of the plant's growth response when supplied with progressively higher levels of N. Accordingly, N supplies were increased in a geometric progression from 1.0 to 81.0 milequivalents/liter of NO_3. The low-N treatment was deficient while maintaining some limited growth; high N (81.0 meq/l) offered a vastly greater N supply than most tropical grasses can utilize. With sugarcane, for example, NO_3 levels in sand culture exceeding about 20.0 meq/l are utilized only in the sense of "luxury consumption" (14). For sugarcane, 9.0 meq/l of NO_3 in sand culture are roughly comparable to a field treatment amounting to 100-150 pounds of elemental N per acre year.

Growth data recorded at 4 and 8 weeks after seeding are illustrated in Figure 5. At 4 weeks there was little response to NO_3 levels higher than 3.0 meq/l, owing in part 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 8 weeks with 9.0 meq/l of NO_3 being optimal. Nitrogen levels higher than this appeared to be growth-repressive. Present data are incomplete in that they pertain only to the rapid growth phase and exclude the main period of dry matter accumulation, ie, from 8 to 12 weeks.

Nutritional information gathered by the sand-culture technique is not directly applicable to field conditions; however, the shape 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 70-A 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.

8. Importation and Quarantine of Candidate Tropical Grasses

A number of Saccharum 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. Chu, a project collaborator and a recognized authority on Saccharum 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 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 in itself greatly expands the germplasm selection for biomass screening in Puerto Rico (Table 13). They are all intergeneric or interspecific hybrids representing parental material from the genera Saccharum, Eccoilopus, Sorgo, Sclerostachya, Miscanthus, Erianthus, and Ripidium 1/. Each of these clones and those to arrive during 1978 have displayed an exceptionally robust growth habit and profuse tillering.

B. FIELD PLOT STUDIES

1. Saccharum Species Candidates; 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

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1/ Ripidium was formerly classified as an asiatic sub-group of Erianthus.

of S. spontaneum and S. sinense 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 humid 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 980 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 in forage-making operations, eventhough their tonnages 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 980 (Table 14, US 67-22-2 and US 72-70). Two other candidates, Tainan (S. sinense) and US 72-144 (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 Saccharum 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-months interval show a very superior performance by two S. spontaneum clones (US 67-22-2 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 Trials; Lajas Substation

The project's first replicated field-plot experiment was established 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 sugarcanes (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 Fraternidad Clay soil. Plot size is 1/50 acre and there are six 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 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, ie, at 2 months (six times per year), at 4 months (three times per year), and at 6 months (two times per year). Two subsamples of 10 plants each are harvested for dry matter determinations and for tissue samples used in various tissue-component analyses. The latter include N, P, K, S, Si and ash for leaves, and invertase, 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 a time-course of several years.

(b) Establishing Field-Plot Parameters: The project's field-plot phase is essentially an extension of the greenhouse screening studies. Because biomass candidates will commonly vary at the genus level certain decisions have to be made as to the establishment and maintenance of controlled parameters. At a planning conference on herbaceous species screening held recently 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 US. Candidate species for much of the screening work there will have little or no history of intensive cultivation or genetic improvement. This is particularly true of wild plants and arid-land species 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 level for napier grass (600 lbs/acre year) was set at three times 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 (24). Under semi-arid conditions this could theoretically occur as soil water is replenished in stepwise flooding operations requiring two or three days to cross the experimental area. Moreover, the Lajas Substation canal system carries water continuously from one side of the Station to the other. The lateral movement of water from these canals to adjoing experiments is a recognized possibility, depending upon the respective soil class and its water-receiving capacity at any given interval (25). 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 establishing cane and napier grass within the same experimental design. Following the initial 2-month harvest, foliar discolorations possibly indicative of nutrient deficiency appeared in some of the napier grass plots. At about 3 1/2 months foliar symptoms similar to manganese deficiency appeared in virtually all napier grass plots. None of the sugarcane plots revealed foliar symptoms eventhough these had received only 1/3 of the fertilizer level given napier grass. The symptoms in napier grass were greatly diminished or disappeared entirely following a second fertilizer application to all plots at 4 months. If the suspected deficiencies in napier grass are verified by foliar diagnosis it will be necessary to consider still higher fertilizer rates together with micronutrient additives to the fertilizer mixes administered to napier grass in the Lajas valley.

(c) First-Year Trends in Biomass Production: By the close of Year 1 field-plot data had been gathered 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 complete 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 decreasingly so with advancing age; (c) dry matter yields increase with decreasing frequency of harvest; (d) early maturation of the candidate species, ie, the capacity for rapid conversion of succulent new growth to dry matter, is a decisive factor in determining ultimate yields; and (e), fertilization treatments based on conventional sugarcane and cattle forage production data are inadequate to sustain optimal biomass yields.

(d) Varietal responses; Sugarcane vs Napier Grass: Napier grass has generally out-performed sugarcane as a producer of biomass during the first ten months. Their differences were most evident at the first 2-month harvest when 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 10-months 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 8-months harvests (Table 18-20). 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 attained statistical significance (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 980 was the leading producer when harvested at 4- and 6-month intervals (Tables 22 and 23).

(e) 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 (Tables 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 increase 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 PR 980, and the highest dry matter yield was 13.6 tons/acre for napier grass variety common Merker. 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 increases from close spacing were larger in Louisiana (around 60%) than in Florida (about 10%), eventhough 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 intrarow 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.

(f) 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, owing 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 message 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.[1/]

[1/] 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 succulant 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) indicate 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. Hence, 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- weeks interval save for the emergence of some tassels and a few yellowing leaves. In Sordan 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 fiber as a consequence of a profuse tasseling habit, but many more varieties produce few or no tassels in the course of a year (14).

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 an assumed constant percentage of green weight values. Similar 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.

(g) 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 present 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 masked 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 eventhough its fertilization rates exceeded those of cane by a factor of three. Hence, at the 4- and 6-months harvests, napier grass yields were 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 1940's much information has been gathered on foliar tissue analysis as a means of monitoring the macronutrient requirements of sugarcane (28, 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 to do 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.

(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 in 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 important would be a different handling of the crown-establishment process. Rather than to initiate immediately the frequent recutting operations, 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.

3. Sordan 70-A and Napier Grass Trials

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 PI 30086) were also tested for the first time as possible replacements for Common Merker. PR 980 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 1/3 the commercial distance for PR 980. 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; 1/3 at planting, 1/3 at 2 months, and 1/3 at 4 months.

TROPICAL GRASSES EVALUATED AS SHORT-ROTATION CANDIDATES; LAJAS SUBSTATION, 1978

Cultivar	Species	Row Center (cm)	Harvest Interval
PR 980	<u>Saccharum</u> Hybrid	50	2, 4, & 6 Months
Common Merker	<u>Pennisetum</u> <u>Purpureum</u>	50	" " " "
PI 7350	<u>P</u>. <u>purpureum</u> <u>Hybrid</u>	50	" " " "
PI 30086	<u>P</u>. <u>purpureum</u> <u>Hybrid</u>	50	" " " "
Sordan 70-A	Sorghum x Sudan Hybrid	25	" " " "

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.

(a) <u>Total Dry Matter</u>; <u>Napier Grass vs Sordan 70-A</u>: From the initial 2-month harvest Sordan 70-A emerged as a superior short-rotation candidate, producing about 18 green tons and 4 dry tons/acre in the course of 8 weeks (Table 30). This yield was significantly greater than that of the napier hybrids, and the latter in turn outyielded common napier grass. The second

2-month harvest revealed a decline of Sordan 70-A to about 17 green tons and 3 dry tons, while the napier hybrids greatly increased their productivity (Table 30). At this time each of the napier hybrids again outyielded common napier grass by a significant margin.

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 oven-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, while each of the napier candidates would greatly benefit from this delay. The message here is that the napier 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.

(b) Rates of Dry Matter Accumulation: Sordan 70-A plants revealed a superior dry matter content (percentage) at both the 2- and 4-month harvests (Table 30). Actually, dry matter will tend to accumulate in conformation with a maturation 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 napier 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 14 for the napier 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; none-theless, the moisture curves presented in Figure 7 indicate some distinct 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 to sustain maximum growth during the first 12 weeks. Alternately, it would appear 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.

(c) Tissue Expansion vs Maturation: As previously noted there are two important phases in the plants' 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 or time axis, slightly overlapping but largely 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 succeeeding 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 crowns.

Similar data plots for napier grass and the Saccharum reference clone PR 980 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 Saccharum 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.

(d) 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.

Especially 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 8 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 expansion ceases for there is much to be gained by waiting two or three weeks longer. After week 11 there is little to be gained by delaying harvest operations.

(e) Relative Plant Densities: 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 pounds/acre.

C. BREEDING STUDIES

Some limited breeding work has been conducted during the project's first year. This includes: (a) Evaluation of local germplasm sources,

(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 "new" Saccharum 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 Río Piedras. No attempt is being made to formally cultivate them. A third wild clone, an unidentified 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 undergoing seed expansion at the AES Gurabo Substation.

(b) Flowering Control in S. spontaneum: Efforts were made to synchronize flowering of local S. spontaneum sources with the flowering of commercial hybrid canes suitable for female parents. The objective is to produce F_1 progeny having dry matter production as their principal attribute. Synchronization studies include: (a) Freezing of whole tassels from early-flowering clones; (b) freezing of pollen collected from early tassels; and (c), delay of early tassel production by physical and chemical means. Pollen and whole tassels from four S. spontaneum clones were frozen during September and October, 1977. Pollen viability tests by the starch-iodine method indicate 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 Río Piedras. This consisted of cutting the 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, ie, during early September. A few tassels 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 spontaneum plants are cut back. Efforts will also be made to delay flowering by treatment of suitable 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.

(c) Evaluation of Local Breeding Progeny: For many years the AES cane breeding program has screened its new progeny with a view toward increased sugar and tonnage yields, suitability for mechanical harvest, disease resistance, and regional adaptability (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.

(d) S. spontaneum Crosses: Two crosses were performed during December of 1977. Two male-sterile hybrids were used as female parents; one hybrid, F-146, originated in Taiwan and the other, PR 63-227, is a local sugarcane (35). Both crosses utilized frozen pollen from the early-flowering S. 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.

D. PROJECT OUTLOOK: FOOD AND ENERGY INTEGRATION

A number of distinct types of candidate tropical grasses have already emerged in accordance with their management and time-frame 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 present data trends and from the claims that biomass energy production will make on land and water resources from the mid 1980's onward (36).

1. Categories of Biomass Candidates

At least three broad categories are required based on the candidate grasses' 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 a conventional food or fiber crop. 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 sugarcane 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 70-A (Northrup-King Company), has shown very excellent promise in greenhouse and field-plot trials.

CATEGORIES OF CANDIDATE TROPICAL GRASSES

Cropping Category	Production Interval (Months)
Short Rotation	2-4
Intermediate	12-18
Long Rotation	30-60
Minimum Tillage	36-120

It seems highly improbable at this point that a short-rotation candidate appreciably superior to Sordan 70-A will be found during the time-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 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, occurring perhaps 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 would appear capable of producing in the order of 8 to 10 dry tons per acre in 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 (<u>Pennisetum</u> <u>purpureum</u>, 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 a 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 are characterized by a more robust growth habit and higher fiber contents than the sugarcanes of commerce. It is also possible that certain of the 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 barest minimum of production inputs. This requirement is underscored by two factors: (a) Puerto Rico's water resources, even in fully developed, would supply only about half the water needed for highly intensive production throughout the Island (5); and (b), economic considerations will not always permit a 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 crowns. Natural rainfall would be the only 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-month

MINIMUM TILLAGE REQUIREMENTS ANTICIPATED FOR TROPICAL FORAGE CANDIDATES IN PUERTO RICO

	Anticipated Annual Requirements For -			Harvest	Crop
Region	Irrigation	Fertilization	Pesticides	Interval(Mo)	Duration (Yrs)
Humid	At Planting Only	At Planting & 12 Months	None	4	2-3
Arid	At Planting & Harvests, Plus 2 Acre Ft.	At Planting & 12 Months	None	6	3-5

intervals. 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 regimes.

3. Production Targets

From project data gathered to the present time, and from prior experience in PR 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.

BIOMASS PRODUCTION "TARGETS" FOR TROPICAL GRASSES

Category	Target
Total Productivity	40 Dry Tons/Acre Year
Production Cost	$22/Dry Ton
Energy Yield	15,000,000 BTU/Ton

The production cost estimate of $22 per dry ton includes delivery of baled material to a hypothetical thermoconversion facility at Mayaguez, 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 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 toward low to moderate productivity from marginal lands that otherwise would ramain 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.

Sordan 70-A is believed to be the definitive candidate for short-rotation cropping. On this basis, Sordan 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 cumbersome and expensive operation. In this connection the failure 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 difficultires and excessive expense in a commercial-scale operation. There remains some possibility that one of the directly-seeded NK 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 incident to their harvest may be as decisive as the selection of specific clones, ie, 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* and *S. spontaneum* hybrids. 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. spontaneum* hesitated to import clones of this species for fear they would establish themselves as noxious weeds. The local "wild" *S. spontaneum* forms described earlier in this report are found in the humid zone near Río Piedras where they probably escaped from AES 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 intergeneric hybrids. One clone incorporates *Saccharum*, *Miscanthus*, and *Erianthus* germplasm, and has aroused considerable interest among authorities at Houma, Louisiana (38).

E. SUMMARY OF FIRST-YEAR PROGRESS

1. Greenhouse Studies

Greenhouse experiments delt 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. spontaneum hybrid, the sorghum variety Roma, and a commercial hybrid originating from a Sudan grass x sorghum cross (Sordan 70-A; Northrup-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 year.

(c) A very favorable nitrogen response curve was established for Sordan 70-A plants propagated by sand culture.

(d) Chemical growth regulator experiments with PR 980 confirmed that the Monsanto product Polaris produces growth increases in the order of 25 to 35% 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.

(e) 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 Studies

Field-plot experiments were established at the semi-arid AES Lajas Substation. 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.

(a) Napier grass (var. common Merker) is superior to commercial sugarcane hybrids as a biomass source under conditions of short- and intermediate-rotation cropping.

(b) Sugarcane responds well to close spacing for approximately 6 months after planting; thereafter the response virtually disappears in each variety.

(c) Napier grass does not respond to close spacing.

(d) Fertilization levels based on conventional sugar- and forage-production practices are totally inadequate to sustain maximum biomass production.

(e) 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).

(g) For all field-plot candidates (sugarcane, napier grass, Sordan 70-A) biomass yield was a function of two growth phases, ie, tissue expansion and tissue maturation. Each candidate's yield potential is very heavily dependent on the maturation phase.

(g) 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.

(h) 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.

(i) The napier grass hybrids, PI 30086 and PI 7350,appear to have significantly larger biomass-production potentials than does common napier grass (var. Merker).

F. 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, ie, the Lajas Valley. It will eliminate about half of the repetitious 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. Field Plot Tests: These experiments will be reduced in number to about 2/3 of those originally planned. Duration 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, mowing 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 Sordan 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.

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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

Parameter	Performance (Relative to Reference Clone 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

1/ Total Ash, Silicate, Sulfur

TABLE 3. RELATIVE GREEN WEIGHT PRODUCTION BY CANDIDATE TROPICAL GRASSES OVER A TIME-COURSE OF 7 MONTHS

Species	Clone	Total Green Wt. As % Of Reference Clone (PR 980)
Saccharum Hybrids	PR 980	100
	H 37-1933	124
	NCo 310	120
	POJ 2878	91
	Pindar	141
S. officinarum	Lahaina	119
	Blanca	46
	Black Cheribon	74
	Crystalina	124
	Creole	65
	Rayada	76
	Vellai	109
S. spontaneum	US 56-19-1	89
	US 56-14-4	61
	SES 317	117
	SES 327	122
	SES 231	102
	SES 84-A	91
	Aegyptiacum	85
	Tainan	96
S. sinense	Saretha	111
	Chunnee	122
	Natal Uba	117
S. robustum	NG 57-83	74
	NG 28-219	67
Erianthus maximus	NG 132	89
Erianthus arundinaceous	NG 28-7	78

TABLE 4. INITIAL GREENHOUSE GROWTH RESPONSES OF EIGHT CANDIDATE TROPICAL GRASSES *

Genus	Clone	Total Growth (g/10 Plants)		
		Green Wt.	Dry Wt.	% Moisture
Saccharum	PR 980	105	17.5	83.3
	POJ 2878	80	14.4	82.0
	Badilla	70	11.9	83.0
Sorghum	Sordan 70-A	330	32.0	90.3
	Roma	280	25.5	90.9
	M 71-5	201	20.6	89.8
	M 72-2	220	22.2	89.9
	M 72-3	210	22.6	89.2

* 30 Days After Planting

TABLE 5. DRY MATTER YIELDS FOR NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70-A PROPAGATED IN THE GREENHOUSE AND HARVESTED AT INTERVALS OF SIX WEEKS

Cultivar	Kg/Plot [1/] For Production Interval – Week 1-6	Week 7-12	Week 13-18	Total Yield
PR 980 (Reference)	0.21	0.37	0.35	0.93
Napier Grass	0.75	0.60	0.50	1.85
Napier Hybrid 7350	0.65	0.44	0.51	1.60
Napier Hybrid 30086	0.78	0.60	0.65	2.03
Sordan 70-A	0.84	0.38	0.42	1.64

[1/] Unreplicated greenhouse trial.

TABLE 6. DRY MATTER CONTENT (%) FOR NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70-A HARVESTED AT INTERVALS OF SIX WEEKS

	% DM For Production Interval 1/			
Cultivar	Week 1-6	Week 7-12	Week 13-18	Mean
PR 980 (Reference)	16.9	17.0	21.1	18.3
Napier Grass	10.3	12.5	14.9	12.6
Napier Hybrid 7350	13.5	14.7	15.5	14.3
Napier Hybrid 30086	11.3	13.7	15.4	13.5
Sordan 70-A	11.7	15.5	19.9	15.7

1/ Unreplicated greenhouse trial.

TABLE 7. MONTHLY GROWTH PERFORMANCE BY 16 CANDIDATE TROPICAL GRASSES; JULY-NOVEMBER, 1977

		Green Wt (g/Plant) At Day —				
Species	Clone	30	60	90	120	150
Saccharum Hybrids	PR 980	27	122	303	362	550
	Pindar	11	105	245	497	658
	H 37-1933	13	94	302	520	542
S. officinarum	Crystalina	33	113	375	558	625
S. spontaneum	SES 317	6	105	233	253	270
	SES 327	10	98	182	193	273
	SES 231	3	47	92	106	125
	Tainan	4	40	112	103	112
	Wild Hybrid	28	83	125	153	165
S. sinense	Saretha	12	84	179	247	345
	Chunnee	13	84	172	202	324
	Natal Uba	20	96	397	408	417
Erianthus maximus	NG 132	16	137	250	338	356
E. arundinaceous	NG 28-7	13	84	196	270	362
Arundo donax	Wild Selection	17	30	- 1/	-	-
Sudan Grass x Sweet Sorghum (Hybrid Forage)	Sordan 70-A 1/	47	113	-	-	-

1/ Flowered at 5 to 8 weeks.

TABLE 8. GREEN WEIGHT RESPONSES OF IMMATURE SUGARCANE TO THE PLANT GROWTH INHIBITOR POLARIS 1/

	Response At 6 Weeks		Response At 12 Weeks	
Polaris (ppm)	g/Plant	% Change	g/Plant	% Change
0	263	0	343	0
50	288	+ 10	383	+ 12
100	337	+ 28	451	+ 32
200	322	+ 22	403	+ 18
300	322	+ 22	412	+ 20
400	265	0	335	- 2
500	169	- 36	248	- 28

1/ Variety PR 980. Applied as aqueous foliar sprays at 14 weeks of age.

TABLE 9. GROWTH RESPONSES OF IMMATURE SUGARCANE TO PLANT GROWTH INHIBITORS

Compound 1/	Green Wt (g/plant) At 6 Weeks After Treatment	Deviation From Control (%)
Control	48.6	0
Polaris	62.2	+ 28.0
Mon 8000	28.8	- 40.7
ACR 1093 DA	26.5	- 45.5
Embark	61.8	+ 27.2

1/ Administered as aqueous foliar sprays containing 100 ppm active ingredient.

TABLE 10. STIMULATORY EFFECTS OF MON 8000 ON TILLER (SHOOT) PRODUCTION BY IMMATURE SUGARCANE; 42 DAYS

Mon 8000 (ppm) 1/	Green Wt./Plot		Deviation From Control (%)	
	Tot. Shoots	g/Shoot	Green Wt.	No. Tillers
0 (Control	3516	27.9	0	0
10	3842	32.8	17.6	9.3
25	4525	36.2	27.9	28.7

1/ Applied as aqueous foliar sprays to 10-weeks old plants, variety PR 980.

TABLE 11. STIMULATORY EFFECTS OF EMBARK [1] ON TILLER (SHOOT) PRODUCTION BY IMMATURE SUGARCANE

Applied Embark (ppm) [2]	Yields At 42 Days After Treatment	
	Tillers/Plot	Deviation From Control (%)
0 (Control)	151	0
25	192	+ 27
50	294	+ 95
100	223	+ 48
150	231	+ 53
200	195	+ 29
300	202	+ 34

[1] A 3M Company product. [2] Administered as aqueous foliar sprays to 10-weeks old plants, variety PR 980.

TABLE 12. BRIX AND POLARIZATION VALUES FOR IMMATURE SUGARCANE TREATED WITH THE PLANT GROWTH INHIBITOR POLARIS 1/

	Mean Brix Values At Day –		
Polaris Conc. (ppm)	0	42	84
0	7.2 ab 2/	11.3 ab	12.3 a
50	7.1 abc	10.1 bc	11.1 b
100	6.6 bc	10.7 bc	11.5 ab
200	6.5 c	10.6 bc	11.4 ab
300	7.2 abc	9.4 c	11.3 ab
400	6.5 c	11.2 ab	11.2 b
500	7.3 a	12.3 a	10.9 b

	Polarization Values At Day –		
Polaris Conc. (ppm)	0	42	84
0	10.3 ab	24.9 bc	31.2 a
50	9.6 abc	22.1 bc	27.2 a
100	8.2 c	25.1 bc	28.4 a
200	8.3 c	24.5 bc	29.2 a
300	9.9 ab	19.9 c	28.2 a
400	9.8 c	28.5 ab	28.8 a
500	11.2 a	33.8 a	29.3 a

1/ Variety PR 980. Applied As Aqueous Foliar Sprays At 14 Weeks Of Age.

2/ Mean values in the same column bearing unlike letters differ significantly ($P < .05$). Mean values bearing at least one letter in common are not significantly different.

TABLE 13. INTERGENERIC TROPICAL GRASSES IMPORTED TO PUERTO RICO AS CANDIDATE BIOMASS SOURCES IN 1978

Intergeneric Cross	Clone Identification
Saccharum x *Eccoilopus longisetous*	US 72-1304 US 66-301
Saccharum x *Sorgo rex*	US 61-66-6 US 71-22-2
Saccharum x *Sclerostachya fusca*	US 66-157 US 68-40-1 US 64-37 US 64-35
Saccharum x *Ripidium* sp.	US 56-1-9
Saccharum x *Miscanthus*	US 67-37-1
Saccharum x *Erianthus contortus*	US 66-163-2
Saccharum x *S*. *spont*. (Intrageneric)	US 72-34-1
Ripidium kanashiroi x *R*. *bengalense* (Intrageneric)	US 61-37-7
R. *bengalense* x *R*. *bengalense* (Intraspecific)	US 60-58

TABLE 14. DRY MATTER PRODUCTION BY CANDIDATE S. SPONTANEUM AND S. SINENSE CLONES IN SMALL FIELD PLOTS; MONTHS 4, 6, AND 8 1/

		4-Months Harvest		6-Months Harvest		8-Months Harvest		Total Yields	
Species	Clone	Kg/Plot	% of PR 980	Kg/Plot	% of PR 980	Kg/Plot	% of PR 980	Kg	% of PR 980
Saccharum Hybrid	PR 980	17.1	100	2.5	100	2.2	100	21.8	100
	Saretha	11.3	66	2.7	108	3.3	150	17.3	79
	Chunnee	11.7	68	2.4	96	3.1	140	17.2	79
	Natal Uba	9.5	55	1.9	76	2.4	109	13.8	63
	Tainan	13.3	78	4.1	164	5.0	227	22.4	103
S. spontaneum	SES 231	8.8	52	5.2	208	7.2	327	21.2	97
	SES 317	10.9	64	- 2/	-	-	-	-	-
	SES 327	10.9	64	3.1	124	3.0	136	17.0	78
	US 67-22-2	18.5	108	4.7	188	5.2	236	28.4	130
	US 67-34-24	12.4	73	3.2	128	2.9	132	18.5	85
	US 72-97	12.5	73	4.4	176	5.3	241	22.2	102
	US 72-70	19.9	117	4.6	184	5.1	232	29.6	136
	US 72-72	12.4	72	4.0	160	4.0	182	20.4	94
	US 72-144	15.8	93	4.5	180	4.7	214	25.0	115
Erianthus maximus	NG 132	7.5	44	- 2/	-	-	-	-	-

1/ Plot size = 1/200 acre.

2/ Clones not harvested at months 6 and 8.

TABLE 15. TILLERING AND DRY MATTER VALUES FOR THREE HARVESTS OF CANDIDATE SACCHARUM CLONES IN SMALL FIELD PLOTS [1/]

Species	Clone	4-Months Harvest		6-Months Harvest		8-Months Harvest		Total Plants	Ave. DM (%)
		No. of Plants	% DM	No. of Plants	% DM	No. of Plants	% DM		
Saccharum Hybrid	PR 980	268	17.9	384	16.7	445	20.7	1097	18.4
S. sinense	Saretha	438	21.4	687	15.2	607	16.9	1732	17.8
	Chunnee	534	21.2	739	17.4	832	16.5	2105	18.4
	Natal Uba	330	17.4	328	14.6	395	14.6	1056	15.5
	Tainan	655	24.6	1002	17.5	1079	20.3	2736	20.8
S. spontaneum	SES 231	960	19.5	1528	16.9	1598	19.8	4086	18.7
	SES 327	204	20.8	165	18.3	163	21.3	532	20.1
	US 67-22-2	394	19.6	651	13.9	655	16.0	1700	16.5
	US 67-34-24	258	18.8	462	15.5	427	18.9	1147	17.9
	US 72-97	632	24.4	1403	15.9	898	17.7	2933	19.3
	US 72-70	501	23.5	945	17.0	835	19.9	2281	20.1
	US 72-72	330	23.8	602	17.9	803	22.5	1735	21.4
	US 72-144	473	22.2	731	16.1	839	20.1	2043	19.5

[1/] Plot size = 1/200 acre.

TABLE 16. CONTROLLED VARIABLES FOR INITIAL FIELD-PLOT STUDIES IN THE LAJAS VALLEY, PUERTO RICO

Clone	Row Center (cm)	Harvest Frequency (Mo)
PR 980	150 & 50	2, 4, 6 & 12
NCo 310	150 & 50	2, 4, 6 & 12
PR 64-1791	150 & 50	2, 4, 6 & 12
Napier Grass	50 & 25	2, 4, 6 & 12

TABLE 17. PROJECTED GREEN-AND DRY-MATTER YIELDS FOR THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED 2 MONTHS AFTER PLANTING.

	Tons/Acre At Indicated Row Center-					
	Green Matter			Dry Matter		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	1.5	4.2	177	.24	.70	233
NCo 310	1.2	3.2	167	.21	.54	157
PR 64-1791	1.5	3.4	135	.22	.54	145
Common Merker [1/]	14.1	17.8	26.2	1.8	2.5	39

[1/] Standard and narrow row centers for napier grass are 50 cm and 25 cm, respectively.

TABLE 18. DRY MATTER YIELDS FOR SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS OVER A TIME-COURSE OF 12 MONTHS

Harvest Interval	Cultivar	Estimated Tons/Acre At Indicated Month [1] 2	4	6	8	10	12	Total Yield (For Completed Data)
2 Months	Sugarcane [2]	0.4	1.2	1.2	0.8	1.7	(Incomplete Data)	5.3
	Napier Grass [3]	2.1	1.4	3.0	0.9	4.0	(Incomplete Data)	11.4
4 Months	Sugarcane		3.4		3.6		(Incomplete Data)	7.0
	Napier Grass		5.7		8.4		(Incomplete Data)	14.1
6 Months	Sugarcane			8.6			(Incomplete Data)	8.6
	Napier Grass			13.1			(Incomplete Data)	13.1
12 Months	Sugarcane						(Incomplete Data)	-
	Napier Grass						(Incomplete Data)	-

[1] Based on mean values from replicated, 1/50 acre plots. [2] Mean values for 3 varieties and 2 row spacings.

[3] Mean values for one variety and 2 row spacings.

TABLE 19. DRY MATTER PRODUCTION BY THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED AT 2-MONTH INTERVALS

	Tons/Acre At Indicated Row Center And Interval After Planting –								
	2 Months			4 Months			6 Months		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	.24 d[1]	.70 c	233	1.2 bc	1.3 ab	10	0.9 c	1.4 b	53
NCo 310	.21 d	.54 cd	157	0.9 bc	1.4 ab	48	1.1 c	1.6 b	46
PR 64-1791	.22 d	.54 cd	145	1.0 c	1.5 ab	53	1.0 c	1.4 b	43
Common Merker [2]	1.8 a	2.5 b	39	1.6 a	1.6 a	0	3.0 a	3.0 a	0

	8 Months			10 Months			12 Months		
PR 980	.68 b	.73 ab	7	1.3 b	1.7 b	29	(Incomplete Data)		
NCo 310	.85 ab	.81 ab	-5	2.0 b	2.2 b	10			
PR 64-1791	.69 b	.89 ab	29	1.5 b	1.6 b	9			
Common Merker [2]	.95 a	.81 ab	-15	4.0 a	4.0 a	0			

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[1] Mean values within the same column and harvest interval bearing unlike letters differ significantly ($P < .05$). Values in the same row and harvest interval bearing unlike letters also differ significantly. Different means having at least one letter in common do not differ significantly.

[2] Standard and narrow row centers for napier grass were 50 cm and 25 cm, respectively.

TABLE 20. GREEN MATTER PRODUCTION BY THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED AT 2-MONTH INTERVALS

	Tons/Acre At Indicated Row Center And Time Interval After Planting –								
	2 Months			4 Months			6 Months		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	1.5 d[1]	4.2 c	177	8.1 ab	9.2 a	13.6	4.7 c	7.4 b	65.4
NCo 310	1.2 d	3.2 cd	167	6.5 bc	7.6 ab	16.9	5.6 c	7.7 b	38.8
PR 64-1791	1.5 d	3.4 cd	135	6.2 c	8.1 ab	30.6	5.4 c	7.9 b	45.4
Common Merker [2]	14.1 b	17.8 a	26.2	8.6 ab	9.0 a	4.7	19.6 a	19.2 a	-2.3
	8 Months			10 Months			12 Months		
PR 980	3.7 c	4.1 c	10.2	7.3 b	8.0 b	10.2	(Incomplete Data)		
NCo 310	4.4 bc	4.3 c	-2.1	8.4 a	8.9 b	5.7			
PR 64-1791	4.1 c	4.9 ab	21.1	7.5 b	7.9 b	5.2			
Common Merker [2]	5.9 a	5.6 ab	-4.8	20.3 a	22.6 a	11.3			

[1] Mean values within the same column and harvest interval bearing unlike letters differ significantly (P < .05). Values in the same row and harvest interval bearing unlike letters also differ significantly. Different means having at least one letter in common are not significantly different.

[2] Standard and narrow rows for napier grass are 50 cm and 25 cm, respectively.

TABLE 21. DRY MATTER PRODUCTION BY THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED AT 4-MONTH INTERVALS

	Dry Tons/Acre At Indicated Row Center And Time Interval After Planting –								
	4 Months (First)			8 Months (Second)			12 Months (Third)		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	3.1 cd [1]	4.8 b	54.8	3.7 b	3.8 b	2.7			
NCo 310	2.5 d	3.8 c	52.0	3.4 b	3.7 b	8.8	(Incomplete Data)		
PR 64-1791	2.3 d	3.7 c	60.8	3.3 b	3.6 b	9.0			
Common Merker [2]	5.5 ab	5.9 a	7.2	8.0 a	8.7 a	8.7			

1/ Mean values within the same column and harvest interval bearing unlike letters differ significantly ($P < .05$). Values in the same row and harvest interval bearing unlike letters also differ significantly. Different means having at least one letter in common are not significantly different.

2/ Standard and narrow row centers for napier grass are 50 cm and 25 cm, respectively.

TABLE 22. DRY MATTER YIELDS FOR THREE SUGARCANE VARIETIES PROPAGATED WITH VARIABLE HARVEST INTERVALS OVER A TIME-COURSE OF TWELVE MONTHS

Harvest Interval (Months)	Variety	Row Center (cm)	Estimated Tons/Acre At Indicated Month 1/						Total Yield (For Completed Data)
			2	4	6	8	10	12	
2	PR 980	150	.24	1.3	0.9	.68	1.3	(Incomplete Data)	4.4
		50	.70	1.5	1.4	.73	1.7		6.0
	NCo 310	150	.22	1.2	1.1	.85	2.0		5.4
		50	.55	1.3	1.6	.81	2.2		6.5
	PR 64-1791	150	.22	0.9	1.0	.69	1.5		4.3
		50	.54	1.3	1.4	.89	1.6		5.7
4	PR 980	150		3.1		3.7		(Incomplete Data)	6.8
		50		4.8		3.8			8.6
	NCo 310	150		2.5		3.4			5.9
		50		3.8		3.7			7.5
	PR 64-1791	150		2.3		3.3			5.6
		50		3.7		3.6			7.3
6	PR 980	150			8.7			(Incomplete Data)	8.7
		50			9.6				9.6
	NCo 310	150			7.7				7.7
		50			9.1				9.1
	PR 64-1791	150			7.2				7.2
		50			9.3				9.3
12	PR 980	150						(Incomplete Data)	
		50							
	NCo 310	150							
		50							
	PR 64-1791	150							
		50							

1/ Based on mean values from replicated, 1/50 acre plots.

TABLE 23. GREEN AND DRY MATTER PRODUCTION BY THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED AT 6-MONTH INTERVALS

Green Tons/Acre At Indicated Row Center And Harvest –

	6 Months (First)			12 Months (Second)		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	41.7 bcd 1/	48.5 a	16.3	(Incomplete Data)		
NCo 310	37.0 d	47.7 ab	28.9			
PR 64-1791	37.3 d	46.8 abc	25.4			
Common Marker 2/	41.3 cd	40.0 d	-3.1			

Dry Tons/Acre –

	6 Months (First)			12 Months (Second)
PR 980	8.7 c	9.6 bc	10.3	(Incomplete Data)
NCo 310	7.7 d	9.2 bc	19.4	
PR 64-1791	7.2 d	9.3 bc	29.1	
Common Marker 2/	13.6 a	12.6 ab	-7.3	

1/ Mean values in the same column and harvest interval bearing unlike letters differ significantly ($P < .05$). Values in the same row and harvest interval bearing unlike letters also differ significantly. Means having at least one letter in common are not significantly different.

2/ Standard and narrow row centers for napier grass are 50 cm and 25 cm, respectively.

TABLE 24. HAND REFRACTOMETER VALUES FOR THREE SUGARCANE VARIETIES PROPAGATED AT STANDARD AND NARROW ROW CENTERS

	Refractometer Readings At Indicated Period And Row Center 1/					
	6 Months			8 Months		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	14.2 b	14.9 a	4.9	17.4 c	19.2 a	10.3
NCo 310	14.8 a	14.9 a	0.6	19.1 ab	18.9 ab	-1.0
PR 64-1791	13.5 b	14.2 b	5.1	17.9 bc	18.1 abc	1.1
	10 Months			12 Months		
PR 980	17.9 b	18.0 b	0.5			
NCo 310	19.6 a	20.3 a	3.5	(Incomplete Data)		
PR 64-1791	18.5 b	18.6 b	0.5			

1/ Mean values in the same column and sampling period bearing unlike letters differ significantly (P < .05). Values in the same now and sampling period bearing unlike letters also vary significantly. Means having at least one letter in common are not significantly different.

TABLE 25. DRY MATTER CONTENT OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED AT 6-MONTH INTERVALS

	% DM At Indicated Row Center And Harvest —					
	6 Months (First)			12 Months (Second)		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	20.8 b[1]	19.7 b	-5.3			
NCo 310	20.9 b	19.1 b	-8.6	(Incomplete Data)		
PR 64-1791	19.2 b	19.8 b	3.1			
Common Merker[2]	32.9 a	31.5 a	-4.3			

[1] Mean values in the same column and harvest interval bearing unlike letters differ significantly ($P < .05$). Values in the same row and harvest interval bearing unlike letters also differ significantly. Different means having at least one letter in common are not significantly different.

[2] Standard and narrow row centers for napier grass are 50 cm and 25 cm, respectively.

TABLE 26. DRY MATTER CONTENT OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED AT 2-MONTHS INTERVALS

	% Dry Matter at Indicated Row Center And Time Interval After Planting –								
	2 Months			4 Months			6 Months		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	15.8 abc	16.6 ab	5.0	14.7 de	14.3 e	-2.7	19.1 a	18.7 a	-2.0
NCo 310	17.9 a	17.1 a	-4.4	16.4 bcd	18.3 a	11.5	19.1 a	20.1 a	5.2
PR 64-1791	14.6 bc	15.9 abc	8.9	15.4 cd	16.6 abc	7.7	18.0 ab	17.7 ab	-1.6
Common Merker	12.9 d	13.9 cd	7.7	18.3 a	18.1 ab	-1.0	15.0 b	15.7 b	4.6
	8 Months			10 Months			12 Months		
PR 980	18.4 abc	17.6 bcd	-4.3	18.1 b	21.0 ab	16.0	(Incomplete Data)		
NCo 310	19.9 a	18.9 ab	-5.0	24.0 a	24.5 a	2.0			
PR 64-1791	16.8 cd	18.1 abcd	7.7	20.1 b	21.0 ab	4.4			
Common Merker	16.2 de	14.8 e	-8.6	19.8 b	17.6 b	-11.1			

1/ Mean values within the same column and harvest interval bearing unlike letters differ significantly (P < .05). Values in the same row and harvest interval bearing unlike letters also differ significantly. Means bearing at least one letter in common do not vary significantly.

2/ Standard and narrow row centers for napier grass were 50 cm and 25 cm, respectively.

TABLE 27. GREEN MATTER PRODUCTION BY THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT STANDARD AND NARROW ROW CENTERS AND HARVESTED AT 4-MONTH INTERVALS

	Green Tons/Acre At Indicated Row Center And Time Interval After Planting –								
	4 Month (First)			8 Months (Second)			12 Months (Third)		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	24.6 bc[1]	34.6 a	40.7	22.1 bcd	22.6 abc	2.3	(Incomplete Data)		
NCo 310	17.8 d	25.4 b	42.7	16.9 e	18.3 de	8.3			
PR 65-1791	18.5 d	26.1 bc	41.1	19.6 cde	20.3 cde	3.6			
Common Merker[2]	20.7 cd	22.4 bcd	8.2	25.0 a	26.4 ab	5.6			

[1] Mean values within the same column and harvest interval bearing unlike letters differ significantly ($P < .05$). Values in the same row and harvest interval bearing unlike letters also differ significantly. Different means bearing at least one letter in common do not vary significantly.

[2] Standard and narrow row centers for napier grass are 50 cm and 25 cm, respectively.

TABLE 28. DRY MATTER CONTENT OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED AT VARIABLE ROW CENTERS AND HARVESTED AT 4-MONTH INTERVALS

	% Dry Matter At Indicated Row Center And Time Interval After Planting –								
	4 Months (First)			8 Months (Second)			12 Months (Third)		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	12.4 c [1/]	13.8 bc	11.2	15.9 c	16.6 c	4.4			
NCo 310	13.9 bc	15.1 b	8.6	20.4 b	20.3 b	-0.4	(Incomplete Data)		
PR 64-1791	12.5 c	14.2 bc	13.6	16.6 c	17.6 c	6.0			
Common Merker [2/]	26.4 a	26.2 a	-0.1	32.1 a	33.4 a	4.0			

[1/] Mean values in the same column and harvest interval bearing unlike letters differ significantly ($P < .05$). Mean values in the same row and harvest interval bearing unlike letters also differ significantly. Means having at least one letter in common are not significantly different.

[2/] Standard and narrow row centers for napier grass are 50 cm and 25 cm, respectively.

TABLE 29. PERCENT DRY MATTER FOR SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS OVER A TIME-COURSE OF 12 MONTHS

Harvest Interval	Cultivar	Percent Dry Matter At Indicated Month 1/						Average % DM (For Completed Data)
		2	4	6	8	10	12	
2 Months	Sugarcane 2/	16.3	16.2	18.8	18.3	21.7	(Incomplete Data)	18.3
	Napier Grass 3/	13.4	18.2	15.4	15.3	18.6	(Incomplete Data)	16.2
4 Months	Sugarcane		13.7		18.0		(Incomplete Data)	15.9
	Napier Grass		26.3		32.8		(Incomplete Data)	29.6
6 Months	Sugarcane			19.9			(Incomplete Data)	19.9
	Napier Grass			32.2			(Incomplete Data)	32.2
12 Months	Sugarcane						(Incomplete Data)	
	Napier Grass						(Incomplete Data)	

1/ Based on mean values from replicated, 1/50 acre plots. 2/ Mean values for 3 varieties and 2 row centers. 3/ Mean values for one variety and 2 row centers.

TABLE 39. PROJECTED TONNAGES FOR NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70-A HARVESTED AT VARIABLE INTERVALS

	Projected Tons/Acre At Indicated Interval[1]					
	First 2-Month Harvest			Second 2-Month Harvest		
Cultivar	Green	Oven-Dry	% DM	Green	Oven-Dry	% DM
PR 980 (Reference)	1.54 e[2]	0.41 e	26.6 a	7.71 d	1.34 c	17.4 b
Common Napier	8.73 d	1.22 d	14.0 c	29.16 b	3.35 b	11.5 d
Napier Hybrid 7350	11.00 c	1.88 c	17.1 bc	31.70 a	4.14 a	13.0 c
Napier Hybrid 30086	13.88 b	2.37 b	17.1 b	32.42 a	3.97 a	12.2 cd
Sordan 70-A	18.69 a	3.92 a	21.2 a	16.87 c	2.94 b	18.9 a

	First 4-Month Harvest		
PR 980 (Reference)	20.99 b	3.55 c	16.9 d
Common Napier	44.76 a	8.41 a	18.8 d
Napier Hybrid 7350	43.50 a	8.87 a	20.4 bc
Napier Hybrid 30086	41.80 a	9.07 a	21.7 b
Sordan 70-A	13.21 c	4.28 b	32.4 a

[1] Based on mean values from replicated, 1/50 acre plots. [2] Mean values in the same column bearing unlike letters differ significantly (P .05). Mean values having at least one letter in common do not differ significantly.

TABLE 31. DRY MATTER YIELDS OF NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70-A RELATIVE TO THE SUGARCANE CONTROL, PR 980

	% Increase Over PR 980, For Production Interval—		
Cultivar	First 2 Months	Second 2 Months	4 Months
PR 980 (Control)	0	0	0
Napier Grass	198	150	137
Napier Hybrid 7350	359	209	150
Napier Hybrid 30086	478	196	155
Sordan 70-A	856	119	21

TABLE 32. TOTAL DRY MATTER YIELDS FOR NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70-A HARVESTED AT 2-AND 4-MONTH INTERVALS OVER A TIME-COURSE OF FOUR MONTHS

	Total DM (Tons/Acre) From Harvest Interval —	
Cultivar	Two, 2-Month Harvests	One 4-Month Harvest
PR 980	1.75	3.55
Common Napier	4.57	8.41
Napier Hybrid 7350	6.02	8.87
Napier Hybrid 30086	6.34	9.07
Sordan 70-A	6.86	4.28

1/ Statistical analyses for the same harvests are found in TABLE 30.

TABLE 33. PLANT POPULATIONS FOR NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70-A AT 8 WEEKS AFTER PLANTING

Cultivar	Stems/Acre 1/
PR 980	90,192
Napier Grass (Var. Merker)	107,992
Napier Hybrid No. 7350	102,456
Napier Hybrid No. 30086	150,490
Sordan 70-A	316,650

1/ Calculated from stem counts on 1/50 acre plots.

TABLE 34. PR SACCHARUM GERMPLASM SOURCES SELECTED FOR BREEDING CANDIDATE BIOMASS CLONES

Source	Breeding Stage
S. spont. (Aegyptiacum)	Frozen Pollen Frozen Whole Tassels
S. spont. Hybrid, Wild	Frozen Pollen Frozen Whole Tassels Flower Synchronization
Unidentified *S. sponts.*, (2), Wild	Frozen Pollen Frozen Whole Tassels

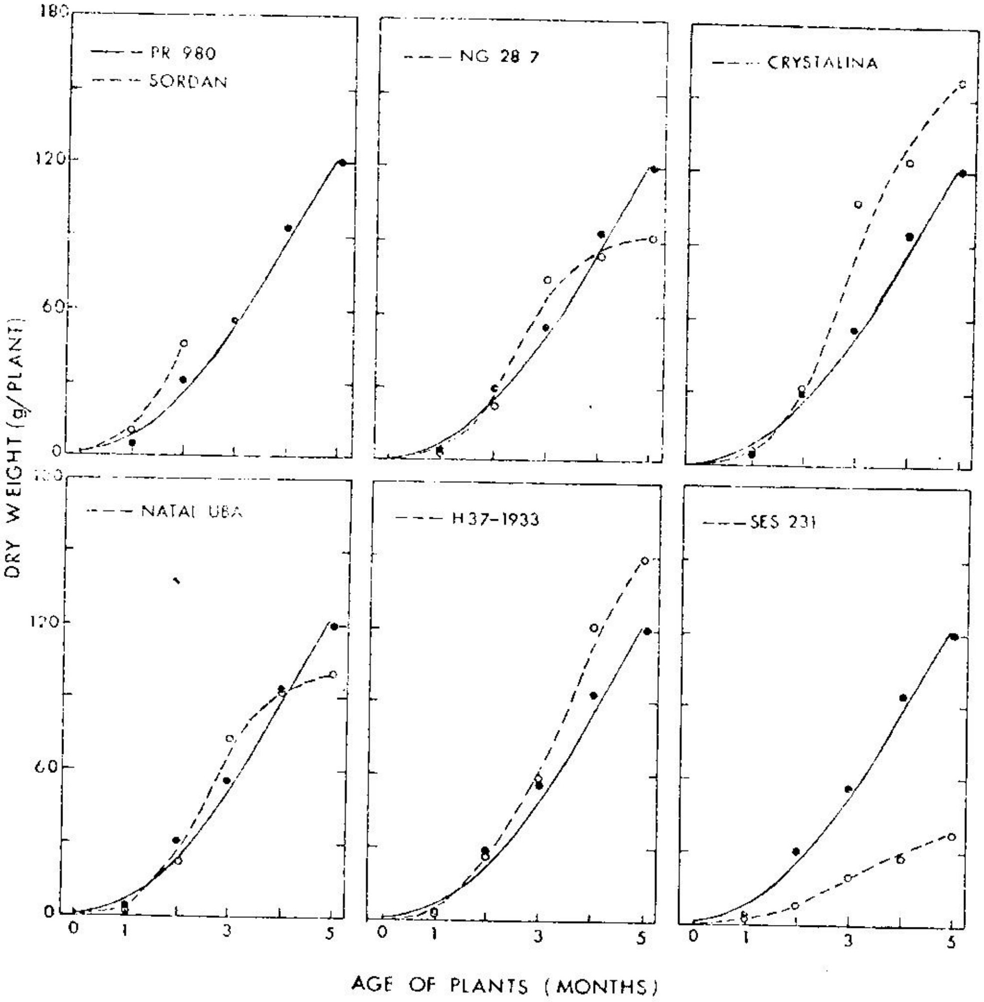

FIGURE 1. Growth curves of candidate tropical grasses propagated in a soil-cachaza mixture with controlled water supply. Sugarcane variety PR 980 served as the reference or standard clone. The hybrid forage grass Sordan 70-A flowered shortly after the 2-month harvest.

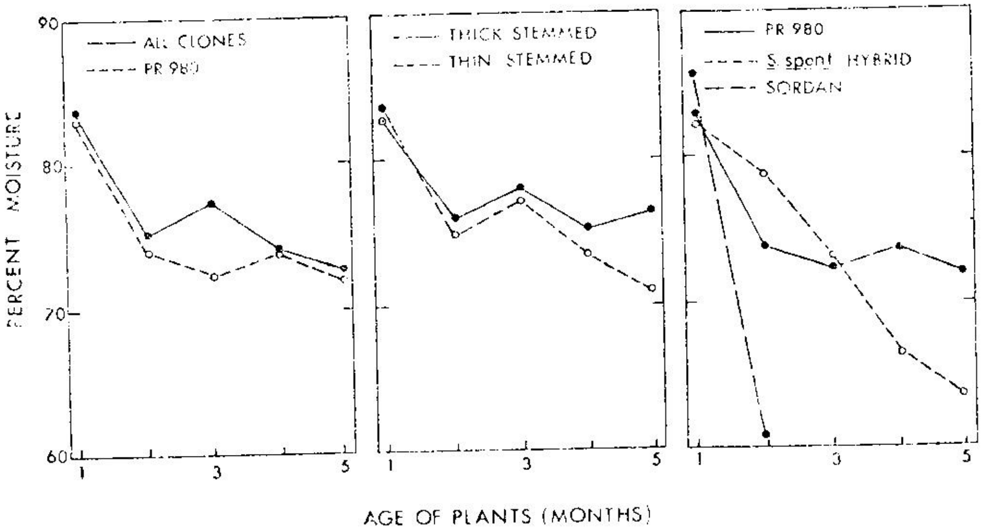

FIGURE 2. Percent moisture changes in candidate tropical grasses during a 5-month growth period. Sordan 70-A attained the moisture status of a mature plant in about 60 days.

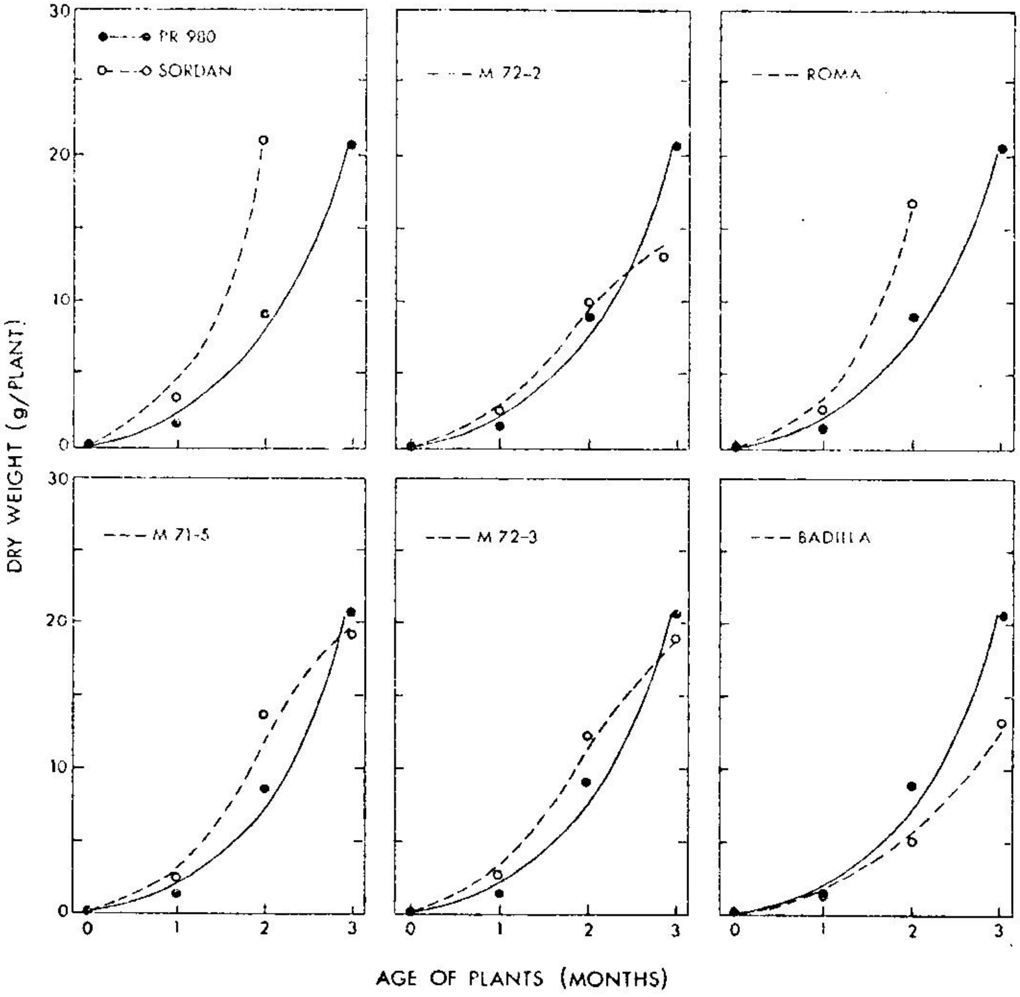

FIGURE 3. Initial growth curves of candidate tropical grasses consisting of a sugarcane hybrid control (PR 980), the sweet sorghum varieties M71-5, M72-2, M72-3, and Roma, the *S. officinarum* variety Badilla, and the hybrid forage grass Sordan 70-A. Sordan 70-A and Roma flowered shortly after the 2-month harvest.

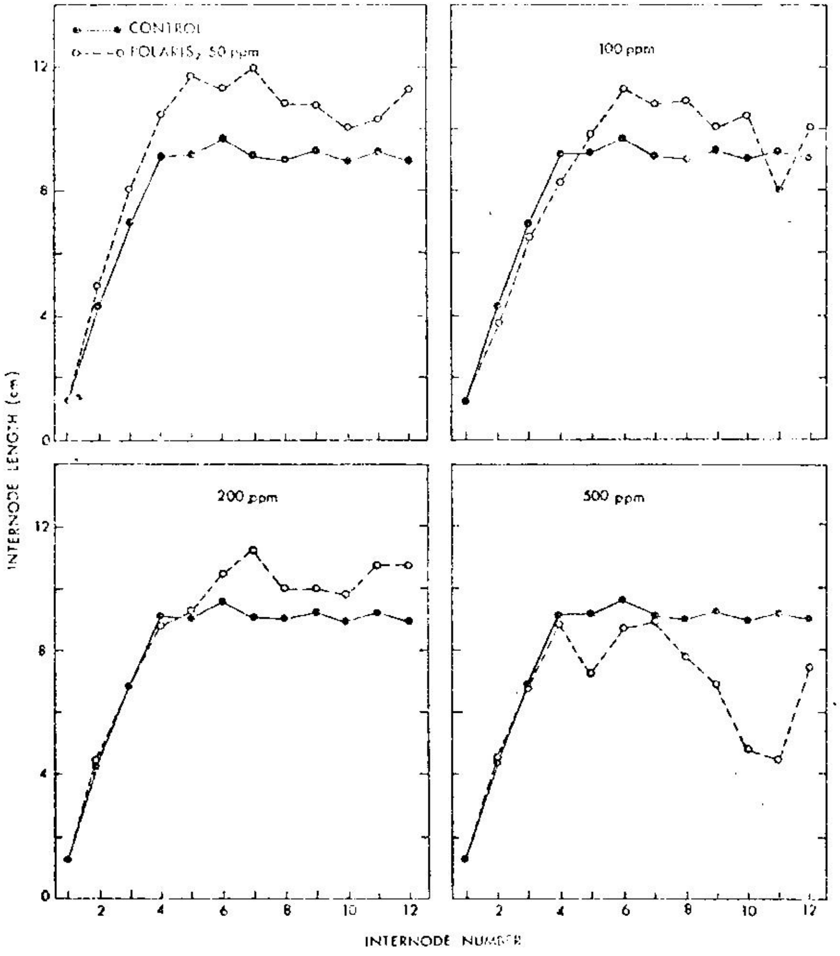

FIGURE 4. Internode expansion in sugarcane variety PR 980 treated with aqueous foliar sprays of the plant growth inhibitor Polaris / N, N-bis (phosphonomethyl) glycine/.

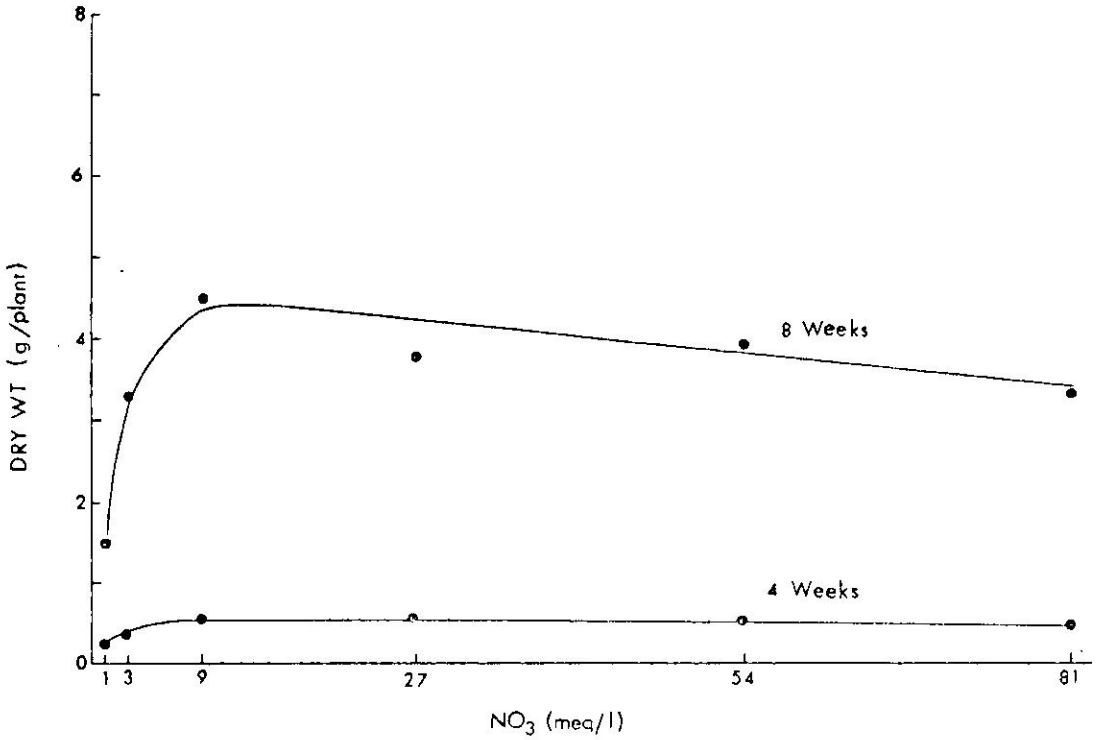

FIGURE 5. Nitrogen-response curves for the short-rotation candidate Sordan 70-A. Variable nitrate was supplied in nutrient solutions to plants propagated by sand culture (Incomplete data).

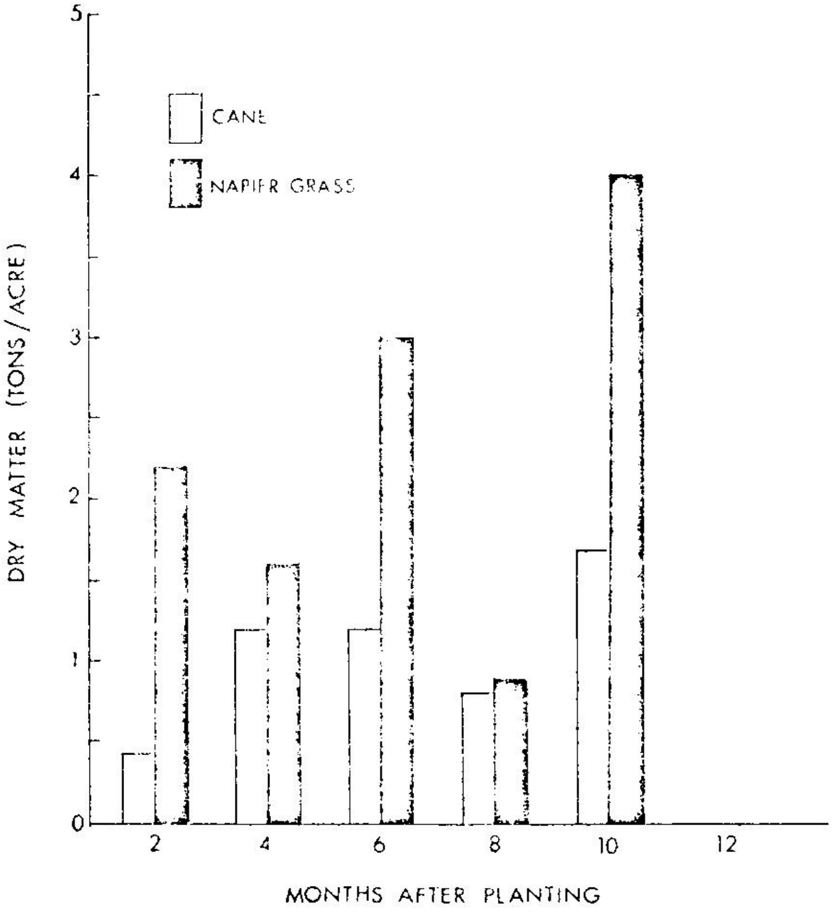

FIGURE 6. Variable dry matter production by sugarcane and napier grass as a function of incremental fertilizer supply. Both species received 1/3 of their annual fertilizer compliment at planting, 1/3 following the 4-month harvest, and 1/3 following the 8-month harvest. (Incomplete data).

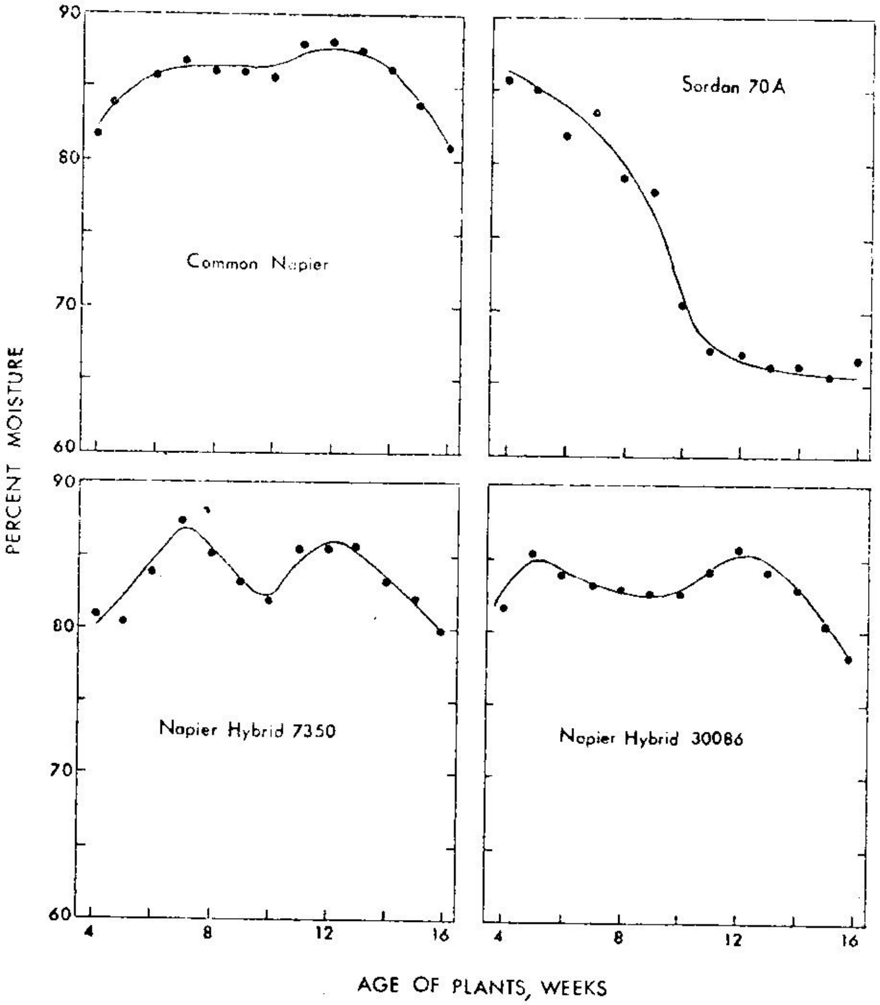

FIGURE 7. Percent moisture changes in common napier grass (var. Common Merker), two napier grass hybrids, and the hybrid forage grass Sordan 70-A (sweet sorghum x Sudan grass). Irrigations were administered at seeding, at 4 weeks, and at 10 weeks.

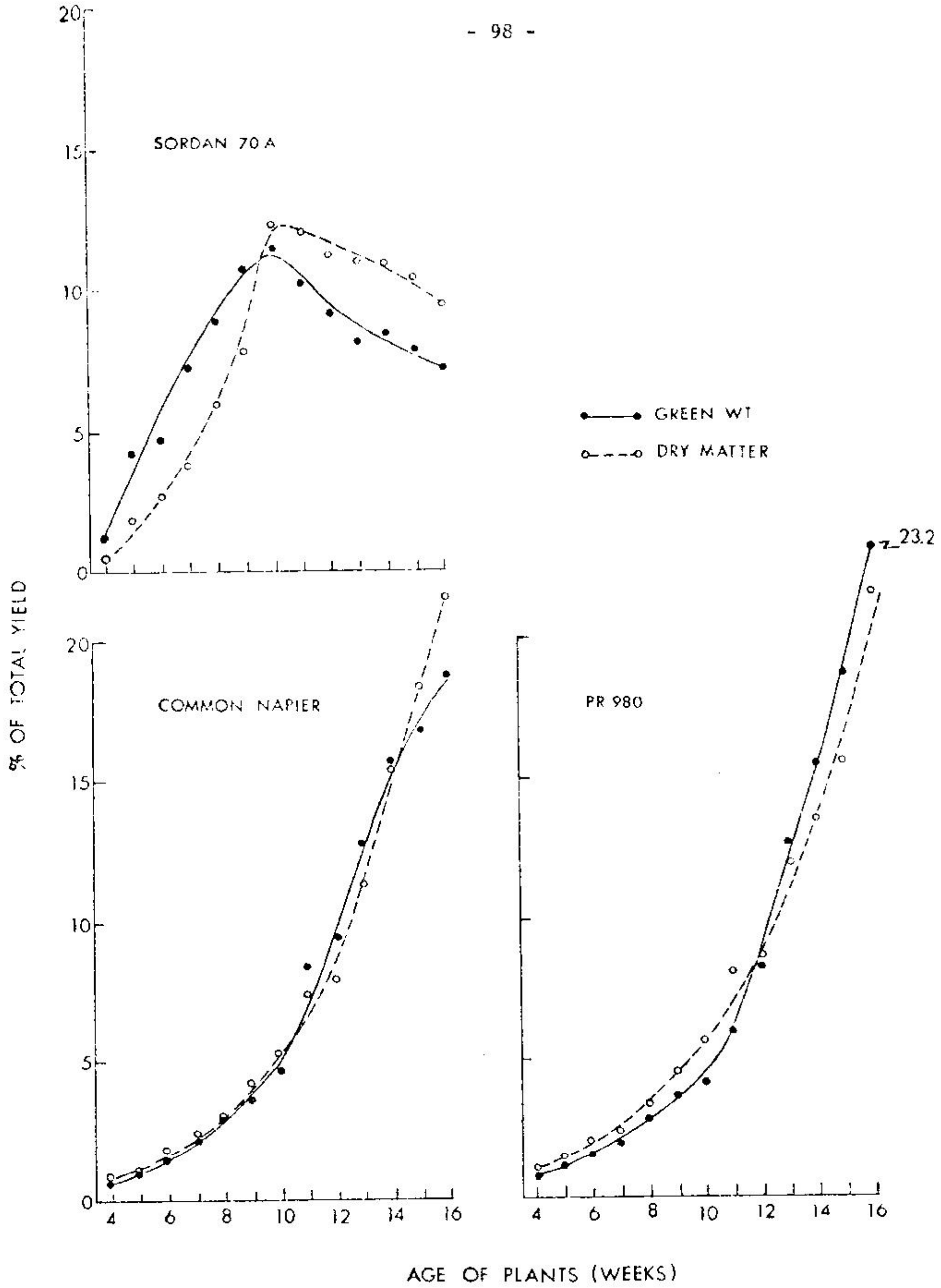

FIGURE 8. Green- and dry-matter production by Sordan 70-A, common napier grass, and the *Saccharum* hybrid PR 980. Weekly increments for each parameter are plotted as percentages of that parameter's total yield accumulated over a time-course of 16 weeks. Two discrete growth phases are depicted, ie, tissue expansion and dry matter accumulation. The optimal harvest period for Sordan 70-A, a short-rotation candidate, is clearly indicated at 10 weeks after seeding. Neither napier grass (intermediate rotation) nor sugarcane (long rotation) have attained a comparable state of maturation.

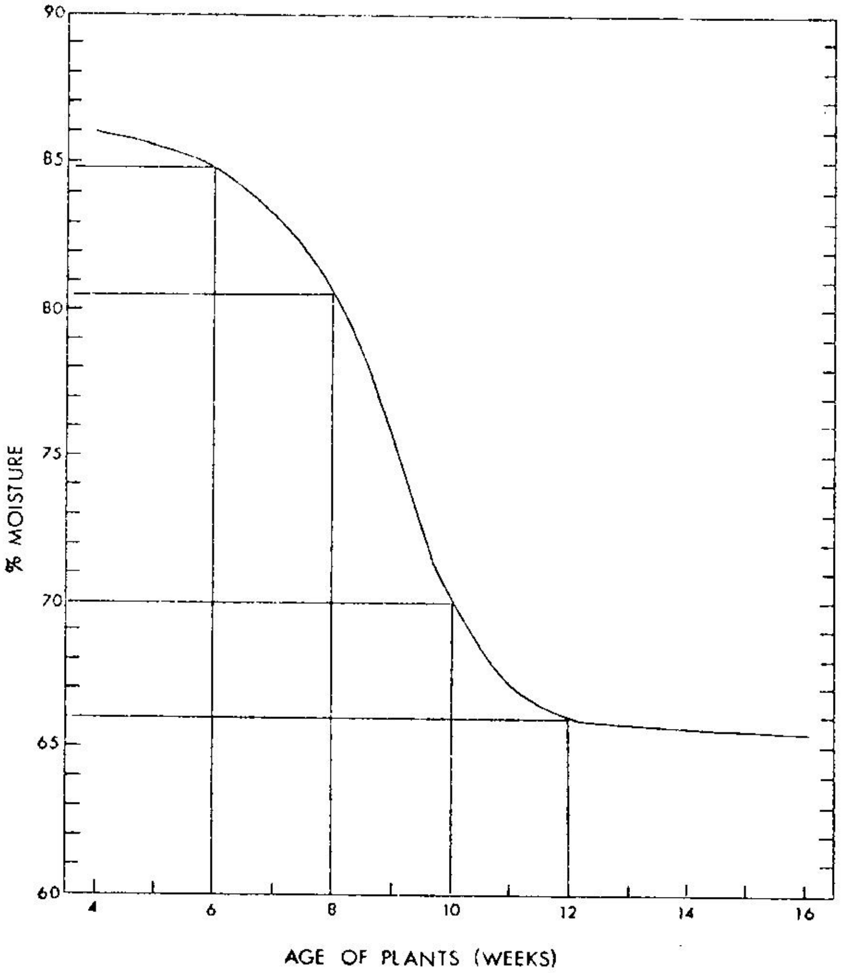

FIGURE 9. A plot of the declining moisture content (maturation curve) for Sordan 70-A. The decisive period for fiber accumulation is the 2-week interval from week 8 to 10.

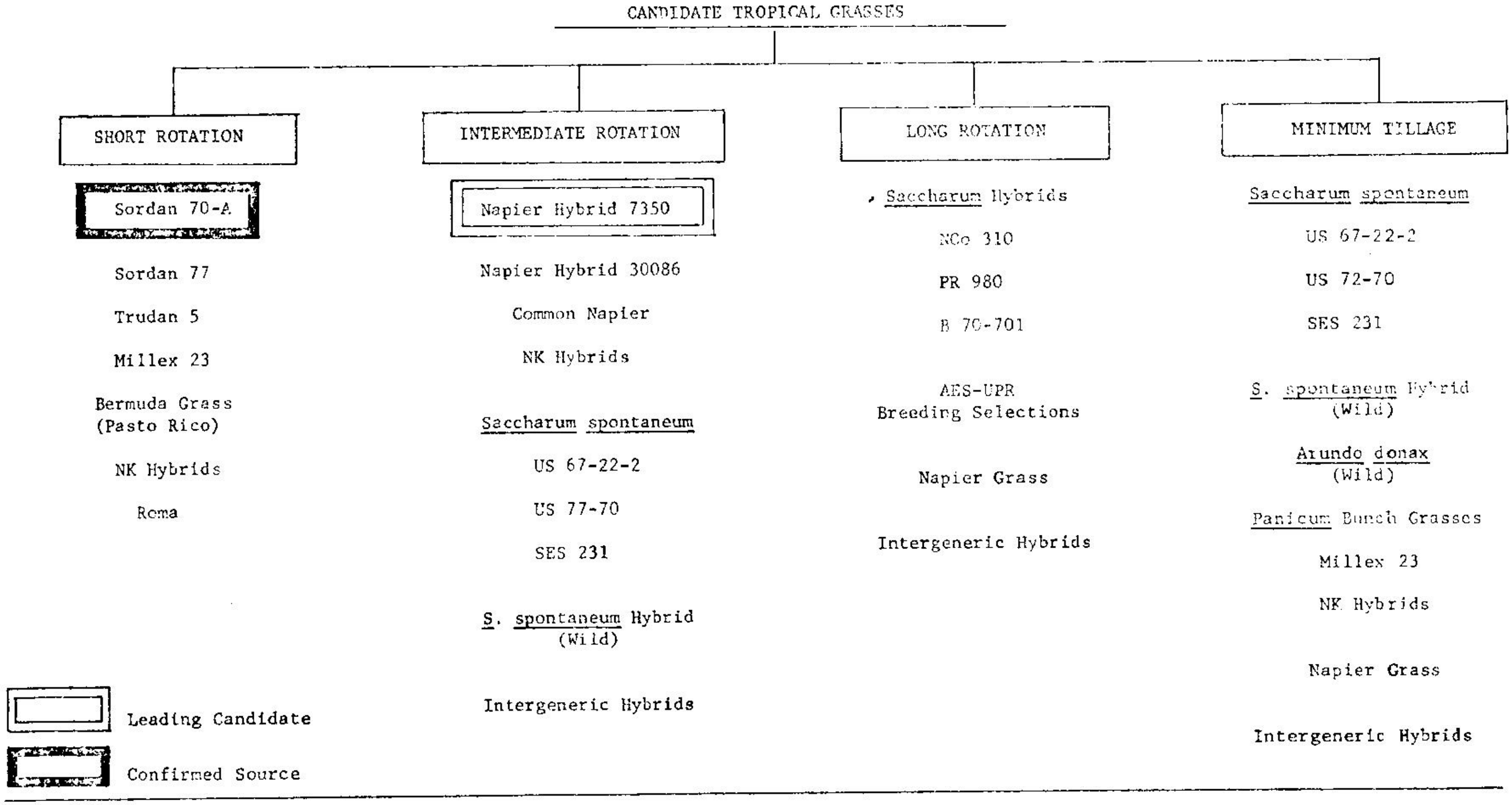

FIGURE 10. Categories of tropical grasses and leading candidate clones under investigation as renewable energy sources in Puerto Rico.