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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

FINAL REPORT
June 1, 1977 — May 31, 1982

To

THE UNITED STATES DEPARTMENT OF ENERGY
Oak Ridge Operations Office, and Division of Solar Technology
Biomass Energy Systems Branch
Washington, D. C.

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

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Center for Energy and Environment Research
University of Puerto Rico

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A. G. Alexander, W. Allison
C. González-Molina, J. Ortiz-Vélez, G. Ramírez
J. Vélez-Santiago, A. Vélez, and T. L. Chu [1]

ABSTRACT [2]

A 5-year study on the production of sugarcane and related tropical grasses as energy crops was completed with all objectives attained. Begun in 1977 with screening of candidate grasses at the greenhouse level, the project progressed to field-plots and then to mechanized field-scale production technologies emphasizing maximum total dry matter yield at minimum cost on a continuous, year-round basis. Final cost and energy balance analyses indicate that tropical grasses are unquestionably an economic and reliable energy resource with multiple benefits when managed specifically as energy crops in a tropical environment.

Culminating in an "energy cane" concept for optimal fuels and feedstocks production, the 5-year study underscored two points: (a) Revised management technologies that emphasize growth rather than sugar storage, and (b), multiple species integration for year-round supply of fuels and feedstocks to biomass-utilizing industry.

Through revised management, sugarcane yields in the order of 83 short tons/acre year were attained for whole green cane (as opposed to 27 short tons/acre year for conventional sugarcane in PR). Sugarcane managed in this way is now depicted as energy cane, or "first-generation" energy cane. "Second-generation" energy cane, consisting of revised field management technologies plus varieties specifically selected for biomass

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[1] AES-UPR, CEER-UPR, and UPR Mayaguez Faculty.

[2] Contract Nos. EG-77-G-05-5422, ET-78-S-05-5912, and DE-AS05-78ET20071. (AES-UPR project no. C-481).

produced over 110 short tons/acre year. Production costs were slightly higher than $1,000/acre year but less than $10.00 green ton. Recoverable energy yields were in excess of 450,000,000 BTUs/acre year at costs under $2.00/million BTUs. Combined values for fuels (pegged to fuel oil at $33.00/barrel) and high-test molasses (at $0.76/gallon) exceed $3,000/acre year for second-generation energy cane.

A major component of the energy cane concept was the development of alternative tropical grass species as supplemental biomass sources. Consisting of generic-level relatives of <u>Saccharum</u>, these are thin-stemmed, fibrous, non-sugar bearing grasses whose entire production, harvest, and post-harvest dewatering management is performed directly in the field. Type species for this group include Sordan 70A ("short-rotation", harvested at 10-12 week intervals) and napier grass ("intermediate-rotation, harvested at 4-to 6-month intervals). This component of the project was highly successful with all operations effectively mechanized.

Tropical grasses production as energy crops is seen as an economically viable enterprise for regions having tropical agriculture capabilities. It is particularly attractive for relatively advanced tropical societies, such as Puerto Rico, with heavy reliance on imported fossil energy. Considerable "fine tuning" potential remains for future energy cane management research. A vast amount of work remains in the breeding of "third generation" energy canes. Certain components of the completed DOE project are being continued in Puerto Rico under UPR and Commonwealth sponsorship.

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 dealt 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 fossil energy forms that are currently imported at enormous expense.

A. 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 Saccharum progeny having superior biomass productivity as their principal attribute.

B. SCOPE OF THE PROJECT

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

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[1] Contract Nos. EG-77-G-05-5422, ET-78-S-05-5912, and DE-AS05-78ET20071.

from conventional cane and cattle feed production in that total dry matter rather than sugar and food components was the principal salable commodity. Management of production inputs — particularly water, nitrogen and candidate species, together with harvest frequency — varies significantly from established procedures. On the other hand, advances in mechanized production and harvest operations within the sugar and cattle forage industries have been 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 was accomplished in three phases, including greenhouse, field-plot, and field-scale investigations (Table 1). A fourth phase, commercial-industrial operations, follows logically but was beyond the scope of the present project.

The tropical grasses have never before been evaluated under conditions such that biomass energy would be the principal salable product. As a consequence it was necessary to screen a broad range of candidate cultivars. 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 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 were evaluated in a stepwise program involving greenhouse, field-plot, and field-scale trials. In certain respects this was a tropical application of the herbaceous species screening concept formulated by the DOE Fuels From Biomass Program (3).

[1/] Numbers in parenthesis refer to relevant published literature. Complete citations are listed on pages 67-72.

A breeding program designed to intensify the biomass-yielding attributes 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 was included in the present project. This work was 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 were also evaluated as long-rotation [1] biomass candidates. Under such circumstances some prospect is created for the emergence of superior new progeny at very little expense.

C. STATEMENT ON DATA PRESENTATION SEQUENCE

This report covers the period June 1, 1977 through May 31, 1982, the entire contract period for the work under this project title. Some of the longer-term experiments were not initiated until after July 1, 1977, and two major experiments are continuing to provide data after the May 31, 1982 termination date. The latter experiments are being maintained through the first-ratoon crop with CEER-UPR funds.

TECHNICAL REPORT

A. GREENHOUSE STUDIES

The project's greenhouse phase was 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

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[1] Categories of tropical-grass candidates for biomass production are discussed in detail on pages 37-40

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 was 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 were 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 were 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 were established with true seed. Insects were controlled with weekly applications of Malathion. All plants received controlled water and nutrient supplies at levels 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 was not satisfactory. Its major dry matter accumulation begins after 6 months and the project required some cultivars that will do this as early as two to three months after

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

planting. Also, several Saccharum imports and AES cane breeding progeny were identified as tonnage producers superior to PR 980. Subsequent reference clones were selected from the specific category of candidates under scrutiny, ie, Sordan 70-A for short-rotation candidates, napier grasss (var. Merker) for intermediate rotation, and a suitable S. spontaneum hybrid for the long-rotation category.

Harvest intervals were 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 three or four months of growth. Growth-regulator trials require sampling at precise intervals following chemical penetration.

The principal biomass parameters included total green weight, dry weight (oven dried to about 6% moisture), and dry matter content (% DM). Leaf samples, including the entire blades of leaf ranks +1 and +2 [1/] were initially harvested for foliar mineral analyses. In some early experiments leaf samples were harvested for blade-area and chlorophyll determinations. Biomass production characteristics evaluated during the project are presented in Table 2.

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.

[1/] 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.

The first clearly outstanding candidate to emerge in the project was 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. 7 & 8), 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, and in subsequent years were included in field-scale yield and harvest equipment evaluations.

3. Sudan Grass And Sorghum Hybrids

A series of sudan grass and sorghum hybrids developed by the Northrup-King Company (the "NK" hybrids) were 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 had 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 were subsequently 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 was Sordan 70-A. Additional candidates screened during the project's second and third years included 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 was concluded (correctly) that one or more varieties could successfully extend the Puerto Rico habitat for this type of biomass candidate without having greater productivity than Sordan 70-A.

4. Growth Curve Evaluations

Initial project emphasis was 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 were measured for 16 varieties from the genera Saccharum, Erianthus, and Arundo (Table 7). Arundo 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 ft^2), 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 1/ 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 from 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).

1/ Subsequently confirmed as an S. spontaneum hybrid which apparently "escaped" from a germplasm collection maintained by AES-UPR during the 1930's.

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). At the onset of this project it was felt that biomass yields from tropical grasses might be increased by this means at very little expense. Initial trials were made using juvenile sugarcane propagated by sand culture. The Monsanto products Polaris and CP 70139 were tested at subrepressive 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.

While interesting, trials with growth regulatory chemicals as a means of increasing biomass yields were discontinued after the project's first year. Field equipment today simply isn't adequate to simulate under field conditions the greenhouse-level treatments discribed above. This is the same constraint which has prevented full development of "chemical ripeners" in the commercial cane industry. Precision administration of hormone-like materials does remain an option for future study with tropical-grass energy crops.

(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/ alo 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). Future experiments with growth regulatory materials on tropical grasses could include their coadministration with pesticides and/or urea.

6. Regrowth Studies

Initial data collection on plant regrowth rates was initiated during the project's first year. These measurements 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 would have identified several clones within each category of tropical grasses that would withstand repeated recutting over a period of many years. In the upshot, one napier grass variety (PI 7350) and one long-rotation cane variety (US 67-22-2) were shown to have this attribute. None of the short-rotation grasses have this characteristic.

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 1977-78 using Sordan 70A 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.

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

Variable irrigation studies were initiated in 1978 using a series of Northrup King hybrid grasses as test species (25, 28). These included Sordan 70A, Sordan 77, Trudan 5, Trudan 7, Millex 23, NK 300, and NK 326. Humid, "normal", and semi-arid conditions were simulated by variable frequency of watering. All plants were propagated in the greenhouse in a 1:2 mixture of soil and cachaza, with Sordan 70A serving as the control variety.

Both arid and semi-arid moisture regimes gave yield profiles that were distinctly different from normal, while essentially equal to one another (Figure 6). In the case of "arid" plants the yield reduction was decisive; very little production was recorded from week 5 onward. Alternatively, the NK variety Trudan 7, although repressed by arid conditions, significantly out-produced the control variety Sordan 70A (Figure 7). Subsequent trials at the field-plot level verified that both Trudan 7 and Sordan 77 were superior to Sordan 70A under water-stress conditions.

9. 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 remained unavailable for testing in Puerto Rico.

The first fourteen clones were received from Houma during January, 1978, and were placed in quarantine at the AES-Gurabo Substation. This group greatly expanded 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]. These clones and those arriving in 1978 displayed an exceptionally robust growth habit and profuse tillering.

During the summer of 1978 two shipments of candidate grasses were imported into Puerto Rico and placed in quarantine at the AES-UPR Gurabo Substation. These included a group of five clones from the USDA-World collection at Beltsville, Maryland, and a group of 32 clones from the USDA-World collection at Canal Point, Florida (Table 15). The Beltsville shipment consisted entirely of S. robustum clones, a species which has been notably lacking in Puerto Rico. The bulk of the Canal Point group were S. spontaneum clones. The latter group also includes germplasm from the genus Ripidium [1], Miscanthus, and Erianthus, together with the Saccharum species S. fusca, S. narenga, and S. robustum.

These candidates were planted in soil-cachaza mixtures and all but one gave satisfactory germination. Growth was adequate though unremarkable for most clones. Several clones produced tassels late in November and December, 1978. Saccharum species very rarely flower under greenhouse conditions, but the late flowering trait could be a useful factor in its own right since it would enable these clones to be crossed with hybrid sugarcanes which normally tassel at this time [2]. The observed flowering could also be an artifact of the plant's greenhouse environment or their late-summer time of planting.

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

2/ The sugarcanes of commerce tend to flower later than the more primitive Saccharum species. This is an unfortunate trait of considerable importance to sugarcane breeders concerned with utilizing the widest possible range of Saccharum germplasm in their hybridization programs.

None of the imported species were found to be suitable for short-rotation cropping. They are regarded as candidates for long-rotation and minimum-tillage biomass crops. Certain of the Saccharum species may compare favorably with napier grass and napier hybrids as intermediate-rotation candidates. They might also expand the planting zones of intermediate-and long-rotation species into semi-arid and arid regions too dry to sustain napier grass and conventional sugarcane hybrids.

The principal objective of the clone-screening process was to find superior producers of dry biomass (fiber) for intensive propagation as solar-dried forages. Added to this was the need for minimum-tillage candidates that will survive and produce acceptable yields under arid conditions and various types of marginal lands. This objective was attained.

B. FIELD PLOT STUDIES

Some field-plot work was conducted at the AES-UPR Substations of Gurabo and Corozal, but most experiments were performed at the Lajas Substation in the semi-arid Lajas Valley. This phase of the project began during July of 1977. Certain experiments established during years 4 and 5 are still underway and are being completed with CEER-UPR "inhouse" funding.

1. Field Plot Methods

The majority of the project's field-plot experiments were planted on a Fraternidad soil series, a moderately well drained soil which is highly plastic when wet and crumbly when dry. It is representative of much of Puerto Rico's better agricultural lands. Plot size was ordinarily 1/50 acre and there were 4 to 6 replications of each treatment arranged in a randomized block design. Controlled variables included species, varieties, row spacing, seedbed preparation techniques, seeding rates, fertilizer supply, water supply, harvest frequency, postharvest seedbed management, and longivity of established plant populations.

Except in the variable irrigation treatments, all plants received an "adequate" water supply, administered first by overhead sprinklers (at seeding) and later by flood (border) irrigation. Fertilizer was ordinarily provided in three increments (one-third at planting and the remainder at 2-to 4-month intervals thereafter).

The principal harvest parameters for all experiments were total dry matter (DM), percent moiture, and total green matter (GM). These were usually reported on a "per acre" or "per acre year" basis. In some experiments, particularly the later studies on energy cane, foliar samples were taken periodically for nutrient assay (N, P, K, Ca, Mg) and millable stems were harvested for juice quality and sugar analyses. Also during the energy cane studies a more detailed breakdown was made of total DM on a plant compositional basis. Hence, cane plants before oven drying were subdivided into millable stems, immature stems, green foliar canopy, detached trash 1/, and attached trash.

2. Gurabo Substation Screening; US 67-22-2

The project's field plot experiments began at the humid AES-UPR Gurabo Substation and rapidly extended to the Lajas Substation in the semi-arid Lajas Valley. Subsequently, most of the field plot work was performed at Lajas. The early work at Gurabo was an observation study of candidate *Saccharum* species. This group consistsed of clones imported for breeding purposes in 1976, and a series of *S. spontaneum* and *S. sinense* clones that had already shown favorable biomass attributes under greenhouse conditions (24). The most significant result of this trial was the emergence of the *S. spontaneum* hybrid US 67-22-2 as a superior candidate for biomass production (Table 14). In this and subsequent trials, US 67-22-2 consistently outperformed the control clone (PR 980) in total green and dry matter yield, percent germination, rate of development, stems per acre, canopy development, and regrowth vigor. It also equalled or exceeded PR 980 in sugar content of millable stems and tons sugar per acre (TSA). Ultimately, US 67-22-2

1/ The term "trash" herein refers to leaf and leaf-sheath tissues that have died and desiccated; some fraction usually adhers to the stem while the remainder drops to the ground.

became the standard "second generation" energy cane [1] in the project's final years (25, 26, 27). By the close of the project this variety had become widely recognized both as a source of sugar and biomass and was undergoing seed expansion for plantation-scale production.

3. First-Generation Energy Cane; Lajas Substation

Throughout its long history as a cultivated crop, sugarcane has been planted for its yield of sugar rather than biomass. Yet, the plant itself, a combination of Saccharum species (usually mixtures of S. officinarum and S. spontaneum germplasm in modern hybrids) is a far better producer of biomass than sugar. Even the "sweetest" varieties of commerce consist roughly of 70% lignocellulosic matter and only 30% sugars or fermentable solids. Given adequate water, nutrients, and a warm climate, the sweetest varieties will opt to grow — to produce new shoots in an ever-expanding crown — rather than accumulate sucrose. As a consequence, sugarcane normally yields more energy than is consumed in its production operations, eventhough it is not normally managed for optimal energy yield.

An important goal of the field-plot studies was to determine the increased tonnages of biomass that could be expected when cane is managed for maximum biomass rather than sugar. One way of doing this is to select candidate varieties from existing commercial canes already available in large quantities and to alter their production technologies accordingly. An alternative approach is the selection and breeding of canes specifically created for the purpose of energy storage. In this project the first approach was mandated by time, resources, and the ready availability of seed. This phase was completed over a time-course of three years. The results were highly remarkable; they formed the basis for the "first-generation"energy cane concept initially revealed by CEER-UPR in a 1979 biomass symposium (29). Work began on "second generation" canes during the final two years of the project and continues at present under CEER-UPR funding with assistance from the Commonwealth government (30).

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[1] "Energy cane", a term coined locally in 1979, refers to cane managed for maximum biomass production rather than sugar.

An important feature of the energy cane concept is the production of lignocellulosic feedstocks on a year-round basis (31, 31). Although cane grows continuously throughout the year it cannot be harvested during the tropical rainy season when soil and seedbed structure is severely damaged by heavy equipment. In Puerto Rico, biomass processing facilities could not receive energy cane during the wettest four month of the year (mid August through mid December), and hence would be denied the critical "bagasse" feedstock needed to maintain operations. In the present project we attempted to close the anticipated gap in feedstock delivery by producing alternative tropical grasses that could be solar-dried in the field, compacted, and stored until needed during the rainy season. This phase was ultimately successful. A series of fast-growing, thin-stemmed fibrous grasses were identified as suitable species for this type of operation. The most successful candidate, napier grass (Pennisetum purpureum), was initially confirmed in this role during the studies on first-generation energy cane.

4. Energy Cane And Napier Grass Trials; Lajas

The project's first major field-plot experiment was established during July 1977, at the semi-arid AES-Lajas Substation. Controlled variables included varieties, row spacing, and harvest frequency (Table 16). There were three hybrid sugarcanes (PR 980, NCo 310, and PR 64-1791) and one napier grass variety (Common Merker). Each variety was recognized as a superior producer of biomass tonnage under Puerto Rico conditions.

(a) Procedures: This experiment was planted on a moderately well-drained Fraternidad Clay soil. Plot size was 1/50 acre and there were six replications of each treatment arranged in a randomized block design. All clones received 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 400 pounds per acre year for sugarcane and 600 pounds for napier grass. Water was provided as needed by flood irrigation delivering approximately 2 acre inches per application.

Whole plots consisting of a 600 square foot area were harvested at the appropriate interval, ie, at 2 months (six times per year), at 4 months (three times per year), at 6 months (two times per year) and at 12 months. Two subsamples of 10 plants each were harvested for dry matter determinations and foliar diagnosis of N, P, K, Ca, and Mg.

The nitrogen level for napier grass (600 lbs/acre year) was set at 1.5 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 clearly favor sugarcane. Management practices that were equal for sugarcane and napier grass included the level, method, and frequency of irrigation, the timing and method of multiple fertilizer applications, and all pest control procedures.

(b) Manganese Deficiency: Following the initial 2-month harvest, foliar discolorations possibly indicative of nutrient deficiency appeared in some of the napier grass plots. At about 3.5 months, foliar symptoms similar to manganese deficiency appeared in virtually all napier grass plots. None of the sugarcane plots had foliar symptoms eventhough they received less fertilizer than napier grass. The symptoms in napier grass were greatly diminished or disappeared entirely at 4 months following a second application of fertilizer to which a small amount of $MnCl_2$ had been added. This symptom recurred only briefly during the remainder of the project and was always responsive to small quantities of Mn. Subsequent greenhouse trials with Mn-free nutrient culture in sand culture confirmed that the indicated symptoms were associated with Mn deficiency.

5. Three-Year Trends; First Generation Energy Cane

In 1980 the first data for a complete cropping cycle became available for first-generation energy cane, and for napier grass managed as an energy crop (35). For perennial tropical grasses the first year's tonnages (plant crop) are usually lower than those of the ratoon crops (regrowth) in the years immediately thereafter. Puerto Rico's commercial cane industry normally harvests the plant corp plus four or five ratoon crops before replanting the area. Napier grass is considerably more durable and may reside on a given site for decades before replanting or rotation is deemed necesary.

As the project progressed, data trends were reported on a crop-by-crop, year-by-year basis. In retrospect the decisive trends for such factors as green and dry matter yields and production costs can be stated far more succinctly as the 3-year means of a complete crop cycle (35). Four distinct trends were evident for cane and napier grass: (a) A general failure of close spacing to increase yields; (b) large DM yield increases as harvest frequency was reduced; (c), a moderate superiority of sugarcane variety NCo 310 over other first-generation energy canes; and (d), a superiority of the first-ratoon crop over the plant and second-ratoon crops. Second-ratoon yields were intermediate between those of the plant and first-ratoon crops. The optimal DM harvest interval for cane was 12 months (the longest interval tested) and 6 months for napier grass. Optimal row spacing was 150 cm for cane and 50 cm for napier grass.

On an individual crop basis, the highest yields were recorded for the first-ratoon crop. The highest green matter yield for cane was 92.0 tons/acre year, with 31.3 tons dry matter. For napier grass the highest green and dry matter yields were 88.9 and 22.4 tons/acre year, respectively. Cane quality was low, on a "per stem" basis, but significant sugar yields were obtained on a per acre basis owing largely to the high tonnages of millable cane. Fiber content averaged 16.4% for all varieties.

(a) DM Yields Vs Harvest Interval: Mean DM yields for three crop years (plant crop plus two ratoon crops) underscored the importance of allowing at least 12 months to elapse between cane harvests and 4 to 6 months between napier grass harvests (Table 17). Certain officials in the PR Sugar Corporation have proposed two annual harvests of PR cane (at 6-month intervals) as a means of increasing cane yields. As indicated in Table 17, this would have the effect of lowering DM yield by nearly half. The negative impact on sugar yield would be even greater since very little sugar accumulates in 6-months old cane.

(b) DM Yields By Crop: The first-ratoon crop for energy cane was the most productive crop, particularly for the 12-month harvest interval (the only practical interval of the four tested on cane). As indicated in Table 18, yields from the 2-month harvest interval declined drastically after the first year. As an average response of three varieties, cane was unable to withstand frequent recutting of the above-ground plant. The 4-and 6-month harvests were also causing yield decline in the second ratoon crop (Table 18). The 12-month harvest interval was similarly giving reduced yields in the second ratoon, but in this case the yields were still superior to those of the plant crop.

(c) DM Yields Vs Row Spacing: Early data from the plant crop had indicated some tonnage increases through the use of narrow row spacing (50 cm vs 150 cm), but this effect was subsequently lost (24). As a 3-crop average the final yield data confirm that no gains were made by use of row spacings narrower than the 150 cm traditionally employed by the PR cane sugar industry. The critical 12-month harvest interval actually produced less cane with close spacing (Table 19).

The close spacing concept for increasing cane biomass had been investigated by Battelle-Columbus workers in the late 1970's (36). There is some evidence that higher yields can be gotten by this means under Louisiana cane-growing conditions. It does not appear to be feasible in Puerto Rico, or in Florida (37). In addition to higher planting costs there would be major increased damage by harvest machinery. Even the traditional 5-foot spacing in Puerto Rico does not allow sufficient space for equipment tires and tracks to pass without some injury to the cane stubble and young shoots.

By the project's final year we felt that cane stem population could be optimized by increased stem density within the row. This can be accomplished by higher seeding rates or by use of varieties having a prolific tillering characteristic such as the "second generation" energy cane variety US 67-22-2. Our final energy cane plantings have involved increased distances between row centers (up to 8 feet) as a means of avoiding mechanical injuries to the cane crowns. It appears that this approach is justified by the reduced planting costs coupled with non-significant reductions in yield. It is predicated upon the avilability of a heavy-tillering variety such as US 67-22-2 (see pp. 58-60).

(d) Trash DM Yields: A significant component of the sugarcane plant is the leaf and leaf-sheath fraction which accumulates during the course of a 12-month crop. This fraction amounted to more than 5 tons DM per acre year for energy cane, and more than 3 tons for napier grass, as 3-year averages (Table 20). Row spacing variables had no appreciable effect on trash yield. The cane variety PR 980 produced moderately greater yields (over 6 tons/acre year) than did the varieties NCo 310 and PR 64-1791. It should be noted that a trash DM yield of 6.0 tons/acre year exceeds the entire yield of whole plants for most species being examined as biomass resources today.

(e) Seasonal Influences On Yield: The project's experiments were performed at near sea level at 18° north latitude. This is a tropical setting widely recognized for its "year-round growing season". Nonetheless, there were clearly seasonal variations in the productivity of both cane and napier grass.

The 2-month interval from January 15 to March 15 was the least productive for both sugarcane (Table 21) and napier grass (Table 22). This is attributed to the relatively cool nights in Puerto Rico during this period. Because this interval also falls within the Island's dry season, some claim can be made that the growth reduction was a result of reduced water supply. This is at least a contributing factor, for eventhough the experiments were irrigated it is impractical to simulate completely the region's natural rainy season by this means.

The 4-month harvest interval corresponded roughly with three seasons in Puerto Rico: Late humid summer (July 15 to November 15), semi-arid "winter" (November 15 to March 15), and early humid summer (March 15 to July 15). For both sugarcane and napier grass the season least suitable for growth was the semi-arid winter (Table 23). This was clearly evident for the two ratoon crops of each species. In the case of sugarcane nearly half of the ratoon crops' total annual yield was produced in a 4-month period from July 15 to November 15. The importance of the warm, humid, late summer months to sugarcane growth has been recognized for many years by cane planters seeking to maximize sugar yield. Hence, the Island's "gran cultura" crop was always planted by early August, thereby enabling the cane to pass through two late summer growing seasons before being harvested at 16 to 18 months of age. The same principle could be managed with even greater effect in a future energy-planting enterprise designed to maximize cane biomass tonnages.

(f) Quality; Sugar And Fermentable Solids: Energy cane management practices were designed to maximize biomass tonnage rather than sugar yield. Relatively poor juice quality was obtained for the plant and first-ratoon crops. Second ratoon cane showed some improvement but nonetheless would be regarded as substandard in most cane sugar industries. Sucrose content averaged 7.2% for all varieties and row spacing (Table 24). Variety PR 64-1791, at standard row spacing, produced 8.4% sucrose. Fiber content averaged 16.4 percent, a value which is not exceptionally high.

While the quality of the first-generation energy cane was low, it was nonetheless equal to or better than that of Puerto Rico's commercial sugar industry. Commercial sugarcane in Puerto Rico today rarely yields more than 8% sucrose. This is a consequence of a whole series of field and factory problems which lie beyond the scope of our discussion. However, it must be noted that cane grown for biomass cannot be faulted for low yields of sucrose or fermentable solids when these are computed on a "per acre" basis. For the Year 3 crop the three test varieties averaged 5.18 tons sugar/acre (TSA) at standard row spacing and 5.71 TSA for narrow row spacing (Table 25). By contrast the PR sugar industry produced less than 2.2 TSA in 1980 (38). The Government's long-term goal of 3.0 TSA (39) is virtually unattainable under present conditions in the Island's sugar industry.

In the management of "energy cane", fermentable solids have been depicted as a major byproduct rather than the primary objective of crop production (30, 31, 32). In Puerto Rico, especially when world prices for raw sugar are low, sucrose would be sold to the Island's rum industry as a component of high-test molasses (syrup). As recently as the autumn of 1981 sucrose values appeared constant at around 13 cents/pound, and high-test molasses was periodically priced as high as 95 cents/gallon.

During periods of high sucrose values it could be profitable to recover part of the sucrose for local or foreign sales. One means of doing this would be to retain the "first strike" (containing perhaps 60% of the recoverable sucrose in cane juice) for raw sugar sales. The balance of the sucrose would remain is the molasses. This would be sold to the PR rum industry as a somewhat lower quality "high-test" molasses.

(g) <u>First-Generation Costs</u>: Preliminary cost analyses for energy cane production were performed in 1980 on the basis of first-ratoon yields. A breakdown of production input charges is presented in Table 26. These figures pertain to a family-owned, 200 acre operation yielding 33 oven-dry tons of biomass per acre year. The most expensive equipment items, a whole-cane harvester and low-bed truck, would be hired from the PR Sugar Corporation together with the equipment operators. In an energy-cane industry such items would probably be family owned, in which case the operation and maintenance costs would be appreciably lower. Both water and fertilizer charges are entered moderately higher than project data actually indicate, mainly owing to potentially large consumption differences as varietal and ecological life zone factors. Total costs, including delivery to the milling site, amounted to $25.46 per oven-dry ton, or about $1.70 per million BTUs. By way of reference, Puerto Rico was paying about $4.30 per million BTUs in early 1980 for petroleum boiler fuels.

In an energy cane scenario about 68 percent of this dry matter would be burned as boiler fuel. The remainder would be extracted as fermentable solids during the cane dewatering process and later sold as constituents of high-test molasses. Neither raw sugar nor refined sugar sales are anticipated. The fermentable solids from one acre of energy cane (ie, with yields of 33 OD tons/acre), would be valued at $1,500 to 2,000 dollars if marketed today (1982) as high-test molasses.

The Puerto Rican emphasis on molasses rather than boiler fuel is quite real and probably justified. Rum is one of Puerto Rico's leading sources of revenue, yet her molasses feedstocks are increasingly derived from foreign suppliers. Puerto Rico was one of the world's major molasses exporters in 1934 (40) but declined to an 88% dependency on imported molasses by 1980 (41). Because of this, local interest in the energy cane herein described is directed mainly toward its molasses yield potential rather than its role as a renewable domestic boiler fuel.

Production cost estimates for conventional PR sugarcane were also computed in 1980 for direct comparison with energy cane estimates (Table 27). Sugarcane cost estimates were based on data obtained from Central Aguirre for the 1979 milling season. They probably constitute a "best case" for production operations in the current PR sugar industry as a whole. As indicated in Table 27, production costs for energy cane were higher than sugarcane in five areas: Seedbed preparation, seed, fertilizer, harvest operations, and delivery of harvested cane. Energy cane seed and fertilizer expenditures were double those of conventional sugarcane. Harvest operations and cane delivery expenses were 67 percent higher, and seedbed preparation costs were 50 percent higher. It should be noted also that the sugarcane cost estimates pertain to a private planter (or "Colono") for whom the major machinery items are rented rather than self-owned.

The overall cost for producing a ton of energy cane was 44 percent higher than conventional sugarcane. However, the decisive difference between the two management scenarios lay in the total dry matter yield per acre year (Table 27). Energy cane yield exceeded sugarcane by a factor of about 3.7. Hence, the increased cost of "pushing" sugarcane, ie, to maximize total biomass rather than sucrose, was more than compensated by even larger increases in dry matter yield. As a result of its relatively low productivity the PR sugar industry cane cost in the order of $65.00/OD ton, or about $4.31/million BTUs.

(h) Energy Balances: Preliminary energy balance analyses were performed during 1980 using the first-ratoon crop means for varieties PR 980, NCo 310, and PR 64-1791. These varieties averaged 33 OD tons/acre year for the first-ratoon crop. Energy input estimates for this material are summarized in Table 28.

Total energy inputs for first-generation energy cane production were in the order of 28 x 10^6 BTU/acre year. Energy output amounted to 279 x 10^6 BTU/acre year (Table 29).

The latter figure was computed on the assumption that most of the fermentable solids fraction of the total dry matter yield would be extracted at the sugar mill. The extracted fermentable solids amount to about 640 lbs/OD ton of energy cane. This figure is based on a recorded mean Brix value of 13.1° for energy cane juice and an assumed 80% extraction at the mill. In this instance only 1,360 pounds of dry matter/OD ton, or 22.4 tons/acre, will be used as boiler fuel. On a steam recovery basis, assuming 85% efficiency for a utility boiler, an energy output/input ratio of 9.95/1 is obtained (Table 29).

Some authors have simply divided the total calorific value of their annual OD product by the total production energy input (42). By this method energy cane would have an energy output/input ratio of about 17.7/1.

It is instructive to note that nearly half of the total energy expenditure was for mineral N alone (Table 28). Hence, while the favorable energy balance obtained to date is mainly a reflection of high DM yield, future improvement of this balance can be gained both by increasing yields and by reducing the input of mineral N. One means of lowering N input is to apply the element as a soluble component of the irrigation water, particularly water applied via trickle irrigation (43). The increased efficiency of lower N supplies should compensate for the relatively inefficient plant usage of dry fertilizer administered in larger amounts to the soil surface. Another potential means of lowering mineral N expenditures is through increased usage of N-fixing legumes in conjunction with biomass energy crops. A large number of underutilized tropical legumes have been identified for possible use in this context (44, 45).

6. Second-Generation Energy Cane (PlantCrop)

The project's first three years work with energy cane, from 1977 to 1979, delt exclusively with existing sugarcane varieties originally established in Puerto Rico for the purpose of sugar planting. Their revised management as biomass resources led to vastly greater yields of dry matter, sugar, and fermentable solids, while production costs were lowered on a "per ton" basis. However, it was also recognized from the onset that the canes then available were not entirely suitable for planting as energy crops. They were the first of three "generations" of energy canes, including: (a) Existing sugarcanes of commerce whose biomass yields could be improved by management practices oriented to growth rather than sugar; (b), existing clones having superior biomass yield potentials but otherwise unplanted in the sugar-oriented commercial cane industries; and (c), new hybrid progeny to be bred specifically for high biomass attributes (total dry matter and fermentable solids).

The first plantings of second-generation energy cane were made in 1980, with primavera and gran cultura yield data becoming available in 1981 and 1982, respectively. The performance of these canes together with cultural modifications and production costs is herein reported.

(a) Varieties: Since 1977 a search has been underway for Saccharum clones having superior attributes as biomass energy crops (48). Two outstanding candidates were identified among imported materials maintained as potential breeding stock at the AES-UPR Gurabo Substation (49). One is a Barbados variety (B 70-701), having excellent growth characteristics and high fiber content but little aptitude for producing sugar. The other, US 67-22-2, similarly has outstanding growth potential. It has a rapid, uniform germination and forms a massive stool complex within a year after planting (up to 90,000 stems/acre). It is also a relatively "sweet" cane whose sugar yield usually equals or exceeds that of the commercial interspecific hybrid PR 980.

The search for superior candidate varieties is with UPR and Commonwealth support. This includes the breeding of hybrid progeny from crosses utilizing both B 70-701 and US 67-22-2 as parental clones (49). A seed expansion program for US 67-22-2 is underway at the AES-UPR Lajas Substation. This variety is expected to be the "standard" PR energy cane for at least the remainder of the 1980's.

(b) Agronomic Modifications: The first planting of second-generation energy cane is a field-plot study having 27 treatments with four replications arranged in a randomized split-plot design (Table 30). There are three primary treatments (harvest frequencies at 6-, 12-, and 18-month intervals), three subtreatments (varieties PR 980, US 67-22-2, and B 70-701), and three sub-subtreatments (variable nitrogen at 200, 400, and 600 lbs/ acre year of elemental N). Row spacing is constant among all treatments at standard 60-inches. Irrigation is also constant at approximately 54 acre inches/year administered as needed via border irrigation in 2-inch increments.

Variable harvest intervals underscore the need for more than one year to optimize Saccharum biomass. An important shortcoming of the first-generation studies was a 12-month maximum interval between harvests, a reflection of commercial sugarcane management in Puerto Rico. At least 18 months are thought to be needed to maximize total dry matter in energy cane. Of the three test varieties, US 67-22-2 and B 70-701 are second-generation canes having enormous growth potential under PR conditions. PR 980 is a reference variety typifying the Island's commercial sugarcane. For first generation canes managed as biomass crops, about 400 lbs of elemental N are required per acre year. The new N variables were designed to indicate whether this quantity might be reduced (or profitably increased) in varieties specifically selected for dry matter and molasses. The N source is ammonium sulfate in 16-4-8 fertilizer formulation administered incrementally at 3-month intervals.

Two completely new inputs not received by the first-generation cane include: (a) Rotavation of the seedbed with a heavy-duty land rotavator, and (b), subsoiling the planted seedbed to a depth of about 20 inches. These inputs required additional equipment and fuel, and hence increased production costs to some extent. These costs appear to have been more than compensated by increased yields (see pp. 33-36).

(c) Whole Cane Yields: Yields of whole cane (millable stems plus tops, including attached trash but not detached trash) exceeded 100 short tons/ acre year for each second-generation variety (Table 31). Total GM yields, including millable stems, tops, attached trash and detached trash, averaged 118.4 tons/acre for all treatments.

The highest single yield for 12 months was 130.3 tons/acre, recorded for variety US 67-22-2 receiving 400 lbs elemental N/acre (Table 31). There was little variation between varieties and N levels. This is attributed in part to the use of the heavy-duty land rotavator in the seedbed preparation for all plots.

The highest yield for the 18-month plant crop was 164.5 tons GM/acre, recorded for variety US 67-22-2 (Table 32). This figure is the average of three N levels. It exceeded varieties B 70-701 and PR 980 by approximately 30 tons GM/acre. As shown in Table 32, the delaying of harvest from 12 to 18 months gave large increases of tops and trash (74.0 and 94.4 percent) but only moderate increases of millable stems (27.8 percent).

Actually, in terms of total GM, the highest yield was gained by combining three 6-month harvests (Table 33). Here variety US 67-22-2 gave a cumulative yield of 186.2 tons/acre, about 22 tons/acre more than a single harvest at 18 months. However, this is a deceptive figure owing to the relatively high moisture content, low yields of dry matter, and low yields of millable stems by 6-months old cane. Moreover, production costs are appreciably higher for 6-month cane since three harvests are required rather than one.

(d) Millable Stems: The highest yield of millable cane (topped, gran-cultura cane) was produced by variety US 67-22-2. This amounted to 137.1 tons/acre (Table 34), approximately 20 tons/acre more than three 6-month harvests combined. Also, the 6-month old stems, though "millable", were of vastly lower quality than the 18-month old cane.

(e) Dry Matter (DM): Total dry matter yield (oven-dry basis) is the single most important parameter in the assessment of energy cane performance. The "deceptive" green matter trends noted above (Table 33) are completely reversed in the light of dry matter yields (Table 35). Hence, a single harvest at 18 months yielded 20 tons more DM/acre than three 6-month harvests combined (59.5 vs 39.5 dry tons/acre). Among varieties, the highest yield was again produced by US 67-22-2, some 65.7 tons DM/acre (Table 35).

Among variable N regimes the highest DM yield was recorded for US 67-22-2 receiving 600 lbs N/acre year (Table 36). Some 69.1 tons/acre were harvested. This was only 7.6 tons more than was obtained from 200 lbs N; none of the varieties responded appreciably to increasing N supply.

Unlike green matter, which increased by about 32 percent between months 12 and 18 (Table 32), dry matter increases exceeded 50 percent during the same period (Figure 8). Both US 67-22-2 and B 70-701 gained DM at a higher rate during the final 6 months than during the first 12 months (Table 37). This is a critically important factor. It suggests that an energy planter could maximize his yields through harvest delay, while minimizing his annual production costs by the same practice.

(f) Trash: It is significant that over 23 tons/acre of the maximum DM yield was harvested in the form of trash (Table 38). This fraction consists of dead leaf and leaf-sheath tissues either adhering to the cane stem or detached and lying on the ground. Such materials are normally burned in the field as a preharvest operation for conventional sugarcane. From energy cane they will be harvested and credited to the crop's total yield of lignocellulosic dry matter.

(g) Fermentable Solids: Juice quality analyses (Table 39) indicate little qualitative change between months 12 and 18. The somewhat higher sugar yields/acre at 18 months were by virtue of the higher tonnages of millable stems/acre. Also evident is the distinct inferiority of variety B 70-701 as a sugar producer (Table 39). With an average purity value of 64.1, this variety would have difficulty being accepted at the mill as a sugar source. As energy cane it would be milled in any case to lower its moisture content.

The consistent lack of qualitative gains between months 12 and 18 was anticipated by virtue of the continuing growth inputs received in the form of water and fertilizer applications. Conventional sugarcane, managed for maximum sugar yield, would have received neither fertilizer nor irrigation during the final 6 months. Significantly larger sugar yields would have been expected on an individual plant basis, though not necessarily on a per acre basis.

(h) First Vs Second Generation Yields: Although only plant crop data are available to date, the yield increases of second-generation energy cane over the corresponding first-generation yields are remarkable (Table 40). Total green matter was increased by 47.1 percent, dry matter by 50.7 percent, and detached trash by 86.3 percent (12-month harvest). The percentage of dry matter in second-generation cane was moderately lower, suggesting that these plants were somewhat less mature at 12 months. There were also slightly fewer stems/acre for second-generation cane (Table 40).

Mean sugar yields were also higher for second-generation energy cane (Table 41). These trends reflect moderately higher rendiment values as well as higher tonnages of millable cane. In these averaged data the very poor performance of variety B 70-701 was offset by the superior yields of US 67-22-2 and PR 980.

(i) Second-Generation Production Costs: The initial cost analysis for first-generation energy cane was prepared in January of 1980. It was modified in the summer of 1980 when third-year data were obtained and used to compute a final 3-crop average for first-generation production costs. Cost data for second-generation cane have changed in response to three factors: (a) Cost increases reflecting higher real values of production inputs; (b) cost increases reflecting inflation of the US dollar; and (c) cost decreases reflecting increased productivity of the energy cane operation.

Ideally, the production costs for energy cane should be computed against the average productivity of a complete cropping cycle, ie, the average of three corp years, as was done with first-generation cane. However, only the plant crop data are currently available for second-generation energy cane. For this reason the present revision is preliminary and admittedly a biased assessment favoring higher than real production costs.

Table 42 summarizes production inputs and their costs for first-and second-generation energy cane, together with the percent change of these costs during the 24-month interval from January of 1980 to January of 1982.

The costs of decisive production inputs (transportation, fertilizer, harvest operations) have increased appreciably during the past two years, largely because of increased energy values and inflation of the US dollar. These increases have amounted to roughly 1 percent per month for agricultural operations in Puerto Rico. The largest percentage cost increase is entered for seedbed preparation (Table 42), where a land rotavation process not used for first-generation energy cane is included. Expenses such as that of employing a farm manager have not increased owing to the decline of Puerto Rico's job market.

Total cost estimates for a 200 acre energy cane operation are in the order of $205,000/year, an increase of 22 percent since 1980. The cost per acre of energy cane similarly increased by 22 percent. It would cost today over $1,000/acre year to produce a crop of second-generation energy cane. Alternatively the cost per ton of energy cane dropped from $10.12 in 1980 to $9.33 in 1982, a decline of 7.8 percent. With detached trash included the cost would be $8.81/ton of cane. This results from the increased yield obtained with second-generation cane (110 tons/acre year) as opposed to first-generation material (83 tons/acre).

Reckoned simply as a combustible fuel on a dry weight basis at 15 million BTUs/oven-dry ton, with 38.6 tons harvested/acre year (excluding detached trash) the fuel value of this cane is approximately $1.88/million BTUs. Puerto Rico is currently paying over $6.00/million BTUs in the form of no. 6 fuel oil (July, 1982). Obviously, one cannot continue indefinitely to offset inflation and rising fuel costs with increased productivity. However, the pricing of a biomass fuel below $2.00/million BTUs indicates that energy cane is the most economically viable substitute for oil in PR today.

Subsequent cost assessments are expected to indicate lower production costs for second-generation cane. This projection is based on the following: (a) Proportionately lower costs for gran cultura biomass owing to the delay (spreading) of harvest and delivery expenses; (b) proportionately higher DM yields from gran cultura cane; (c) higher absolute DM yields from the first and second ratoon crops; and (d), lowering N supply from 400 to 300 or 200 lbs/acre year. In addition, the delivery charges reckoned in the prior analyses might be excessively high ($3.00/green ton/3 miles of haul, or approximately $8.60/dry ton). Actual delivery charges from Hatillo to Central Coloso, a highway distance of 25 miles, were $5.50/ green ton in March of 1982.

(j) Energy Inputs And Recovery: Second generation production inputs with attendant energy expenditures are summarized in Table 43. Fully half of the energy inputs derive from commercial fertilizers (14.76 million BTUs/acre year). Some 90 percent of the fertilizer energy input is attributable to elemental N alone. A second major energy expenditure is for diesel fuel (9.85 million BTUs/acre year). Fuel expenditures increased by about

5 percent over first-generation energy cane owing to the use of a heavy duty land rotavator in seedbed preparation. Because much of the yield increases obtained from second-generation cane derive from improved seedbed preparation, the land rotavation input is probably justified in terms of increased energy yield. For example, as indicated in Table 44, the total BTU recovery/acre year for second generation energy cane exceeded that of the first generation by over 58 percent (453 vs 286 million BTUs/acre).

(k) Net Energy Balances: The net energy balances for varieties PR 980, US 67-22-2, and B 70-701 are summarized in Table 45. Variety B 70-701 indicates the most favorable energy output/input ratio at 16.5, while PR 980 is least favorable at 13.7. These ratios are based on a mean nitrogen input of 400 lbs elemental N per acre year. The critically decisive importance of N supply to the crop's net energy balance is shown in Table 46 where energy output/input ratios reflect the 200, 400, and 600 pounds per acre of elemental N actually supplied in this study. Hence, a very superior ratio is obtained with 200 lbs N/acre (19.7) as opposed to 600 lbs N/acre (12.5).

Variety B 70-701, though a poor sugar producer, is the superior variety examined to date as a boiler fuel. In terms of total dry boiler fuel, boiler fuel as a percentage of total biomass yield, total higher heating values of boiler fuel, and heating value of displaced fuel oil, B 70-701 exceeded appreciably both PR 980 and US 67-22-2. The actual fuel could be conventional bagasse (49-51% moisture), partially-dried bagasse, or a processed fuel product derived from bagasse (for example, AGRI-FUEL^{tm} at 6% moisture).

(l) Molasses And Fiber Values: By month 12 the quantities of fiber (combustible DM) and fermentable solids produced per acre by second-generation energy cane were quite considerable (Table 47). Assuming 9.5 lbs fermentable solids/gallon of high-test molasses (HTM), over 2,000 gallons HTM were being produced by varieties PR 980 and US 67-22-2, and over 1200 gallons/acre by variety B 70-701. At the current price of $0.76/gallon HTM, the annual molasses value exceeded $1800/acre for US 67-22-2, $1600/acre for PR 980, and $900/acre for B 70-701 (Table 47).

The value of fiber was reckoned at $0.04/oven-dry pound. This figure is pegged to the current price of no. 6 fuel oil ($33/barrel). At this price the per acre value of fiber at 12 months averaged over $1,900 for PR 980, over $2,000 for US 67-22-2, and $2,200 for B 70-701. Combined values for HTM and fiber were in the order of $3,863 for US 67-22-2, $3,606 for PR 980, and $3,160 for B 70-701 (Table 47).

(m) Energy Cane Benefits For PR: Puerto Rico urgently needs a local molasses supply for her rum industry and a domestic fuel substitute for imported oil (50, 51, 52, 53). High-test molasses is the preferred fermantation substrate of Island rum producers. The combustible fibrous residues can be burned direct or processed into higher-quality fuels and feedstocks. The prospects appear good that sugarcane management for energy, ie, for HTM and fiber, is a potentially profitable enterprise for Puerto Rican cane planters.

Given 70,000 acres for a future cane industry, [1] the production of energy cane as herein described would eliminate entirely the importation of molasses and there would be some molasses left over for export. Energy cane fuels from 70,000 acres would eliminate a significant fraction of the Island's oil imports. Additional benefits include the reestablishment of cane palnting as a profitable enterprise in Puerto Rico, [2] increased rural employment, and, when coupled with other tropical grasses, an extension of annual mill operation from 3.5 months to 11 months.

1/ The Puerto Rico Government has allotted 70,000 acres for sugar planting in its "Modern Agricultural Plan For Puerto Rico" (39).

2/ The PR Sugar Corporation anticipates an $85,000,000 loss during 1982.

C. FIELD-SCALE STUDIES

Field-scale experiments follow logically from greenhouse and field-plot studies. Their purpose is twofold: (a) To simulate, under plantation-level conditions, the production inputs that had appeared most promising under greenhouse and field-plot conditions, and (b), to evaluate mechanization factors that become operational under plantation-level conditions.

The project's field-phase studies were initiated at the AES-UPR Lajas Substation. During the final two years these were extended to a private farm near Hatillo on the humid north coast. Some 30 acres were made available there for energy cane research by Mr. José B. De Castro, the farm's owner. During the project's final six months the field work also extended to government-leased lands near Cabo Rojo. Approximately 50 acres were made available for seed-expansion of the variety US 67-22-2, together with row spacing and seedbed preparation studies with the same variety.

1. Mechanization Methods And Considerations

As indicated above, the project's field work involved increased sizing of production inputs previously identified under smaller-scale but precisely-controlled conditions, and the introduction of farm machinery that had not been used in the preceeding trials. Experimental production inputs extended to the field or farm size included candidate varieties, seedbed preparation, row spacing, seeding rates, fertilizer levels and incremental application, irrigation methods and levels of water application, and frequency of harvest.

The introduction of farm machinery is necessary for the translation of these inputs from a labor-intensive regime (under field-plot conditions) to a labor-extensive regime which is effective both agronomically and economically. For the most part the use of implements and machines offers a work performance that is qualitatively superior to hand labor, in addition to a vastly greater scale of magnitude. For example, a correctly-adjusted and operated grain drill can seed a Sordan-type species with greater precision than a skilled laborer. However, in one decisively critical area, machines have never quite equalled the hand laborer in terms of work precision and quality. This is in the harvest of the cane plant. Even where mechanization has succeeded, much has been lost in the milling qualities of harvested cane (33). In Puerto Rico, where mechanization efforts were largely unsuccessful, the lack of suitable cane harvest machinery, more than any other factor, has led to the demise of sugar planting as an economic enterprise (34).

Alternatively, the use of machinery has made possible a vast range of production technologies that were never possible, let alone economic, with hand labor. This is particularly true of the harvest and post-harvest dewatering of fibrous tropical grasses (napier grass, Sordan, etc.). Such species cannot be shipped to a sugar mill for dewatering, but they can be solar dried directly in the field with great effect. This requires the use of machinery for "conditioning" the grasses, for raking them, for turning over the drying windrows, and for compacting the dried biomass for economic handling, transportation, and storage. None of these steps can be simulated with hand labor at any cost.

Field-scale trials were performed in fields ranging from 2 to 25 acres in size. While still small by plantation standards [1/], these offered realistic conditions for the measurement of fuel consumption, horsepower requirements, and ability to accommodate high tonnages of standing biomass. To a large extent the effectiveness of forage-making implements can be assessed on plots as small as 2 acres; virtually all of the grasses conditioning, solar-drying, and baling trials in this project were performed on unreplicated plots of 3 or 6 acres in size.

Less accurately measured is the long-term durability of machinery tested in this manner. Hence, it was necessary to report data and to draw conclusions on machinery performance based on as little as 10 hours of operating time. A future energy-planting operation could require hundreds of hours service from the same machine.

[1/] Future energy plantations for tropical grasses are expected to range in size from a minimum of 7,000 acres for energy cane to 2,500 acres for napier grass (30).

Alternatively, the relatively brief trials on a University farm represent a more severe test of machinery than one would expect with equal time on a full-size energy plantation. In a commercial, industrial-scale operation, each mechanized task would be assigned to equipment operators having special training and accumulated expertise with a specific unit. For example, on a napier grass plantation, at least one driver would operate a rotary scythe full time, another man would operate a baler full time, while others would concentrate on equally specialized tasks. Such division of responsibility produces equipment operators who become highly skilled specialists in the use and care of their specific machine. This is not the case on a University farm where a given driver is continually assigned to different machines in different projects.

Equally important is the attitude of equipment operators with respect to their charges and the farm operation as a whole. The performance of a self-employed farmer working from sunrise until after sunset to complete tasks that he understands must be completed can differ considerably from that of a University hand working 7.5 hours per day in a 5-day week. Without question, the effectiveness and performance of biomass production machinery will depend heavily on the training, skill, and personal attitude of the machinery operator. In the present project the quality of our equipment operating and maintenance personnel was about average for a land-grant institution. It was considerably higher than average for the Puerto Rican agricultural sector.

2. Scope Of Field-Scale Studies

An important goal of this project was to establish methods for the mechanized harvest and postharvest handling of tropical grasses propagated as biomass energy crops. The scope of this task covered two major areas: (a) Production and harvest of thin-stemmed, fibrous grasses (short-and intermediate-rotation species), and (b), production and harvest of thick-stemmed grasses (long-rotation species). The thin species, such as Sordan 70-A and napier grass, were to be solar-dried in the field as a means of moisture removal. Thick-stemmed grasses are characterized both by the sugarcanes of commerce and the "energy canes" developed in the course of this project. Both must be hauled to a centralized mill for dewatering.

The scope of field-scale studies was further defined by the uses to which the respective grass categories are directed, and the physical mass of material with which the categories confront harvest machinery. Hence, the lighter, thin-stemmed, fibrous grasses were to be dried in the field, baled, and stored for "off-season" use as lignocellulosic fuels/feedstocks. They would serve as substitutes for energy cane bagasse during 3 or 4 rainy months when energy cane cannot be harvested in Puerto Rico (30, 31). Conditions are favorable for their harvest, solar-drying, and storage from roughly mid-December to mid-August in Puerto Rico's south coast. Alternatively, energy cane would be harvested during the same 7 to 9 months and conveyed directly to a centralized dewatering plant. Integration of the grasses and cane operations is depicted schematically in Figure 9.

The critical harvesting tasks can be grouped into three categories based on the density, or standing mass, of plant materials confronting the harvest machinery, and the percentage of fiber contained by these materials at the time of harvset (54). The first group deals with standing green biomass in the order of 15 to 25 short tons/acre. Sordan 70A, a short-rotation crop, is characteristic of species having yields of this magnitude. The project's approach to such materials was to harvest them exclusively as solar-dried forages. Within this category the machinery tasks vary with the state of the crop's maturity, ie, with plants having from 10 to 12% fiber at six weeks to 30 to 35% fiber at 12 weeks. A second category deals with standing biomass in the order of 25 to 50 green tons/acre. The representative species here is napier grass, an intermediate-rotation crop whose dry matter content is maximized between four and six months after planting. Again the crop's state of maturity is critical to the success or failure of harvest machinery. Harvested at two months of age (8-12% moisture) napier grass actually offers no more difficulty than conventional cattle forages. At six months, offering 35% dry matter and up to 50 green tons/acre of standing biomass, the harvesting task approaches the upper capability limits of existing forage-making equipment (54). Our plan was to handle such materials as solar-dried "forages" also.

Biomass crops offering more than 50 green tons/acre comprise a third category in terms of harvesting tasks. The characteristic species here are the hybrid sugarcanes of commerce and the energy canes having still greater tonnage. There is no possibility of dealing with these plants as field-dried forage crops. Not only is there an excessive mass of material confronting the harvest machinery, but also the thickened cane stems do not lend themselves to solar drying, unless first prepared by some process of milling and juice expression. Project plans were based on a combination of solar drying (for leaves and "trash" removed in the field) and mill dewatering for the cane stalks. Bagasse issuing from the sugar mill might also be solar dried and baled, or at least partially dried by stacking in the open air.

3. Initial Machinery Trials

The project's earliest field-scale trials were begun with forage-making machinery imported early in year 2. Specific units included a Model 8700 Ford tractor (the only Category III tractor then available in the UPR College of Agriculture), an M-C rotary-scythe conditioner (Mathews Company Model 9-E) having a 9-foot mowing swath, a heavy-duty, side-delivery PTO forage rake (New Holland Model 57), a New Holland Model 851 Round Baler, and a New Holland Model 393 "tub" forage grinder. The forage rake was soon supplemented by a Farmhand wheel rake and by both front-and rear-tractor mounted loaders capable of handling round bales weighing up to 1500 pounds/bale.

(a) Rotary-Scythe Conditioner: Preliminary tests were made with the rotary scythe using wild Johnson grass (Sorghum halepense) as a test material. This implement does not cut or mow grasses as does a conventional sickle-bar mower, but rather breaks off and "conditions" the grass with a series of steel plates rotating at high speed with extremely powerful force [1/]. The conditioned material is deposited in windrows of adjustable width directly behind the mower. The rotary scythe is a thoroughly rugged machine (55). Relatively few factors can inhibit its performance short of an inadequate power supply (tractors having less than about 90 hp), or the encountering of plant materials of sufficient mass to stop the blades or the tractor engine.

[1/] An illustration of this machine appears in an earlier report (25).

No difficulty of any kind was encountered in the first trial with Johnson grass. This material amounted to roughly 10 to 12 green tons/acre. The rotary scythe was moved to a second field where Johnson grass had grown wild for several years. The implement performed quite adequately, with the exception of "heavy" areas where accumulating dead Johnson grass had formed mats approximately two to three feet thick. In such areas the mats sometimes tended to push ahead of the implement rather than pass under it. Once the rotary scythe passed over material it was effectively conditioned whether matted or not. This was due to a slight curvature of the cutting blades which creates a vacuum effect such that flattened biomass is drawn up into the rotating blades as they pass overhead.

This is a decisively important feature to have in herbaceous biomass harvest systems which by nature will have a high proportion of prostrate (recumbent) materials. The tractor performed "comfortably" in second gear with engine speed at 1800 rpm. There were no apparent stresses on the Tractor's PTO and hydraulic systems nor on the implement's gear box and drive shaft. The usual safety precautions for forage-making equipment need to be observed. Special precaution must be taken againt standing or walking behind the rotary scythe when in operation. The rotating blades can strike loose stones, clods of soil, and other loose objects, throwing them backward with considerable force.

(b) Trials With Sordan 70A: Sordan 70A was the first biomass candidate scheduled for field-scale harvesting trials. Four blocks of approximately six acres each were planted at the close of the third quarter. Seeding rate was 60 pounds/acre, drilled in 9-inch row centers in two directions on the field. The planting of these fields was delayed approximately two months owing to atypically heavy rainfall in December-January, 1978-79. Harvests for the respective blocks of Sordan 70A were performed at 6, 10, and 14 weeks after seeding.

Performance ratings for the rotary scythe are presented in Table 48. The 6-week old material presented no problems of any kind for this machine. The plants were completely upright and succulent. Initial concern that the relatively long stems (averaging 5 1/2 to 6 feet) [1] might cause them to fall backward over the rotary scythe, rather than forward to pass under the rotating blades as intended, were unfounded. All of the upright material fell forward without exception. Nor was there any tendency to form balls or mats in front of the mower, even when operating at higher tractor gear speeds.

A much worse set of harvest conditions was experienced for the 10-and 14-week old crops, but the rotary scythe nonetheless gave a very satisfactory performance (Table 48). Extremely heavy and unseasonal rainfall was received intermittantly from week 8 through week 13. This caused moderate to severe lodging in both the 10-week and 14-week old plants. In both instances much of the Sordan 70A was flattened to a height of 8 to 12 inches and was severely matted, that is, the stems had crossed and interlaced in all directions. The plants harvested at 14 weeks had remained in this condition up to five weeks. During this interval, the matted Sordan 70A was further interlaced with herbaceous weeds (both vines and upright grasses) plus a regrowth of secondary Sordan 70A plants stimualted by the heavy rainfall. Together with the abnormally soft seedbed, these conditions offered the worst possible circumstances that one can reasonably expect in harvesting short-rotation crops. However, the rotary scythe performed quite adequately. At no time was it necessary to stop and clear the machine [2] of balled grasses, and only occasionally was it necessry to shift into a lower operating gear.

A period of intermittant rainfall following the 10-week harvest caused considerable difficulty in drying the conditioned biomass. Good weather followed the 14-week harvest. This material was solar-dried and ready for baling within three days.

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[1] When mowing conventional cattle forages (as its manufacturer intended) the rotary scythe will rarely encounter plant materials more than about three feet high. Hence, the leading edge of the implement which strikes the upright stems will cause them to fall forward without problems. This is not necessarily true of tropical grasses which are much taller and thicker-stemmed, and which offer greater resistance to the rotary scythe.

[2] Such stops would have been an almost continuous feature if we had attemped to harvest the 14-week old material with a sickle-bar mower.

Baling operations for the solar-dried Johnson grass and Sordan 70A were performed without encountering major problems. Minor difficulties incident to hydraulic connections between the Baler (a New Holland product) and the project's Ford tractor were easily corrected. Because no one on the project staff was directly familiar with the baler's operation, it was necessary to practice its handling on solar-dried weeds and Johnson grass. For example, the correct amount of twine needed for a 1500 pound bale, about 150 feet, was determined by trial and error. Such factors as the baler's best operating speed, the correct size and compaction of the bale, and the amount of twine needed to secure the bale for subsequent loading and transport operations are largely a matter of judgement by the machinery operator confronted with a specific set of conditions.

(c) Napier Grass; Three Months: A far greater challenge to harvest equipment is posed by napier grass, an intermediate-rotation species. As a cattle forage it is harvested at 5-to 7-week intervals, when it is of relatively small size and succulent. At 3 months it is somewhat more mature and fibrous; at 6 months it is highly fibrous and "woody" with DM yield at a maximum.

Napier grass was submitted to mechanized harvest and forage-making operations forthe first time during year 3. Approximately four acres of 3-months old napier grass (var. Merker) were mowed with the M-C rotary scythe conditioner. This material was solar-dried and baled with the New Holland Model 851 round baler. At 3 months of age, the total biomass confronting harvest machinery was only slightly greater than that of equally-aged Sordan and there were fewer stems/acre. The primary difference lay in the much thicker and more succulent stems of napier grass. These offer a somewhat different and possibly more difficult task for the stem-shattering or "conditioning" properties of the rotary scythe. The solar-drying tasks are definitely more difficult owing to the greater thickness of napier grass stems. Raking and baling operations are also complicated to some extent by the relative coarseness of the dried material.

All of the harvest and post-harvest operations were performed successfully, but they required somewhat more drying time and machinery work time than short-rotation species such as Sordan and Johnson grass. Mowing heights were varied from 2 to 8 inches. No crown injury was evident at the lower stubble height, but 8-inch stubble posed some difficulty for the forage rake. An additional day was required for solar drying. Occasional stem billets could still be found that were pliable (containing 25 to 30 percent moisture) rather than brittle (containing 14 to 16 percent moisture). Round bales were produced without difficulty. These were somewhat rougher in appearance than Sordan bales owing to protruding stem segments.

(d) Napier Grass; Six Months: The ultimate test of the rotary scythe-conditioner is encountered with 6-months old napier grass. Such material is in an advanced state of maturity with dry matter content approaching 35 percent. Stems appear more woody than herbaceous and are succulent only in the upper canopy area. Standing biomass is in the order of 30 to 40 tons/acre. Stands of grasses having greater mass than this would be approached with a sugarcane harvester rather than forage-making equipment.

The first trials of the M-C rotary scythe on 6-months old napier grass were performed in mid-March of 1980. The varieties Common Merker and PI 7350 were harvested at two stubble heights and two tractor speeds (Table 49). The maximum engine speed was approximately 1900 rpm for all tests.

Because the M-C rotary scythe was designed to harvest forage crops that are morphologically different from napier grass and harvested at less advanced stages of maturity, several discrete kinds of problems were anticipated for this implement when operating in mature napier grass. Any one of these could eliminate the rotary scythe as a candidate harvester if it could not be corrected by adjusting the implement, by modifying the implement's design, or by modifying its mode of operation by options available to the tractor driver. Anticipated problem areas included the following:

(i) Excessive height of napier grass, in the order of 9 to 12 feet, as opposed to a maximum of 2 to 4 feet for conventional forage crops. Since the "cut" grasses must first fall forward and then be drawn backward beneath the implement to be conditioned, the taller napier grass could not have been harvested had it fallen backward on to the upper surface of the rotary scythe. In the actual tests there was no tendency for any material to drop backward on the implement's surface. The leading edge of the rotary scythe strikes the napier grass stem with sufficient force to push them forward, even when operating at the lowest cutting height. Moreover, the elongated stems were forced forward sufficiently far into the standing grass to enable them to be drawn back with ease beneath the rotary scythe. There was no appreciable realignment of the stems, that is, no turning at right angles to the path of the implement, which could lead to bunching of the stems and clogging of the rotary scythe blades.

(ii) <u>An Excessive mass</u> of the napier grass, amounting to approximately 30 to 40 standing green tons/acre, as opposed to about 10 to 12 green tons/acre for a typical forage crop. It was thought that the additional mass confronting the implement might cause its blades to become clogged with bunched material; alternatively, such material could effect a continual breaking of shear pins. The latter are incorporated into the implement's design and are intended to shear off when overloaded to prevent more serious damage. During the present tests there was no clogging or breaking of shear pins.

The implement's performance was generally ragged and unsatisfactory when the tractor was operated in second gear. There was a tendency for the rotary scythe to pass over or only partially condition a small percentage of the stems. This was corrected by shifting to low gear and increasing the tractor's engine speed. While outwardly slowing the harvest process, ie, the visible movement of harvest machinery across the field, the decisive factor is the quantity of biomass being harvested per unit of time. In 6-months old napier grass the rotary scythe was conditioning biomass at full capacity when operated in the tractor's low gear.

(iii) <u>Inadequate conditioning</u> of the relatively woody napier grass stems. Under normal circumstances the rotary scythe "conditions" forage crops that are relatively immature, succulent, and easily disintegrated. The forage plant is shattered by repeated striking of the blades at distances of 4 to 6 inches along the stem. This greatly enhances the solar drying of such materials while easing the windrowing and baling operations. Stems of 6-months old napier grass were quite effectively conditioned by the rotary scythe. Solar drying proceeded normally. Approximately one additional day was needed to attain 15% moisture (four days for napier grass as opposed to three days for Sordan). Increased drying time was mainly a function of the greater stem thickness and total mass of material per acre for napier grass.

(iiii) Inadequate preparation for raking and baling operations. Mature napier grass plants are 3 to 4 meters long with stems up to 3 centimeters in diameter. In order to manage such material as solar-dried forages, it is necessary not only to shatter the stems but also to reduce them to shortened, pliable segments that can be raked into windrows and fed successfully into balers for compaction (rectangular or cube bales) or organization into round bales. In the present trials these requirements were met very effectively.

In practice, the rotary scythe completely disintegrated those stems offering the greatest resistance to the rotating blades. In circumstances where shattering was incomplete (lodged plants, excessively heavy stands), the stems were rendered flexible by partial shattering plus complete severing at fairly frequent intervals. Only rarely could one find a stem segment exceeding 40 to 45 centimeters in length. The longer plant segments that remained intact—both tops and stems—ordinarily bore severe bruises from repeated striking by the rotary scythe blades. These were sufficiently pliable to pass through the subsequent raking and baling operations without difficulty.

(e) Raking And Baling; 6-Month Napier Grass: The very excellent performance by the rotary scythe-conditioner enabled us to solar-dry, rake, and bale mature napier grass which otherwise would have been completely unmanageable with existing forage-making equipment. Problems which did arise related mainly to the excessive mass of material to be managed per unit of working area. To some extent these problems were alleviated by operating the tractor in low gear with increased engine speed.

The rake initially used in these trials is a "heavy-duty", PTO-driven model but one designed for conventional forage crops offering a maximum of about 5 dry tons/acre. At normal raking speed (in second gear) the implement tended to slip over a significant fraction of biomass being raked for the first time. This was corrected to some degree by slowing the tractor to low gear and increasing engine speed, by partially raising the rake when laboring in heavy material, and by reraking the skipped areas. After the windrows had been formed there were no further difficulties in raking, ie, when turning the windrows over a second or third time.

A more serious problem was the frequent breaking of the rake's tines as they snagged against the napier grass crowns. This was especially true of high stubble (8 to 10 inches) but occurred in low stubble (1 to 2 inches) as well. The crown of a mature napier grass plant offers considerable resistance, more like the stump of a sapling tree than a conventional forage grass. Although tines are easily replaced, the rate of breakage on napier grass stubble was prohibitive. Moreover, a significant quantity of biomass lying flattened between the stubble remained unraked.

It was proposed, correctly, that the problems of tine breakage and unraked material could be eliminated by use of a different type of implement, one commonly described as a "wheel" rake. This rake is not driven by a power take-off but rather operates through contact of its tines with the ground surface. The tines are mounted on a series of independent wheels which offer greater flexibility for penetration of a heavily-stubbled surface. A Farmhand model rake was subsequently purchased for trials on solar-dried napier grass.

Baling trials on the 6-month old napier grass with a New Holland round baler proceeded normally. Although the napier grass stems were far heavier than Sordan or conventional forage grasses, they were sufficiently broken up and weakened by the rotary scythe to be organized into round bales without difficulty. As was the case with the rotary scythe and rake, it was necessary to operate the baler in low gear owing to the very large mass of windrowed dry matter.

(f) Napier Grass Yields; 6 Months: A series of 2-to 6-acre harvests were performed with napier grass stands aged 4 to 6 months during the project's fourth and fifth years. An initial trial with 6-months old variety "Merker" evaluated yields and crown injury that could be traced to the rotary-scythe conditioner (27). Two mowing heights were also examined, "high stubble" (8 to 10 inches) and "low stubble" (1 to 2 inches).

Overall dry matter yields averaged 9.3 tons/acre, with high stubble and low stubble plots averaging 8.4 and 10.2 tons/acre, respectively (Table 50). A significant amount of conditioned biomass lay flattened between the stubble and could not be recovered with the available forage rake. This implement, like most standard forage rakes, operates as a single unit driven from the tractor's PTO system. When any portion of the rake is lifted by a plant crown, much of the entire rake is lifted and passes over a layer of biomass untouched by the implement's tines. Subsequent trials with the project's Farmhand wheel rake (which gives a clean raking of all stems except those missed by the rotary scythe) indicated that from 15 to 25% of the solar-dried material had been left unwindrowed by the standard PTO-driven rake.

Upon visual inspection some of the stubble appeared broken and crushed by the tractor and rotary scythe. However, the same crowns generally produced an abundance of new shoots within a few days after mowing. It is believed that a sufficient number of buds survive these operations to re-establish a normal plant stand even when some of the buds are destroyed. It is also possible that some level of crown injury is stimulatory to shoot production.

Midway through the third year of reharvesting at 6-month intervals, regrowth of Common Merker became perceptively weaker and the number of new shoots diminished progressively. However, the hybrid variety PI 7350 continued to respond with vigor and still does so today. From these observations it is felt that Common Merker will require replanting at about 3-year intervals if subjected to a continuous 6-month harvest regime. Similarly, PI 7350 stands appear to be viable for at least 4 years under the same harvest regime.

(g) Fuel Consumption And Estimated Horsepower: Fuel consumption was also measured for the napier grass harvests described above. These measurements refer to the total diesel fuel consumed by a model 8700 Ford tractor (a category III, 120 hp unit), operating a M-C model 9-E rotary scythe (9 foot mowing swath), both idling and in actual movement on the measured test plot areas. They do not include movement of the tractor and implement to and from the fields themselves. Estimates of the horsepower utilized by the tractor were calculated from the fuel consumption figures in accordance with published Nebraska Tractor Test Data for the model 8700 Ford tractor (Table 51).

Diesel fuel consumption was somewhat lower than expected, ranging from 2.38 to 2.95 gallons/hour, or 1.92 to 2.69 gallons/acre. A fuel consumption level in the order of magnitude of sugarcane harvesters had been anticipated (roughly 4 to 6 gallons of diesel fuel/hour). It should be noted that the standing green biomass confronting the rotary scythe (about 40 tons/acre) exceeded the sugarcane tonnages confronting cane harvesters in Puerto Rico today (approximately 27 tons/acre as an Island-wide average). Hence, the lower fuel consumption for napier grass harvest was not function of lower biomass tonnage.

Low-stubble mowing utilized moderately more fuel than high-stubble mowing (Tables 51 and 52). This relates to the greater resistance offered by napier grass stems cose to the soil surface, and to the greater tonnage of biomass to be conditioned with low-stubble harvesting. Alternatively, low-stubble mowing does a much cleaner job. It minimizes the tendency of high mowing to leave long, ragged stubbles which in turn complicate raking and baling operations, in addition to leaving unharvested a significant fraction of the standing green napier grass.

Horsepower usage by the 8700 Ford tractor ranged from 35.7 hp at high-stubble mowing to 41.4 hp at low-stubble mowing (Table 51). Performance data provided by the Ford Company indicate that this tractor can supply about 95 gross hp at the power take-off with an operating engine revolution range of 1500 to 1800 rpm (56). Hence, less than half of the tractor's work potential was being utilized in conditioning the 6-months old napier grass. On the other hand, it is estimated that the rotary scythe itself, although an extremely rugged implement, can utilize a maximum input of only about 60 hp without sustaining major damage (57). Exceptionally heavy stands of biomass, such as mature sugarcane or 12-months old napier grass, could likely place the rotary scythe work load in the 60 hp range. There would be no purpose in attempting this since there are cane harvesters available to deal with such materials.

4. Rotary Scythe Modifications

Mechanized harvest studies for short-and intermediate-rotation grasses have centered on three machinery units: (a) A rotary scythe-conditioner, manufactured by the Mathews Company; (b), a New Holland Company Round Baler; and (c), a Farmhand Company wheel rake. The rotary scythe-conditioner is of decisive importance in the handling of large tropical grasses as solar-dried energy crops. Successful implementation of this unit would virtually assure an adequate performance of successive machines needed to deliver a solar-dried feedstock to the biomass processing or utilization center.

Rotary scythe trials on Sordan 70A and Johnson Grass delt with a maximum mass of about 20 tons/acre of standing green material. No significant problems were encountered and the machine completed the work it was designed to perform. With napier grass, representing 40 to 45 standing green tons/acre, the interior edge of the rotary scythe tended to lift from the ground when passing over exceptionally heavy or lodged clumps of grass. It was felt that this problem could be overcome by increasing the implement's weight. A second and more serious problem lay in its tendency to drag sections of uncut grass along its interior edge. This occurred in lodged and heavily matted materials that were interwoven in a contiguous mass. Such materials extended inward into uncut grass up to several yards beyond the cutting swath edge. In upright stands or where only partial lodging had occurred the rotary scythe easily sectioned off the biomass in normal swath segments.

The rotary scythe's problem in sectioning the heavy and matted napier grass was solved by fitting its interior cutting edge with a parting knife taken from a Klass Model 1400 sugarcane harvester. The parting knife consists of a single 12-inch blade which rotates counter-clockwise against a heavy metal plate and shears off impeding stems in a scissors-like action.

It is normally driven by a hydraulic motor with a force of about 5 horsepower. Fortunately, the heavy-duty construction of the rotary scythe offered a 0.25 inch metal plate to which the parting knife frame and supports could be welded directly.

It was necessary to adapt the parting knife's hydraulic lines to the smaller dual remote outlets of the project's tractor. The lines themselves extend directly backward from the tractor, over the top of the rotary scythe's drive shaft and gear box, and then across the implement's backside where they remain free of entanglement with the conditioning grass stems. As described in earlier reports, the tall grasses being conditioned with this unit invariably drop forward of its leading edge and never backward over the machine itself. Otherwise, neither the rotary scythe nor its affixed parting knife could perform their tasks in heavy tropical grasses.

In the tests made with this system it does not appear that the full cutting force of the parting knife was developed, ie, as designed for operation on a sugarcane harvester. Nonetheless, its performance in 6-months old napier grass has been very good. It clearly sections through dense matter and lodged materials where formerly a rather ragged division was made, coupled with uprooted and dragged crowns of napier grass. Moreover, the rotary scythe ceased elevating above the ground in dense materials once the parting knife became operational. No supplemental weighting of the implement was necesary. The parting knife with accessories weighs about 150 pounds so this in itself may contribute materially to the performance of the rotary scythe.

5. Bale Drying And Storage

Naper grass harvest, drying, compacting (baling), and storage studies continued through project years 4 and 5. Mature stands of napier grass, varieties Common Merker and PI 7350, were "conditioned" in the field with the M-C rotary scythe, solar-dried over a period of 3 to 6 days, baled with a New Holland "round" baler, and transferred to storage in a roofed, open-sided shed. Several trials have also been conducted with bales stored in the open and exposed to rain.

Seven post-harvest storage experiments were established before the close of the project. Completed experiments, utilizing 10 to 30 stored bales of about 1200 pounds each, include the following: (a) Moisture-loss measurements from bales containing less than 20% moisture at time of storage (two trials); (b) moisture-loss measurements from partially-dry bales containing about 35% moisture at time of storage; (c) moisture loss and temperature measurements in bales stored at less than 20% moisture; (d) moisture content measurements in dry bales (less than 20% moisture) stored out-of-doors (open-air storage); and (e), moisture determinations in partially-dry bales (approximately 35-40% moisture) in open-air storage.

Actual measurements were made with a moisture-sensitive probe and recorder ("Hay Moisture Detector", Empire Corp. no. 18252). This unit is equipped with an accessory extension rod enabling the probe to be inserted to any depth desired in the round bales. It offers direct readings in percent moisture with a precision of about ± 2 percent. Because of its ease of operation a large number of readings can be taken quickly and a mean value computed for the entire bale.

(a) Moisture Changes In Stored Dry Bales: The initial two moisture trials were performed with napier grass varieties Merker and PI 7350. Solar-dried material was placed in storage immediately after baling and moisture contents were determined at 48-hour intervals for the subsequent 24 days. Two trends were immediately evident: (a) Moisture content at first increased (up to day 4) and then gradually declined from day 6 onward, and (b), a varietal factor was moderately but persistently affecting moisture content throughout the 24-day period (Table 53).

The temporary increase in bale moisture content was at first thought to be an artifact but has recurred in all subsequent moisture-measurement series. Its initiation apparently relates to the biomass compaction process itself. Possibly it is a function of microbial action within the newly-compacted bale. Neither the magnitude of moisture increase (2 to 3%) nor its duration (about 10 days) appear to be significant factors in the future storage of baled napier grass as fuel or lignocellulose feedstocks.

Varietal differences in moisture contents (Figure 10) are explained on anatomical lines. Variety PI 7350 is a thick-stemmed hybrid and less readily shattered (conditioned) by the rotary scythe action. Its drying time required for optimal baling is presumably a day or two longer than for variety Merker. Given sufficient drying time in post-harvest storage, it is believed that all varieties would lose moisture to a common level dictated by ambient moisture conditions.

An interesting feature of the post-baling moisture changes was their apparent sensitivity to changing relative humidity. Although no direct relationship was determined between bale moisture content and rainfall outside the storage facility, there is some evidence that moisture did increase, (or cease to decline) for 2-to 4-day periods following measurable rainfall (Figure 10). In this context the "dry" round bale ($<30\%$ moisture) appears to act as a "sponge" capable of absorbing small amounts of water from the ambient atmosphere.

(b) Moisture Changes In Partially-Dry Bales: While solar-drying to ambient moisture is both desirable and normal procedure, situations can arise where baling of partially-dry grasses is necessary. This is particularly true where harvest operations are attempted during the rainy season (August through November), or unexpected rainfall has complicated normal dry season conditions. Early baling might also be required to remove aging windrows that are shading out the newly-emerging shoots from harvested stubble. A 10-bale experiment was performed to determine the drying behavior of napier grass bales placed in storage with higher than normal moisture contents.

The average moisture content at time of baling was 31.5 percent (Figure 11). During the subsequent 10 days, moisture increased to 34.5 percent and then began a general decline over the next 82 days to 18.4 percent. Some limited heating was evident in the bale's interior but did not approach spontaneous combustion, possibly because of natural ventilation throughout the storage facility. There was also evidence of mold but no appreciable decomposition occurred.

The following conclusions were drawn relative to wet napier grass baling under inclement weather conditions: (a), Bales could be made and stored with roughly 16 percent excess moisture; (b), such bales could complete the drying process in storage; and (c), about three months time and good ventilation (12-16 inch spacing between rows of bales stacked three high) are needed to assure drying to an ambient moisture level. The 90-day interval includes an initial 10-day period when water content increases by 3 to 4 percent.

(c) Moisture Changes In Open-Air Storage: Owing to the high cost of storing biomass in such structures, biomass planters must seriously consider the option of open-air storage where local climate conditions are favorable. Hay growers in large areas of the western US commonly stack their bales out-of-doors without cover or protection of any kind. Highly-compacted bales tend to resist moisture penetration. At worst, only the outer layer of bales may be damaged by prolonged exposure to precipitation, sun, and wind. Round bales such as those produced in this project are only loosely compacted (9-10 lbs/ft^3). Their behavior when exposed to weather variables was an unknown factor.

Two experiments were performed with napier grass bales stored out-of-doors (Table 54). One experiment utilized partially-dry material (36.6% moisture) and the other fully-dry material (15.8% moisture). Moisture determinations were made at 2-to 3-week intervals over a time course of 61 days. Two important trends were evident: (a) The partially-green bales lost moisture during the first 28 days and remained constant at around 23 percent moisture thereafter, and (b), The dry bales gained moisture during the first 14 days of open-air storage, but thereafter their moisture content declined to approximately the original level (Table 55).

The magnitude of moisture change for both bale groups was surprising. The semi-green bales lost 37% of their total moisture within 28 days. More striking was their loss of 63% of the removable water, that is, moisture in excess of 15% (ambient moisture). The dry bales increased moisture by nearly 55% during the first 14 days. This increase was considerably larger than that observed for bales stored under a roof (Figures 10 and 11). However, the stabilized moisture level (from 28 days onward) was only slightly higher than the original level at time of baling.

These results suggest that the storing of bales in a roofed facility is not really necessary in the semiarid climate of Puerto Rico's Lajas Valley. Further to this, the open-air storage tests were performed during the rainy season. It is logical to expect that during the 8-month dry season the drying of semi-green bales would be accelerated and the temporary gain of moisture by dry bales would be reduced.

6. Hatillo Energy Cane Farm

The project's original work plan called for at least one major study with sugarcane somewhere on the Island's humid north coast. A site more closely integrated with private farms than is possible with Experiment Station lands was also desired. A favorable opportunity arose for establishing such a study during the spring of 1980. Mr. José B. De Castro, an elderly landowner having a strong personal interest in biomass energy cropping, offered CEER-UPR the use of 30 acres near the northwest coastal town of Hatillo. The offer was accepted and an energy cane demonstraton study was established there during July and August of 1980.

The land itself is situated on a deep alluvial plain bordered by the Camuy River. There are two soil series: A well-drained Coloso clay loam, occupying about 40% of the site, and a poorly-drained Toa clay occupying the remaining area. The soils appear to be at least four to six feet deep. The well-drained sections constitute an "all weather" site insofar as most agricultural production operations are concerned. The De Castro farm had not been cultivated for seven years and was occupied by a mixture of volunteer sugarcane and wild grasses.

Approximately 25 acres were mowed with a rotary scythe, plowed, rotavated land-planned, limed, and planted into three field-scale treatments: (a) An energy cane planting, of approximately 17 acres, in which intensive production operations are demonstrated; (b), a control plot of about 2.5 acres managed as conventional sugarcane; and (c), a second control plot, about 6 acres, simulating the unmanaged wild sugarcane that had been occupying the site until the summer of 1980. In addition, about 2 acres were planted in the "second generation" energy cane US 67-22-2, as part of the seed expansion program for this variety. The energy cane planting is subdivided into irrigated and nonirrigated sections.

(a) Plant Crop Yields: Field-scale trials at Hatillo include both first-and second-generation energy cane varieties (PR 980 and US 67-22-2, respectively), plus supplemental irrigation as a controlled variable. There are two control treatments simulating "standard" sugarcane (Sugar Corporation control) and minimum tillage (low-till control). Yield and quality data were obtained from 1000 ft^2 area samples taken at tri-monthly intervals from months 6 to 18.

The main objective of this study was to demonstrate the feasibility of producing 90 tons of whole cane in an 18-month gran cultura crop. At that time there was skepticism among local agronomists and sugar officials as to whether the 80-plus tonnages being reported for energy cane were in fact feasible (or even possible) on a field scale. By month 9 it was evident that the 90-ton goal would be attained. Accordingly, no additional fertilizer was administered after month 8, 1/ and no irrigation was provided after month 12. This change in management emphasis was quite apparent in the subsequent yield data.

(b) Whole Cane And Dry Matter: Four trends are evident in the plant-crop data from Hatillo: (a) Energy cane, both first-and second-generation varieties, appreciably outyielded control cane; (b) over 90 tons of whole green cane were produced by month 12; (c) relatively little biomass was produced after month 12; and (d), the second-generation variety US 67-22-2 was distinctly superior to variety PR 980. Also, the control yields were consistently higher than expected. This is attributed in part to an erroneous inclusion of the land rotavator in preparing the control seedbed. This implement is almost never used either on Sugar Corporation lands or private "Colono" farms.

Yields of total green matter (Table 56) attained over 95 tons/acre by month 12 in first-generation cane. Variety US 67-22-2 (second generation) yielded about 125 tons/acre at 12 months; however, neither treatment appreciably increased yield in the subsequent 6 months. Similar trends were recorded for millable stems (Table 57), although small yield gains were made after 12 months. Dry matter also had essentially maximized by

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1/ Four increments of 100 lbs elemental N each had been planned, ie, at planting (beneath the seedpiece), and at months 4, 8, and 12.

the twelfth month (Table 58). Variety US 67-22-2 was by far the superior producer, attaining over 50 tons DM by month 12. There was virtually no gain in total DM after that time.

(c) Cane Quality And Sugar Yield: Cane quality values did not vary greatly among control and energy cane treatments (Table 59). Rendiment figures were generally low, even for 18-month cane. Sugar yields were high (by Puerto Rico standards) but this was a reflection of the generally high tonnages of millable cane/acre. The highest sugar yield (TSA) was 9.2 tons/acre, produced by variety US 67-22-2 at 18 months.

The withholding of water and fertilizer after month 12 does not appear to have increased cane quality or sugar yield appreciably (Table 59). In US 67-22-2, purity remained unchanged between 12 and 18 months and sugar increased by only 1.4 tons/acre. The fiber content of US 67-22-2 was perceptively lower than PR 980, being only 11.6% at 18 months. The US 67-22-2 variety is widely regarded as a "soft" cane.

(d) Plant Density And Trash: The second-generation variety US 67-22-2 displayed a prolific tillering habit observed elsewhere in field-plot studies. Stubble counts, recorded trimonthly from 6 months onward, indicate a persistent and dramatic increase in the number of stems/acre (Figure 12). This is a highly desirable characteristic. It assures complete occupation of the planted area and complete closure of the cane field canopy. It also provides for self replacement of crowns destroyed by harvest machinery.

This variety is not only a prolific producer of stems. It also maintains a foliar canopy that is perceptively larger than normally seen in the sugarcanes of commerce. It is common to see an intact green canopy extending from top to ground level as late as month 6 or 7. This propensity for leaf production is later reflected in trash yields 1/. At Hatillo, by month 12,

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1/ Cane "trash" consists of leaf and leaf-sheath tissues that have died and desiccated, and either remain adhereing to the mature stem or detach and drop to the ground.

US 67-22-2 had accumulated over 23 tons of trash/acre (Table 60). This equals the average whole cane tonnage currently produced by the sugarcane Colonos in Puerto Rico (50).

7. Field-Plot Vs Field-Scale Yields

A point of interest in energy planting is the contention by some "authorities" that field-plot data are meaningless if extrapolated to field-scale conditions. The assumption is that the precision control over production inputs enjoyed at the small plot level is lost in the field, and hence the field productivity must be significantly less. The present studies were not designed to test this thesis; however, the treatments at Lajas (field plot) were established in the same season and maintained essentially the same sequence of inputs as those at Hatillo (field scale), up to the end of month 8 when further fertilizer increments were cancelled.

Out of curiosity the primary yield trends of US 67-22-2 at the two sites were plotted in Table 61. For total dry matter, the single most important parameter, yields were actually higher under field-scale conditions through the first 12 months. Millable cane yields were about 3% lower and sugar was 8% lower. This suggests that comparable management gives comparable yields whether in the field or in field plots.

8. Energy In The Field Vs The Factory

The cane quality figures herein reported represent the cane condition within one day after harvest. For unburned whole cane these values are sustained at the mill for 3 to 4 days after harvest. Burned and chopped cane usually experiencces a more rapid quality decline.

The need for coordination betwen field and mill opeations was underscored recently when the second-generation energy cane at Hatillo was being harvested. Average rendiment readings were between 8.0 and 8.7 at the time of harvest. However, the first load of cane, hauled 5 days later, gave a rendiment value of 5.9, while the final load, delivered 15 days after harvest, gave a rendiment value of 2.9. Purity values had also declined drastically. Such cane is not worth its delivery costs as a sugar resource.

As a source of lignocellulosic feedstocks, or as a boiler fuel, the value of this cane had diminished relatively little.

Loss of moisture also occurs in harvested cane experiencing long delays in delivery (Figure 13). The sugar planter would be paid for less tonnage, and sugar extraction efficiency would decline at the mill. As an energy crop the loss of moisture in the field is not necessarily bad. Less water would need to be hauled while the lignocellulose fraction remained intact.

D. BREEDING STUDIES

The genus Saccharum can be viewed as an enormous and largely untapped pool of germplasm bearing large potentials for production of both sugar and lignocellulose (58, 16, 1, 2). A "secondary" but nonetheless important goal of this project was to establish a cane biomass breeding program that would enable at least a limited number of new progeny to emerge having specifically biomass attributes. This was accomplished with very limited resource inputs, in part through the use existing AES-UPR facilities for conventional sugarcane breeding, but primarily through the personal interest of Mr. T. L. Chu, a recognized world authority on breeding in the genus Saccharum.

1. Evaluation Of Local Germplasm Sources

Four local clones bearing "new" Saccharum germplasm were identified early in year 1 and evaluated as potential male parents in crosses with suitable female (male-sterile) sugarcanes (24). All exhibited 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 near Río Piedras. No attempt was ever made to cultivate them directly as biomass candidates. A third wild clone, an unidentified S. spontaneum hybrid, is a highly promising biomass producer in its own right. Throughout the course of the project this hybrid served as a highly-visual example of massive growth potential by wild, uncared for tropical grasses (24, 48, 58). A fourth Saccharum clone, "Aegyptiacum", was available in collections maintained at Río Piedras and Gurabo.

2. Evaluation Of PR Breeding Progeny

For many years the AES-UPR 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 (59, 60, 61). Total biomass *per se* has not been a decisive parameter in the selection of new sugarcane hybrids (62, 58). 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. Some 15 of these were planted in a separate "nursery" to be used as parental clones in energy cane breeding.

3. Initial Crosses

The project's initial two crosses were performed in December of 1977, utilizing made-sterile female parents, and frozen pollen in an effort to synchronize tasseling with that of the early-flowering *S. spontaneum* hybrid described above. Although pollen tests by the starch-iodine method had indicated a probable viability, only 5 seedlings were obtained from these crosses, suggesting that the freezing process was almost totally destructive. A more suitable method for flower synchronization in cane is the leaf-trimming method developed by Chu and Serapión (63, 64).

Ultimately, a "cutback" technique was adopted which successfully enabled us to utilize the wild *S. spontaneum* hybrid in crosses with normal-flowering canes. By this method a select stand of wild material is cut off between May 15 and June 1. The subsequent regrowth is too young to initiate tassels at the clone's preferential photoperiod in August, but a limited number of stems do initiate flower primordia at about the same time that "late" commercial canes are doing so in Puerto Rico. This enabled us to obtain *S. spontaneum* tassels during the period November 25-December 15. Five crosses performed by this means in the autumn of 1979 are summarized in Table 62.

4. Seedling Trials; Lajas Substation

The project's breeding phase aimed at producing new sugarcane progeny with superior biomass attributes was confined to the AES-UPR Gurabo Substation during the first three years. In 1980, 92 seedlings showing some preliminary evidence of high tonnage capability were transferred to the Lajas Substation for second-phase evaluation (27). They were planted in unreplicated, 5' x 20' plots.

A total of six crosses were represented, each made by Mr. T. L. Chu during the autumn of 1979. All crosses were part of the AES-UPR Sugarcane Breeding Program, but in these instances there were parental types involved having important biomass attributes. Of special interest is the S. spontaneum hybrid US 67-22-2 which served as both female and male parent. Under Gurabo conditions this clone has shown very superior potential for the production of both sucrose and total biomass. From this point onward some probability has existed for the emergence of "third generation" progeny having biomass attributes superior to those of any preceeding clone.

5. Second-Generation Energy Canes

The sugarcane varieties US 67-22-2 and B 70-701 were imported into Puerto Rico from USDA collections in 1974 and 1977, respectively. The purpose of these introductions, together with other basic breeding lines structured with new clones of Saccharum species, was to broaden the genetic base of the Island's sugarcane germplasm (58). Based on an initial evaluation of the AES-UPR breeding collections, varieties US 67-22-2 and B 70-701 were identified as outstanding candidates for biomass cropping.

Variety US 67-22-2 is a second generation (BC_1) hybrid of the S. spontaneum clone Passoeroean. It has excellent germination, rapid early growth with strong tillering and ratooning capability, and an erect growth habit. It has a relatively low fiber content and average sucrose content. Plant crop data have revealed that variety US 67-22-2 produced the highest green matter yield at 130 tons/acre, with total dry matter at 41.9 tons/acre. Only 25.0 tons/acre were obtained from first-generation energy cane (var. PR 980) in the plant crop.

In a seed-expansion study performed at the Hatillo energy cane demonstration farm, variety US 67-22-2 produced 125 tons/acre in total green matter for the 12-month harvest, as opposed to 108 tons/acre for variety PR 980. Sugar yield exceeded 7.7 tons/acre for US 67-22-2 and 6.2 tons/acre for PR 980. A seed-expansion program for US 67-22-2 is currently underway at the AES-UPR Lajas Substation and at the Hatillo energy cane farm.

The clone B 70-701 is a first generation S. spontaneum hybrid (F_1). It is characterized by exceptionally rapid growth with good tillering and ratooning ability. It has distinctly higher fiber and lower sugar contents. The average dry weight of B 70-701 at Hatillo was 37.2 tons/acre year, as compared to 41.9 tons for US 67-22-2. In view of its high fiber and low sugar values, variety B 70-701 appears to be a potential candidate for biomass production solely for fiber.

6. Third-Generation Energy Canes

(a) Crosses Designed To Maximize Fiber: During the 1978 cane breeding season the cross US 67-22-2 x B 70-701 was performed. Total fiber rather than sucrose or fermentable solids was the primary objective. The F_1 progeny from this cross exhibit an exceptionally vigorous growth habit plus a large number of stems per seedling. Twenty-four clones selected from this cross, together with their parents, were planted in a replicated field trial at the AES-UPR Gurabo Substation during May of 1980. Highest yields were obtained from the progeny PR 79-1-10, amounting to 93.7 green tons and 30.6 dry tons per acre year, as opposed to 67.1 green tons and 21.5 dry tons/acre year for its female parent, variety US 67-22-2 (Table 63). It outyielded US 67-22-2 in tons of dry matter/acre by approximately 43 percent. The impressive performance in total biomass tonnage by PR 79-1-10 evidently resulted from its high number of stems/acre and remarkable stem height (Table 64). Two additional progeny in this experiment produced appreciably more dry matter than US 67-22-2, ie, by approximately 35 and 33 percent, respectively, for PR 79-1-3 and PR 79-1-5 (Table 63).

An examination of qualitative values for these clones revealed that PR 79-1-10, PR 79-1-3, and PR 79-1-5 are substantially lower in Brix, pol, purity, and sucrose-percent-cane than the reference variety US 67-22-2

(Table 65). This suggests that these three are potential candidates for the production of combustible biomass while having little prospect for sugar or fermentable solids production.

(b) Crosses Maximizing Fiber And Fermentable Solids: During the past four breeding seasons, beginning in 1978, an attempt was made to develop new energy cane varieties which could maximize both fiber and fermentable solids. The parentage and breeding lines of the crosses performed during this period are presented in Tables 66 to 69.

A preliminary evaluation of progeny from the crosses involving variety US 67-22-2, either as a male of female parent (Table 66), indicates a number of selections having excellent growth combined with good Brix values. Yield data for these clones in 20' x 20' field-plot tests are expected to be available by the summer of 1982.

An impressive performance was obtained from hybrid progeny of the cross PR 70-395 x PR 77-151-137, which was made during the 1979 breeding season (Table 67). The clone PR 77-251-137 [1] is an F_1 hybrid of the clones US 56-14-4 (2n = 80), a Thailand S. spontaneum. This suggests that the Thailand S. spontaneum source may provide excellent germplasm for improving cane biomass yields 65).

7. Energy Cane Breeding Potential In Sacharum

(a) S. spontaneum Vs S. robustum: During the 1979 breeding season additional crosses were performed which incorporated both growth and quality attributes. An extremely vigorous clone of S. spontaneum (RP) and a clone of S. robustum (57 NG 54), both "wild" clones, were crossed with the high-yielding and good juice-quality varieties previously developed in the AES-UPR cane breeding program (66). A study was made on the performance of the F_1 hybrid progeny of the two wild Saccharum species, the primary objectives of the progeny being high fiber and fermentable solids. Thirty original seedlings sampled randomly per cross were analyzed using the pol

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[1] The parentage of PR 77-251-137 is PR 67-1336 x US 56-14-4.

ratio method. Each sample consisted of five millable canes harvested approximately 12 months after planting.

An examination of frequency distribution for sucrose content in the three groups of hybrids revealed that the *robustum* F_1 hybrids contained more sucrose than the *spontaneum* F_1 progeny (Figure 14). With reference to Brix values, the *robustum* F_1 progeny demonstrated an even more remarkable performance than the *spontaneum* F_1 hybrids (Figure 15). In terms of fiber, the results indicate that far more *spontaneum* F_1 hybrids have distinctly higher fiber contents than do the *robustum* F_1 progeny (Figure 16).

These preliminary results seem to suggest that, when breeding exclusively for fibrous biomass, the first generation hybrids (F_1) of *S. spontaneum* offer a better source of candidates than do those of *S. robustum*. When breeding for both fiber and fermentable solids, the *S. robustum* F_1 progeny might offer a better source of biomass candidates.

(b) *S. spontaneum Hybrid Progeny*; BC_1 Vs BC_2: In an attempt to determine the growth potential for the BC_1 and BC_2 hybrid progeny of *S. spontaneum*, measurements were taken of stem height, stem diameter, and number of stems per plant for 100 original seedlings sampled randomly for each cross. These were recorded at approximately eight months after planting. Stalk volume per seedling was then computed from available data (Figure 17).

In terms of stalk volume/M^3/100/seedling, the BC_1 of the cross NCo 310 x B 70-701 (F_1 *spontaneum*) indicated a far better performance than the BC_2 progeny of the cross NCo 310 x US 67-22-2 [BC_1 *spontaneum* (Figure 17)]. The growth potential of two additional BC_1 progeny was also seen to be greater than that of the BC_2 progeny (Figure 17).

(c) *S. robustum* x *S. spontaneum*: The same measurements as described above were made for the hybrid progeny of the crosses F_1 *robustum*[1] x F_1 *spontaneum*[2], and F_1 *robustum* x *S. spontaneum*, RP. In terms of stalk

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[1] The parentage of F_1 *robustum* is PR 68-355 x 57 NG 54.

[2] The parentage of F_1 *spontaneum* is PR 67-1070 x *S. spontaneum* RP.

volumes/M^3/100/seedling, the progeny of the cross F_1 *robustum* x F_1 *spontaneum* RP indicated a far better performance than that of the cross F_1 *robustum* x *S. spontaneum* RP (Figure 18). The hybrid progeny of the reciprocal cross of the former demonstrated a nearly identical performance in terms of stalk volume/M^3/100/seedlings.

All these initial results appear to suggest that two wild *Saccharum* species, *S. spontaneum* and *S. robustum*, should be regarded as the most valuable source of genetic material in breeding canes for biomass planting. Nevertheless, they must be incorporated into appropriate conventional high yielding and good juice cane varieties in order to be able to produce biomass candidates combining the exceptionally good vigor with high fiber content and fairly good juice quality. The second-generation hybrid progeny (BC_1) of these two wild species appears to provide a better source of such biomass candidates than either the first generation (F_1) or more advanced-generation progeny of *S. spontaneum*. Concerning the two primary objectives (high biomass tonnage and high fermentable solids) for biomass candidastes, it is advisable that neither *S. spontaneum* F_1 nor *S. robustum* F_1 progeny should be crossed back to the original clones of the two wild species.

E. SUMMARY

A five-year study on production of sugarcane and related tropical grasses as energy crops was successfully completed with all objectives attained. Certain components of the study are continuing with UPR and Puerto Rico Commonwealth funding.

Originally a loosely-affiliated appendage of the ERDA "Fuels From Sugar Crops" program, the Puerto Rico work continued as a purely tropical application of grasses management for fuels and lignocellulosic feedstocks production. Neither sugar nor total fermentable solids were ever primary considerations, yet they figured prominantly in the emergence of the study's most important new concept, ie, the "energy cane" concept for boiler fuels and molasses production.

Essentially a synthesis of revised field management technologies, "energy cane" production encompasses a range of thin-and thick-stemmed tropical grasses having the capability to cross with *Saccharum* species as a common attribute. Sugarcanes of commerce played a major role in this project, but primarily as sources of high biomass tonnage rather than sugar. The co-production of related grasses, for the most part fibrous, thin-stemmed species having little sugar, provides a continuous, year-round supply of dry lignocellulose feedstocks. The latter are solar-dried and baled in the field while *Saccharum* components of energy cane are still hauled to a centralized mill for dewatering.

Technologies were developed and demonstrated for the production of tropical grasses as economically-profitable enterprises. Although production costs are moderately higher on a *per acre* basis than conventional sugarcane planting, yields are vastly higher and costs correspondingly lower when reckoned on a *per ton* basis. For boiler fuel, solar-dried grasses can be produced for less than $2.00/million BTUs. This is easily the most cost-effective fuel available to Puerto Rico today, and the only one that is both renewable and domestically produced. Syrup (high-test molasses) costs less than 0.70/gallon as a by-product of energy cane production. From these studies it is concluded that tropical grasses are thoroughly viable energy crop commodities for tropical countries. They are particularly attractive for tropical societies like Puerto Rico where decades of social progress have intensified energy demand.

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APPENDIX

Figures 1-18

Tables 1-69

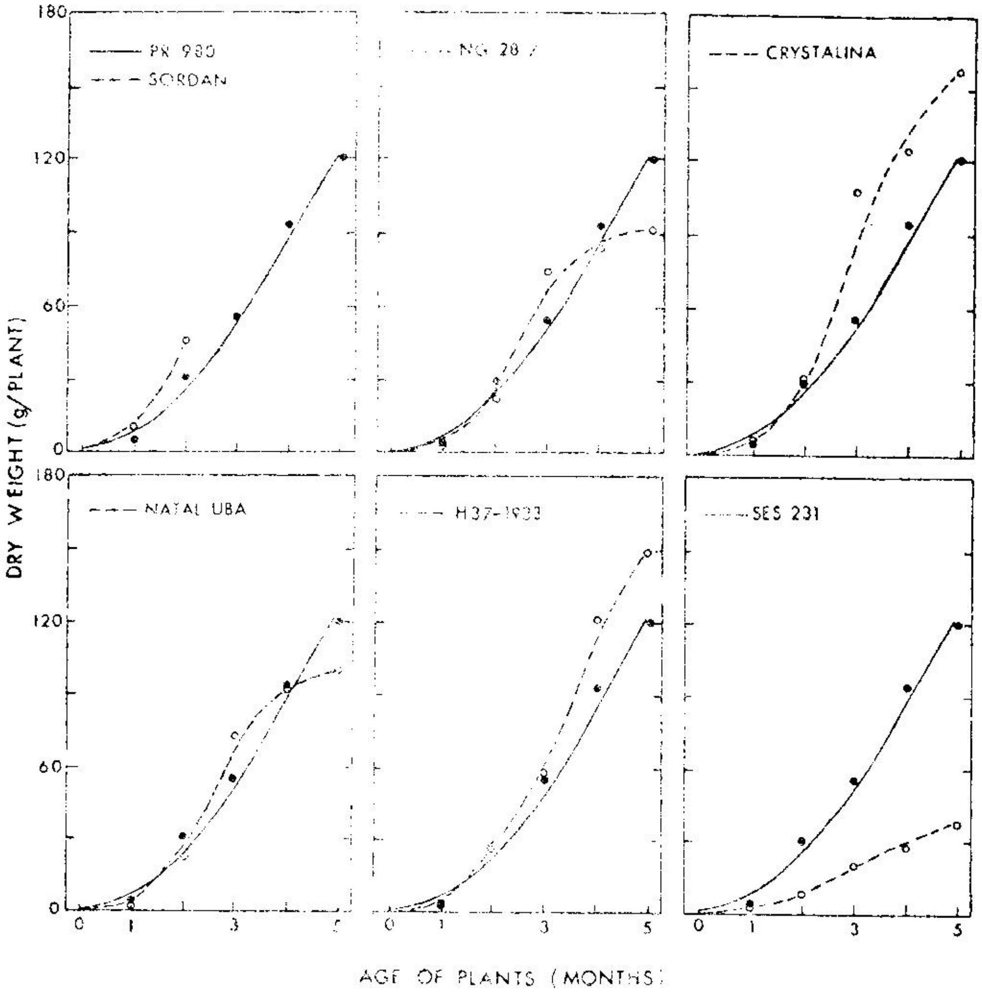

FIGURE 1. Growth curves of candidate tropical grasses propagated in a soil-cachaza mixture with controlled water supply. Sugarcane variety PR 980 served as the reference or standard clone. The hybrid forage grass Sordan 70-A flowered shortly after the 2-month harvest.

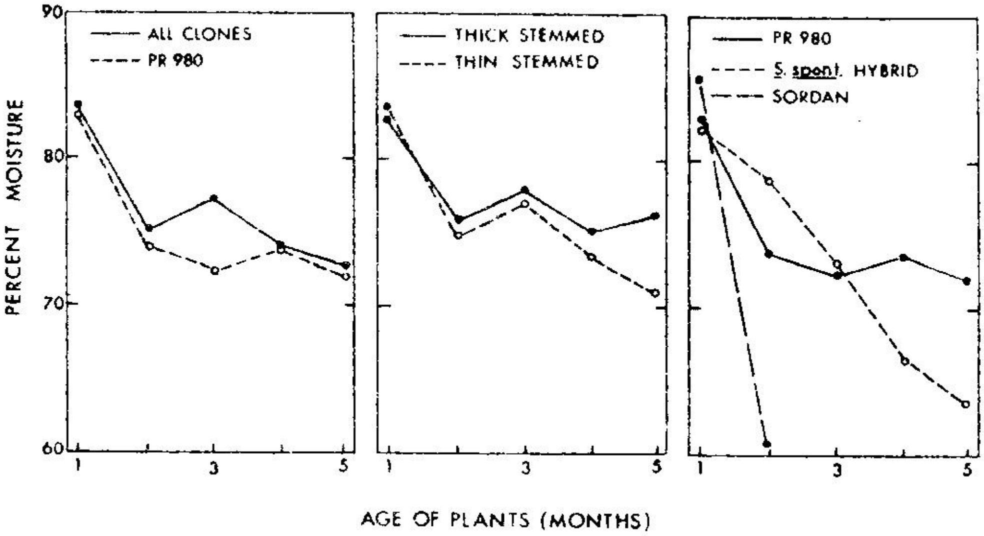

FIGURE 2. Percent moisture changes in candidate tropical grasses during a 5-month growth period. Sordan 70-A attained the moisture status of a mature plant in about 60 days.

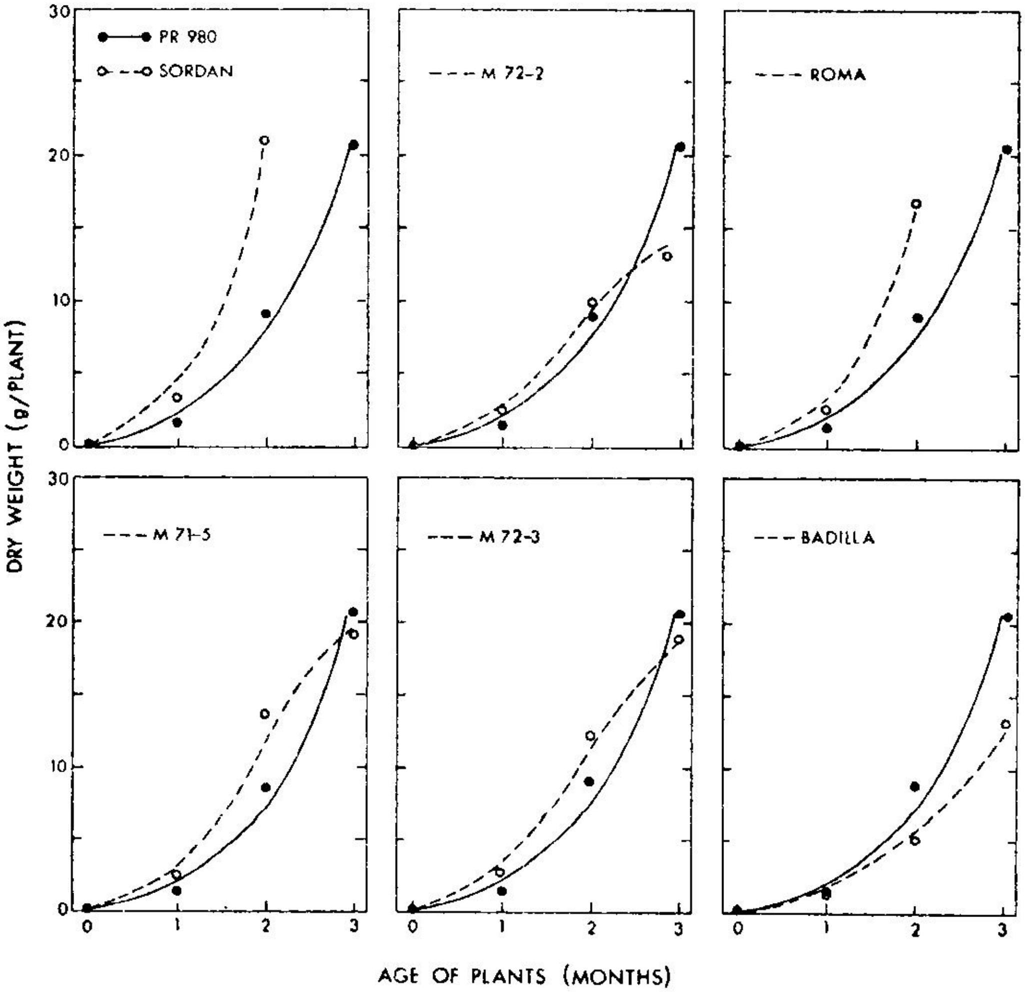

FIGURE 3. Initial growth curves of candidate tropical grasses consisting of a sugarcane hybrid control (PR 980), the sweet sorghum varieties M71-5, M72-2, M72-3, and Roma, the *S. officinarum* variety Badilla, and the hybrid forage grass Sordan 70-A. Sordan 70-A and Roma flowered shortly after the 2-month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

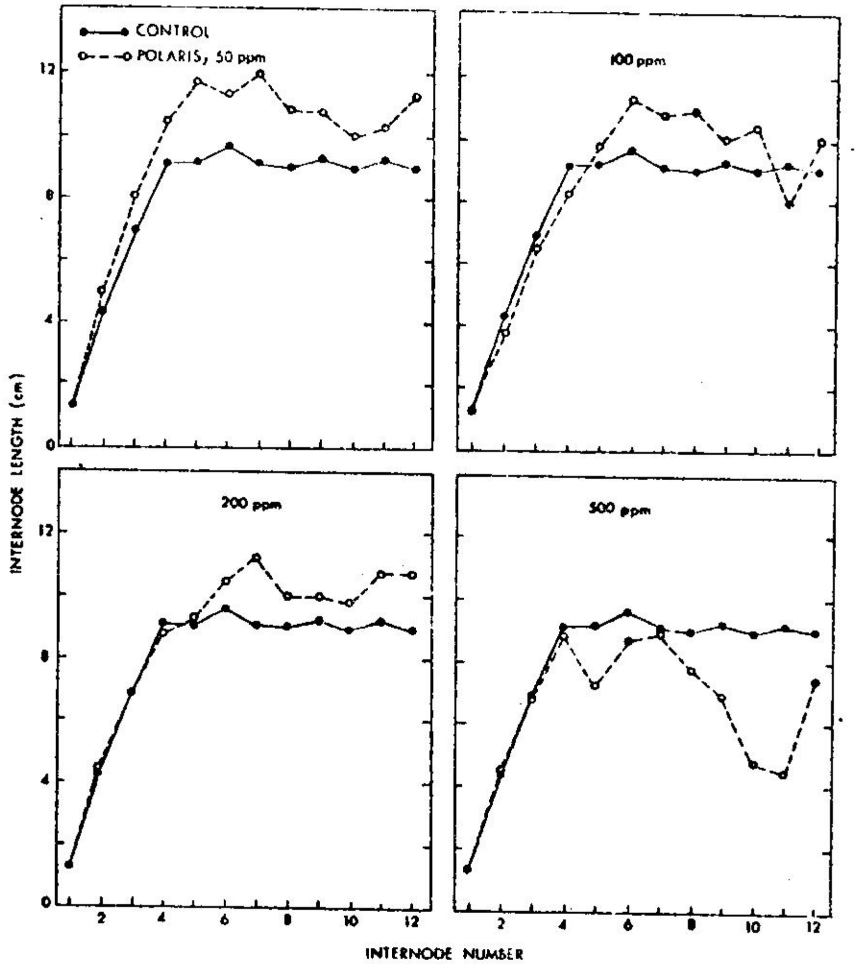

FIGURE 4. Internode expansion in sugarcane variety PR 980 treated with aqueous foliar sprays of the plant growth inhibitor Polaris [N, N-bis (phosphonomethyl) glycine].

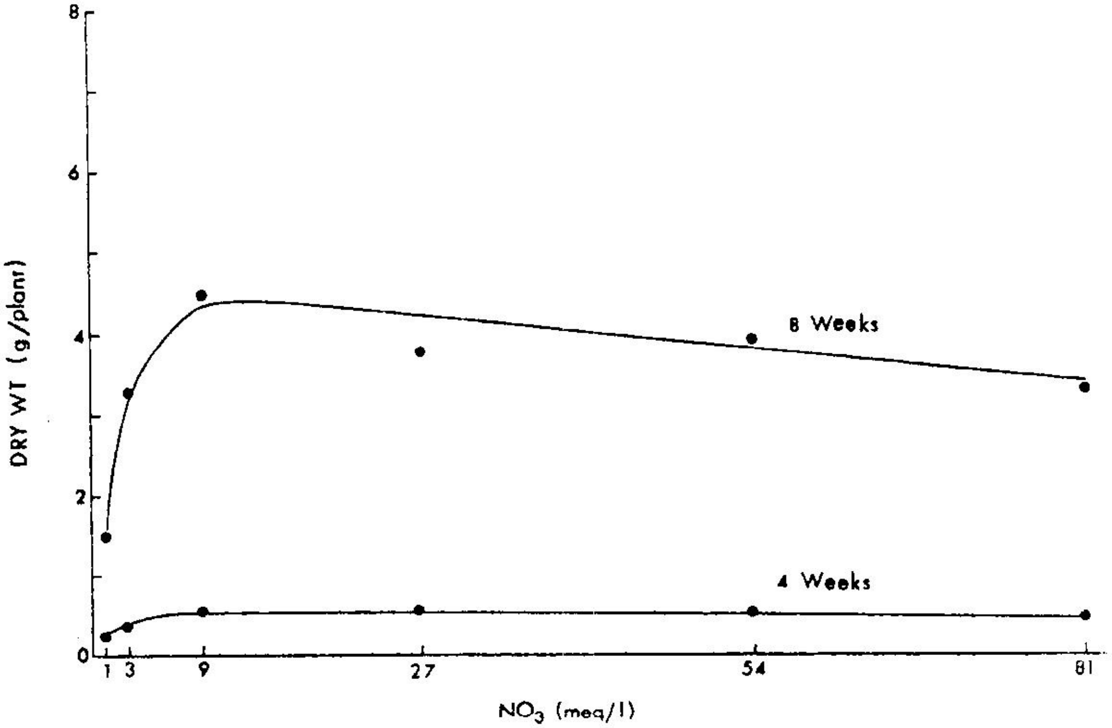

FIGURE 5. Nitrogen-response curves for the short-rotation candidate Sordan 70-A. Variable nitrate was supplied in nutrient solutions to plants propagated by sand culture (Incomplete data).

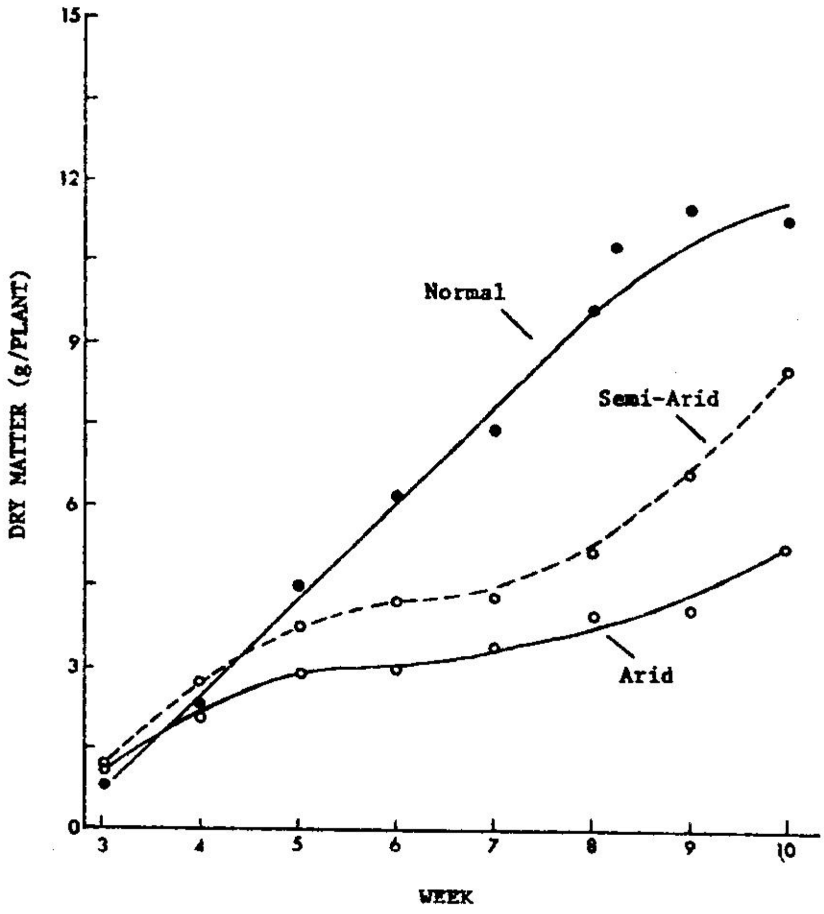

FIGURE 6. Dry matter yields for eight tropical grasses under simulated normal, semi-arid, and arid moisture regimes. Each curve is derived from the computed means of seven *Saccharum* and one *Sorghum* species.

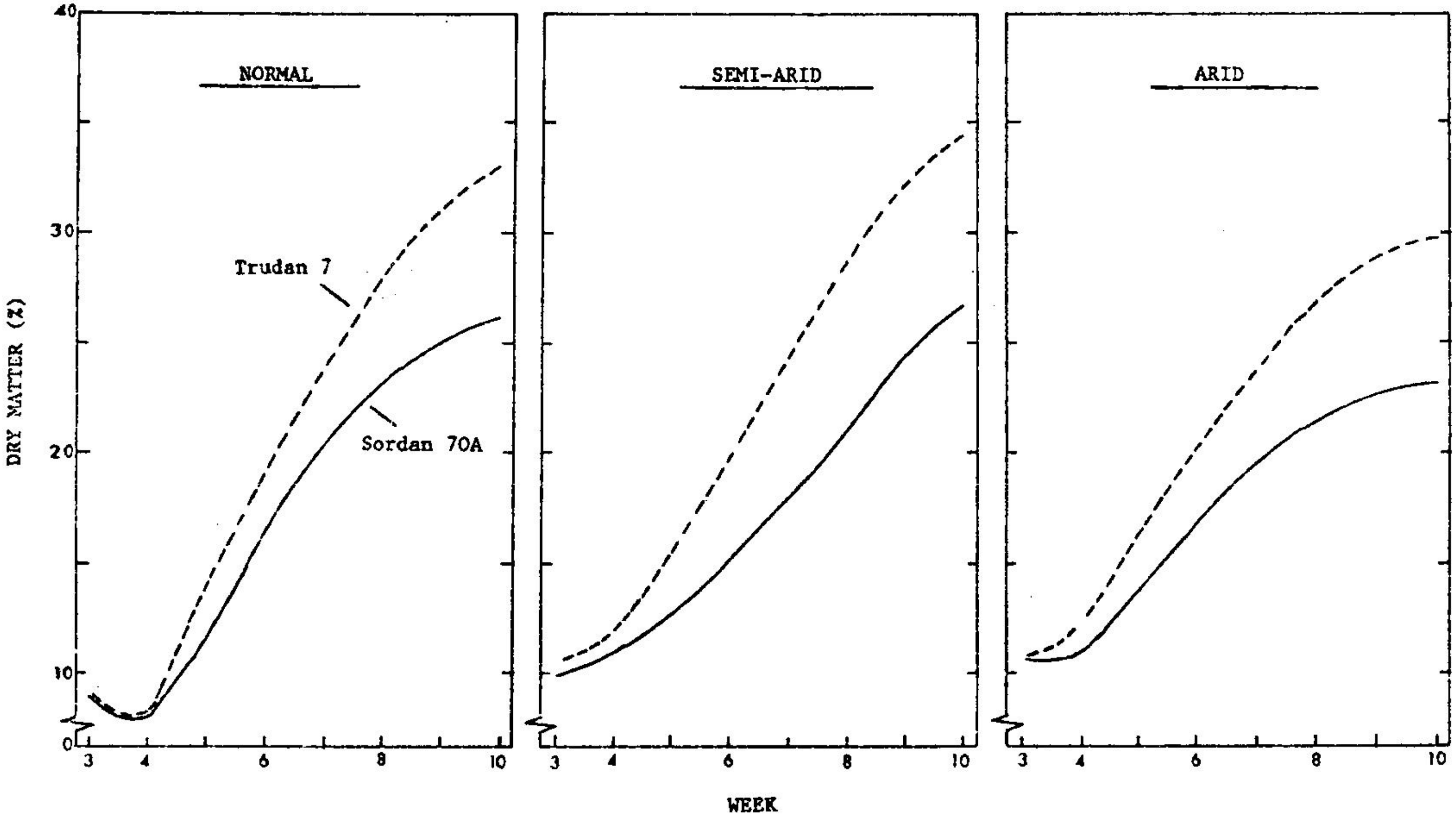

FIGURE 7. Dry matter accumulation in the Northrup-King hybrids Sordan 70A and Trudan 7. The plants were propagated with variable moisture regimes simulating normal, semi-arid, and arid conditions.

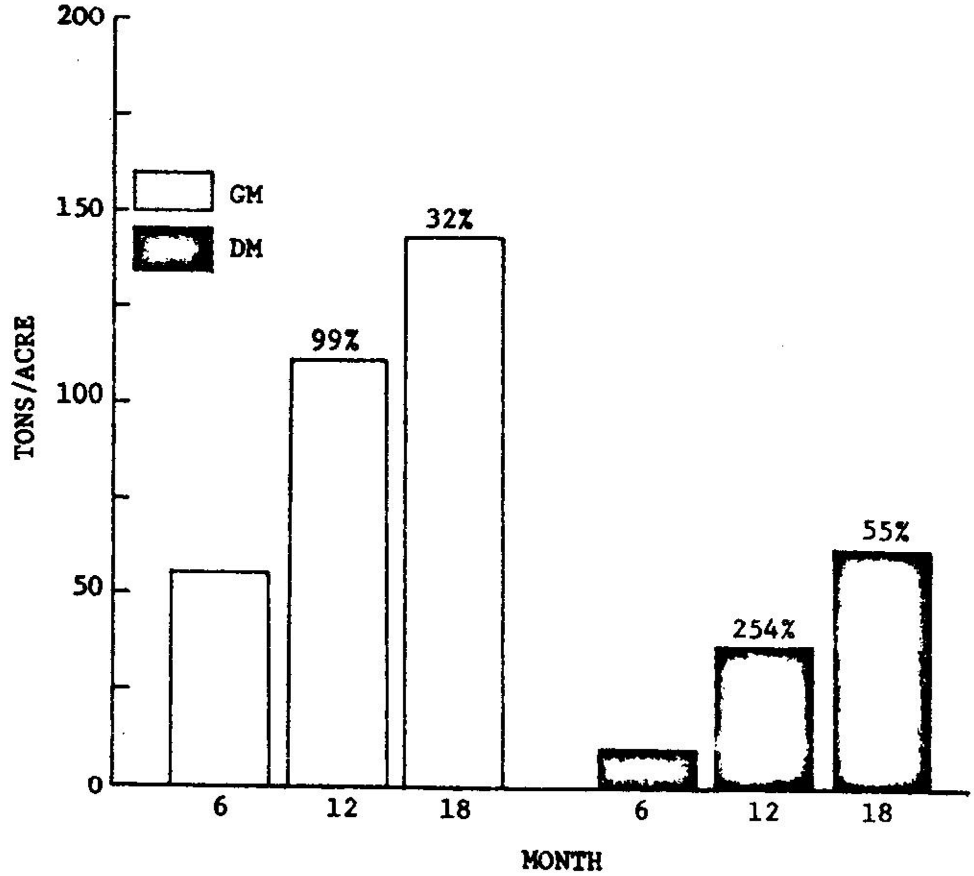

FIGURE 8. Relationship of 12-and 18-month harvests to green and dry matter production by second-generation energy cane. Percentage figures indicate the relative gain in yield over the previous harvest period (ie, DM yield at 18 months was 55% greater than at 12 months, while GM yield at 18 months was only 32% greater than at 12 months).

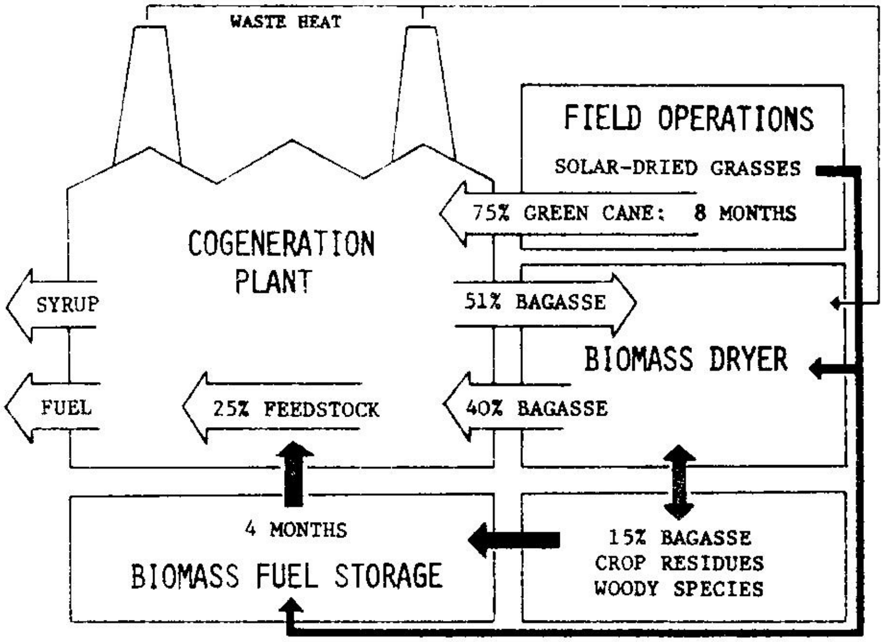

FIGURE 9. Integration Of Energy Cane And AGRI-FUEL Technologies For Year-Round Production Of High-Test Molasses (Syrup) And Fuel.

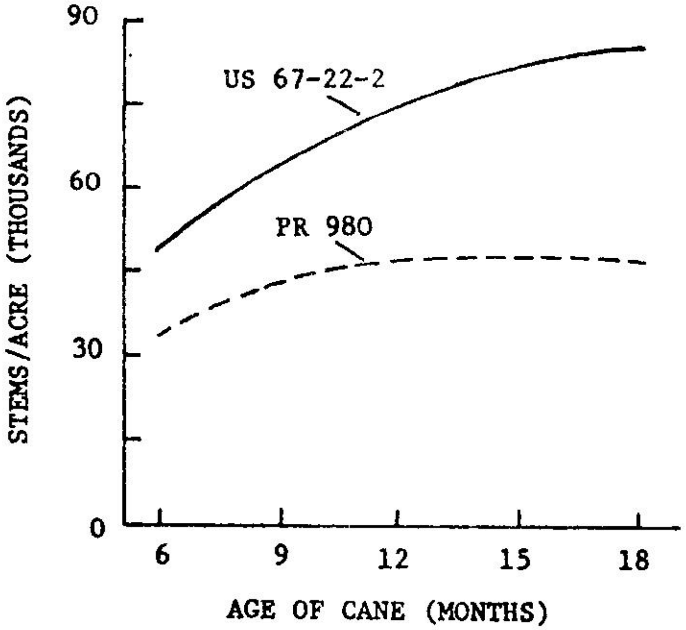

FIGURE 10. **Number of stems produced/acre by energy cane varieties PR 980 and US 67-22-2**

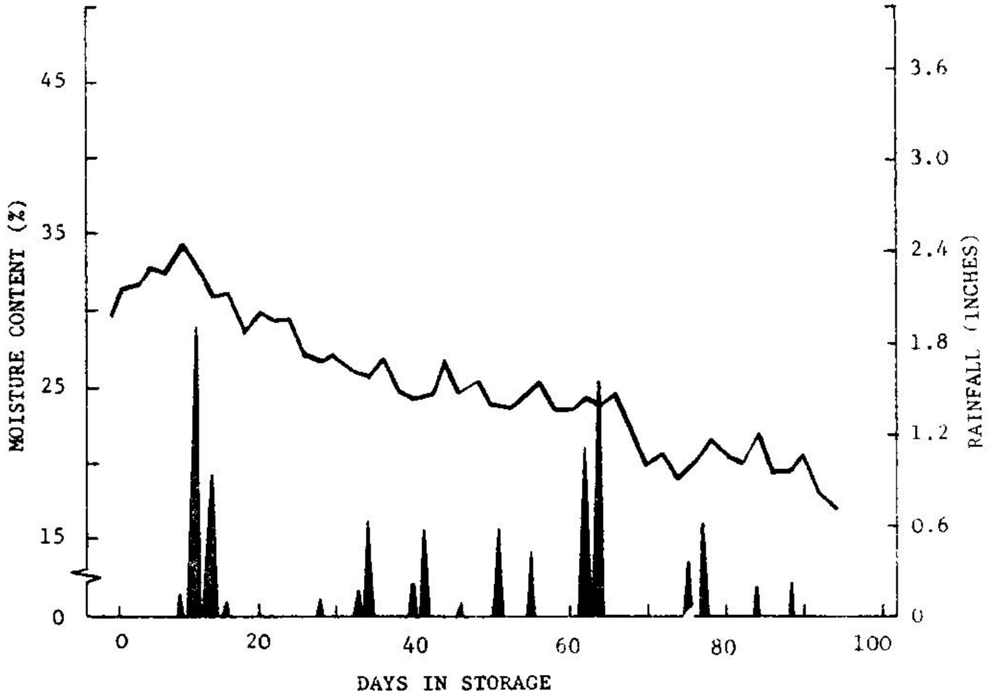

FIGURE 11. Moisture Content Changes For Mature Napier Grass Baled And Stored At Approximately 33% Moisture. Rainfall Data Are Also Indicated.

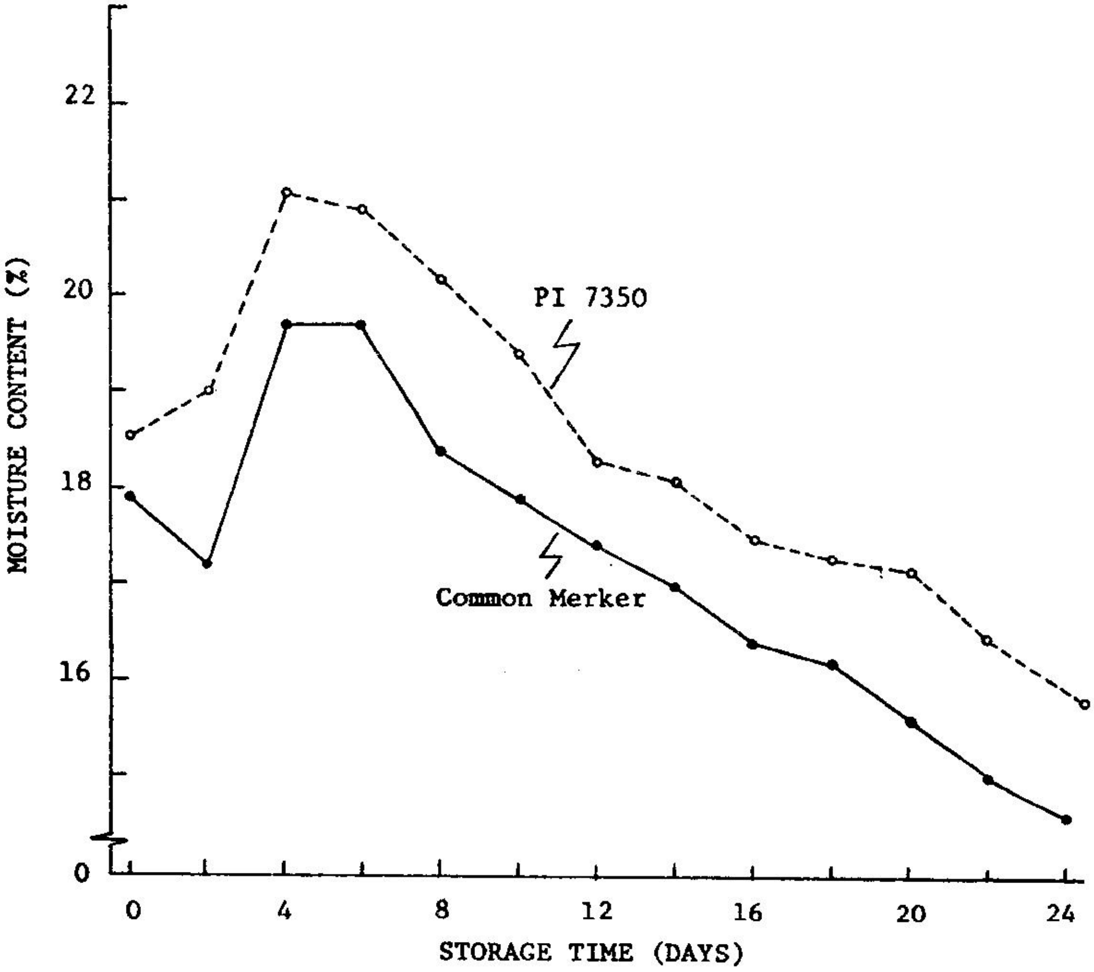

FIGURE 12. Moisture Loss From Two Varieties Of Napier Grass That Were Solar-Dried, Baled, And Stored In An Open-Sided Shed At Less Than 20% Moisture.

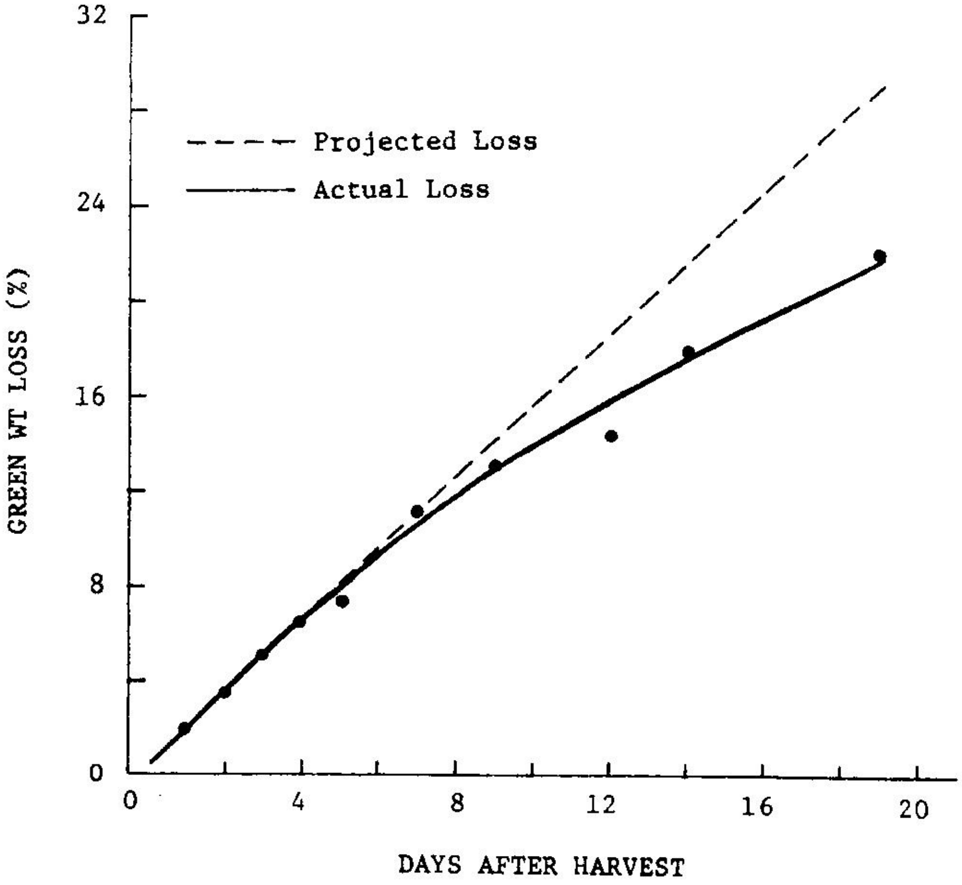

FIGURE 13. GREEN WEIGHT LOSS FOR HARVESTED WHOLE STEMS OF ENERGY CANE; 18 MONTH (GRAN CULTURA) HARVEST AT HATILLO.

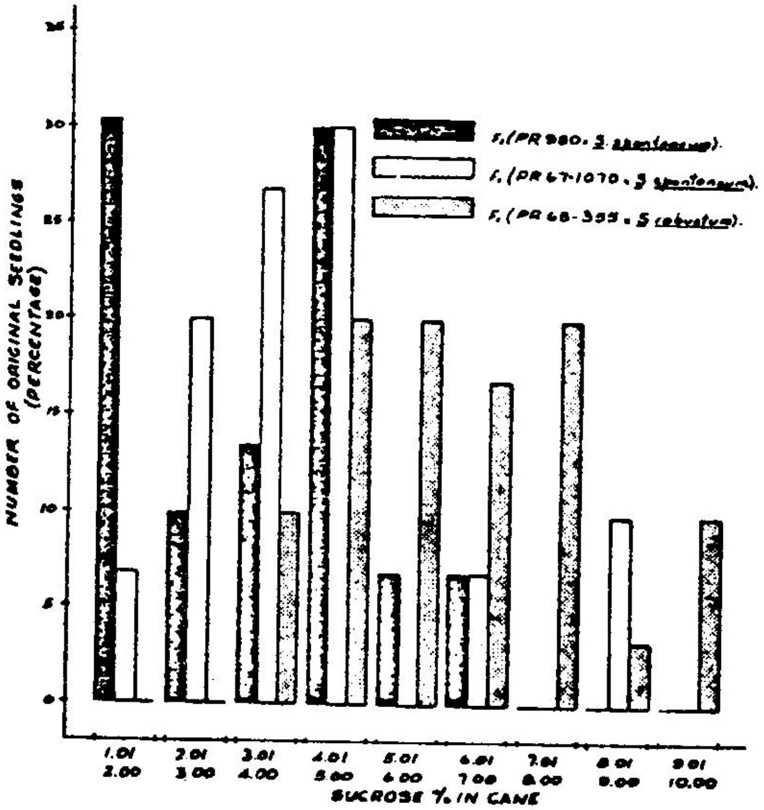

FIGURE 14. Frequency distribution for sucrose (%) in 30 F_1 hybrid progenies of each of 3 crosses: PR 980 x S. spontaneum RP, PR 67-1070 x S. spontaneum RP, and PR 68-355 x S. robustum 57-NG-54.

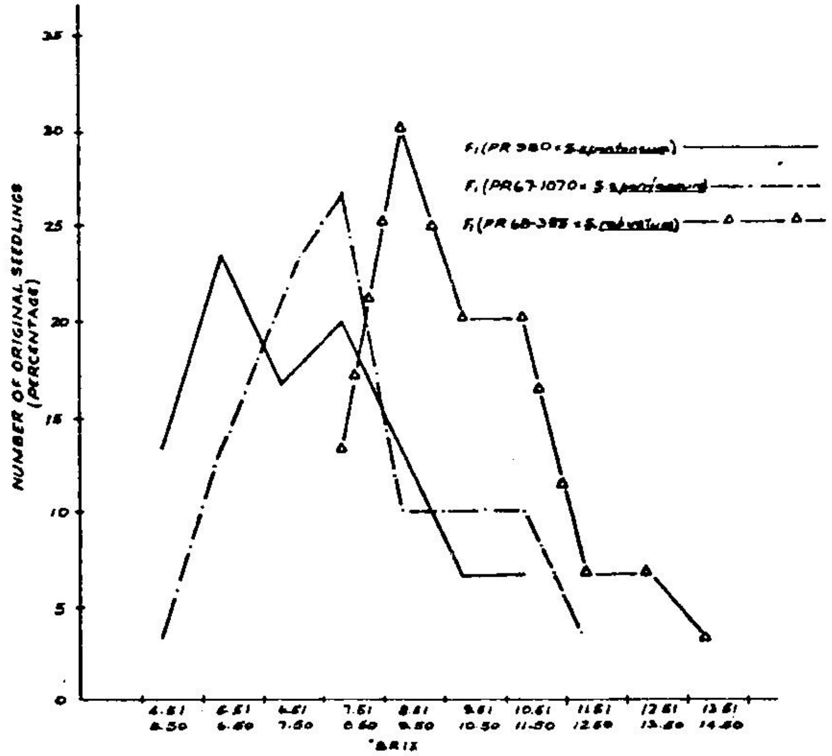

FIGURE 15. Frequency distribution for °Brix in 30 F_1 hybrid progenies of each of 3 crosses: PR 980 x S. spontaneum RP, PR 67-1070 x S. spontaneum RP, and PR 68-355 x S. robustum 57-NG-54.

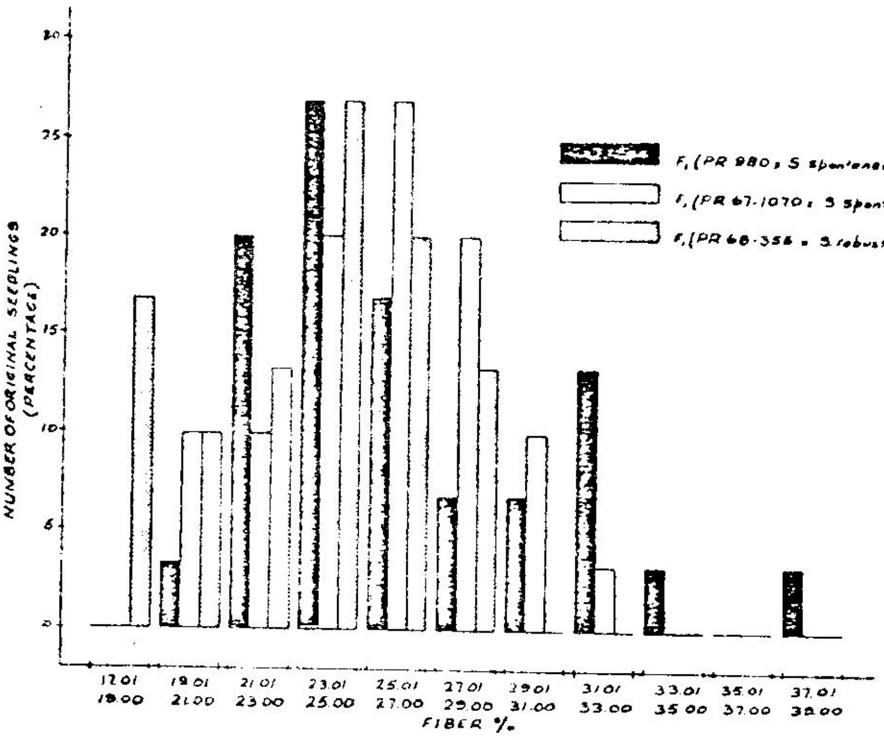

FIGURE 16. Frequency distribution for fiber (%) in 30 F_1 hybrid progenies of each of 3 crosses: PR 980 x S. spontaneum RP, PR 67-1070 x S. spontaneum RP, and PR 68-355 x S. robustum 57-NG-54.

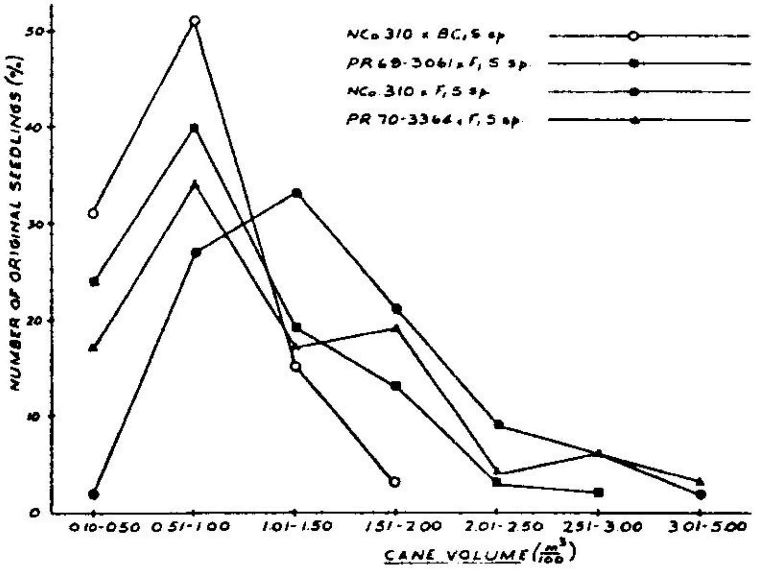

FIGURE 17. Frequency distribution for stalk volume in 100 hybrid progenies of each of 4 crosses: NCo 310 x F_1 S. sp.; NCo 310 x BC_1 S. sp.; PR 69-3061 x F_1 S. sp., and PR 70-3364 x F_1 S. sp.

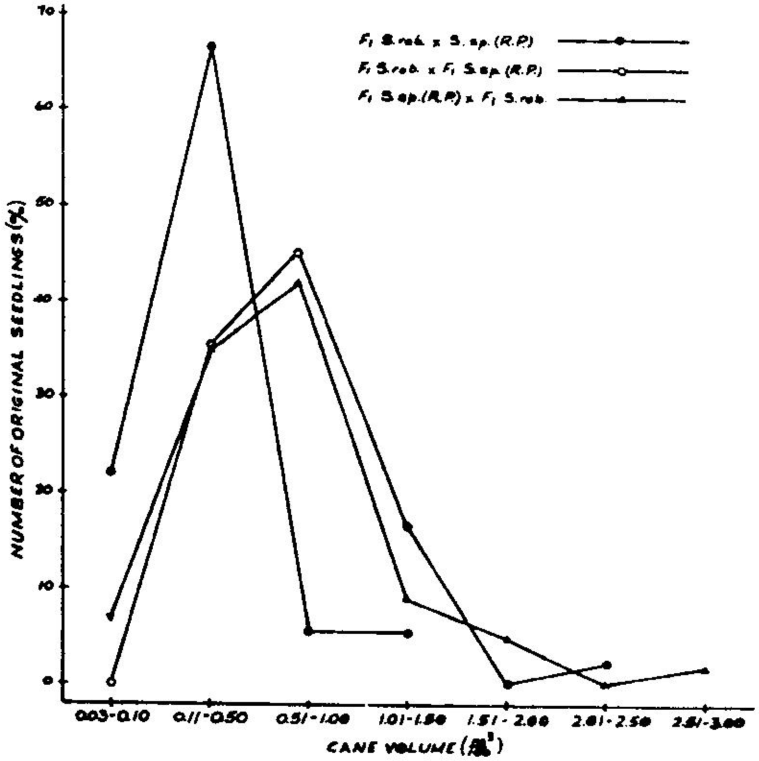

FIGURE 18. Frequency distribution for stalk volume in 100 hybrid progenies of each of 3 crosses: F_1 (PR 68-355 x 57-NG-54) x F_1 (PR 67-1070 x *S. sp.* RP); F_1 (PR 68-355 x 57-NG-54) x *S. sp.* RP; and F_1 (PR 67-1070 x *S. sp.* RP) x F_1 (PR 68-355 x 57-NG-54).

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*

		Total Growth (g/10 Plants)		
Genus	Clone	Green Wt.	Dry Wt.	% Moisture
<u>Saccharum</u>	PR 980	105	17.5	83.3
	POJ 2878	80	14.4	82.0
	Badilla	70	11.9	83.0
<u>Sorghum</u>	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

	Kg/Plot 1/ For Production Interval –			
Cultivar	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
AGR 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 Spray 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 71-22-1
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 [1]

Species	Clone	Dry Matter Yields (Kg/Plot) At Month –				Total Yields	
		4	6	8	10	Kg	% Of PR 980
Saccharum Hybrid	PR 980	17.1	2.5	2.2	1.1	22.9	100
	Saretha	11.3	2.7	3.3	1.4	18.7	81.6
	Chunnee	11.7	2.4	3.1	3.1	20.3	88.6
	Natal Uba	9.5	1.9	2.4	1.1	14.9	65.0
	Tainan	13.3	4.1	5.0	2.8	25.2	110.0
S. spontaneum	SES 231	8.8	5.2	7.2	5.8	27.0	117.9
	SES 317	10.9	- [2]	-	-	-	-
	SES 327	10.9	3.1	3.0	0.9	17.9	78.1
	US 67-22-2	18.5	4.7	5.2	3.6	32.0	139.7
	US 67-34-24	12.4	3.2	2.9	1.5	20.0	87.3
	US 72-97	12.5	4.4	5.3	2.9	25.1	109.6
	US 72-70	19.9	4.6	5.1	2.8	32.4	141.4
	US 72-72	12.4	4.0	4.0	2.6	23.0	100.4
	US 72-144	15.8	4.5	4.7	2.3	27.3	119.2
Erianthus maximus	NG 132	7.5	- [2]	-	-	-	-

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[1] Plot size = 1/200 acre.

[2] Clones not harvested at months 6, 8, and 10.

TABLE 15. TROPICAL GRASSES IMPORTED INTO PUERTO RICO FOR EVALUATION AS BIOMASS SOURCES FOR INTENSIVE AND EXTENSIVE PRODUCTION

Clone	Species	Planting Date	Remarks
28 NG 251	*S. robustum*	July 20, 1978	PI, From Beltsville
US 57-89-8	"	"	
51 NG 140	"	"	
SS 58-6	"	"	
Teboc Salak	"	"	No Germination
US 63-51	*S. spontaneum*	Sept. 30, 1978	PI, Canal Point
US 71-10-1	"	"	
US 71-10-2	"	"	
Elegans	"	"	
US 56-12-2	"	"	
SES 300	"	"	
US 57-2-2	"	"	
US 57-2-4	"	"	
SES 293-43	"	"	
SES 270	"	"	
SES 274	"	"	
SES 294	"	"	
SES 343	"	"	
SES 306	"	"	
Tabongo	"	"	
Taiwan	"	"	
UM 69-012	"	"	
SES 189	"	"	
SES 197 A	"	"	
SES 84-85	"	"	
SES 69	"	"	
India	"	"	
US 61-66-6	US 59-66-1 x *S. spontaneum*	"	
US 68-40-1	CP 52-68 x US 56-5-5	"	
US 55-1-9	? x Ripidium	"	
US 61-37-7	*R. kanashiroc* x *R. bengalense*	"	
US 64-37	*S. fusca* x *S. narenga*	"	
US 60-58	US 59-106-2 x US 57-182-2	"	
US 67-37-1	L 60-25 x *S. sinense*	"	
US 64-35	US 56-5-5 x *S. narenga*	"	
US 66-163-2	US 56-5-5 x US 65-106-1	"	
	(*S. fusca*) (*E. contortus*)	"	
US 66-157	US 56-5-5 x Mol. 4826	"	
	(*S. robustum*)	"	

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

Clone	Row Center (Centimeters)	Harvest Interval (Months)
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. MEAN DRY MATTER YIELD VS HARVEST INTERVAL

	TOT. DM (TONS/A/Yr) For --	
Interval	Cane 1/	Napier 2/
2 Months	3.7	11.4
4 Months	9.9	23.4
6 Months	16.2	27.5
12 Months	29.0	21.5

1/ Average of 3 varieties and 3 crop years.

2/ Average of one variety and 3 crop years.

TABLE 18. ENERGY CANE YIELDS BY PLANT AND RATOON CROPS

Harvest Interval	Tons DM/Acre Yr, For Crop [1] Plant	1st Rat.	2nd Rat.	Mean
2 Months	6.2	3.5	1.0	3.6
4 Months	11.1	11.9	6.6	9.9
6 Months	16.5	20.6	11.4	16.2
12 Months	25.5	33.6	27.8	29.0
Mean	14.8	17.4	11.7	14.6

[1] Average values for three varieties.

TABLE 19. MEAN ENERGY CANE YIELDS BY VARIABLE ROW SPACING [1]

Harvest Interval	Tons DM/Acre Yr, At Row Center –		
	150 cm	50 cm	% Spacing
2 Months	3.4	3.8	11.7
4 Months	9.5	9.9	4.2
6 Months	16.0	15.8	-1.2
12 Months	29.6	28.4	-4.0
Mean	14.6	14.5	-0.6

[1] Average of 3 varieties and 3 crop years.

TABLE 20. MEAN TRASH YIELDS FOR CANE AND NAPIER GRASS [1]

Species	Variety	Tons/Acre, At Row Center — 150 cm	50 cm	% Change
Cane	PR 980	6.91	6.69	- 3.1
	NCo 310	4.25	5.17	21.6
	PR 64-1791	4.48	5.03	12.2
Mean		5.21	5.63	
Napier	Merker	3.24	3.15	- 2.7

[1] Average of 3 crop years.

TABLE 21. SEASONAL INFLUENCE ON DRY MATTER YIELD BY THREE CROPS OF SUGARCANE; 2-MONTH HARVESTS

Period	% Of Crop's Total Yield, For Crop —			
	Plant	1st Ratoon	2nd Ratoon	Mean
July 15—Sept. 15	6.1	30.3	29.8	22.1
Sept. 15—Nov. 15	18.4	21.2	20.2	19.9
Nov. 15—Jan. 15	18.4	18.1	10.0	15.5
Jan. 15—Mar. 15	12.3	6.0	9.9	9.4
Mar. 15—May 15	26.1	15.1	20.0	20.4
May 15—July 15	18.4	10.0	10.0	12.8

TABLE 22. SEASONAL INFLUENCE ON DRY MATTER YIELD BY THREE CROPS OF NAPIER GRASS; 2-MONTH HARVESTS

Period	% Of Crop's Total Yield, For Crop —			
	Plant	1st Ratoon	2nd Ratoon	Mean
July 15—Sept. 15	16.5	20.1	21.0	19.2
Sept. 15—Nov. 15	11.0	21.8	13.6	15.5
Nov. 15—Jan. 15	23.6	15.9	14.7	18.1
Jan. 15—Mar. 15	7.0	7.5	13.6	9.3
Mar. 15—May 15	31.4	21.8	25.2	26.1
May 15—July 15	10.2	12.6	11.5	11.4

TABLE 23. SEASONAL INFLUENCE ON DRY MATTER YIELDS BY THREE CROPS OF SUGARCANE AND NAPIER GRASS; 4-MONTH HARVESTS

	Sugarcane			
	% Of Crop's Total Yield, For Crop —			
Period	Plant	1st Ratoon	2nd Ratoon	Mean
July 15 — Nov. 15	30.6	47.1	46.8	41.5
Nov. 15 — Mar. 15	32.4	14.2	21.8	22.8
Mar. 15 — July 15	36.9	38.6	31.2	35.6
	Napier Grass			
July 15 — Nov. 15	25.2	38.6	34.3	32.7
Nov. 15 — Mar. 15	37.1	21.9	23.6	27.5
Mar. 15 — July 15	37.6	39.4	41.9	39.6

TABLE 24. JUICE QUALITY VALUES FOR THREE SUGARCANE VARIETIES PROPAGATED WITH STANDARD AND NARROW ROW SPACING; SECOND RATOON CROP

	Brix Values, At Row Center —		
Variety	150 cm	50 cm	% Change
PR 980	10.92	10.60	- 2.9
NCo 310	11.64	11.92	2.4
PR 64-1791	10.34	11.20	8.3
	Polarization		
PR 980	8.81	9.35	6.1
NCo 310	8.90	8.75	- 2.0
PR 64-1791	9.73	8.83	9.2
	Fiber		
PR 980	17.07	16.94	- 0.7
NCo 310	16.30	15.68	- 3.8
PR 64-1791	16.42	16.05	- 2.2
	Purity		
PR 980	79.94	87.45	9.3
NCo 310	76.15	72.62	- 4.6
PR 64-1791	93.28	78.06	-16.3
	Rendement (% Sucrose)		
PR 980	6.89	7.77	12.7
NCo 310	6.75	6.42	- 4.8
PR 64-1791	8.45	6.86	-18.8
	Tons Sucrose/Acre (TSA)		
PR 980	5.22	5.56	6.5
NCo 310	6.21	5.79	- 6.7
PR 64-1791	7.10	5.78	-18.5

TABLE 25. TONS SUCROSE PER ACRE (TSA) FOR THREE SUGARCANE VARIETIES PROPAGATED AT STANDARD AND NARROW ROW SPACING; SECOND RATOON CROP; 12-MONTH HARVEST

	TSA, At Row Spacing –		
Variety	150 cm	50 cm	**% Change**
PR 980	5.22	5.56	6.5
NCo 310	6.21	5.79	- 6.7
PR 64-1791	7.10	5.78	-18.5
Mean	6.18	5.71	- 7.6

TABLE 26. PRELIMINARY COST ANALYSIS FOR TOTAL DRY MATTER PRODUCTION BY FIRST-RATOON SUGARCANE MANAGED AS AN ENERGY CROP

LAND AREA: 200 Acres
PRODUCTION INTERVAL: 12 Months
DRY MATTER YIELD: 33 OD Tons/Acre; Total 6600 Tons*

Preliminary Cost Analysis

Item		Cost ($/Year)
1.	Land Rental, at 50.00/Acre	10,000
2.	Seedbed Preparation, at 15.00/Acre	3,000
3.	Water (800 Acre Feet at 15.00/ft)	12,000
4.	Water application, at 48.00/Acre Year	9,600
5.	Seed (For Plant Crop Plus Two Ratoon Crops), 1 Ton/Acre Year at 15.00/Ton	3,000
6.	Fertilizer, at 180.00/Acre	36,000
7.	Pesticides, at 26.50/Acre	5,300
8.	Harvest, Indluding Equipment Charges, Equipment Depreciation, And Labor	20,000
9.	Day Labor, 1 Man Year (2016 hrs at 3.00/hr) 1/	6,048
10.	Cultivation, at 5.00/Acre	1,000
11.	Land Preparation & Maintenance (Pre-& Post-Harvest)	600
12.	Delivery, at 7.00/Ton/3 miles of Haul	46,200
13.	Subtotal:	152,748
14.	Management: 10% of Subtotal	15,275
15.	Total Cost:	168,023

1/ Labor which is not included in other costs

Total Cost/Ton: (168,023 ÷ 6600): 25.46
Total Cost/Million BTUs: (25.46 ÷ 15) = 1.70

* One ton of this dry matter would contain approximately 800 pounds of fermentable solids. At 80% extraction this represents 640 pounds of fermentable solids, equal to about 61 gallons of high-test molasses.

TABLE 27. PRELIMINARY COST ANALYSIS FOR ENERGY CANE vs CONVENTIONAL SUGARCANE PRODUCTION IN PUERTO RICO (1979 DOLLARS).

Analysis For A Privately Owned 200 Acre Operation 1/

	Estimated Cost ($/Year) For--		
Item	Sugarcane	Energy Cane	% Increase
1. Land Rental, at 50.00/Acre	10,000	10,000	0
2. Seedbed Preparation	2,000	3,000	50
3. Water, at 15.00/Acre Foot	12,000	12,000	0
4. Water application, at 48.00/Acre Year	9,600	9,600	0
5. Seed (For Plant Crop Plus Two Ratoon Crops)	1,500	3,000	100
6. Fertilizer	18,000	36,000	100
7. Pesticides, at 26.50/Acre	5,300	5,300	0
8. Harvest, Including Equipment Charges, Equipment Depreciation, And Labor	12,000	20,000	67
9. Day Labor, at 3.00/hr 2/	6,048	6,048	0
10. Cultivation, at 5.00/Acre	1,000	1,000	0
11. Land Preparation & Maintenance (Pre-& Post-Harvest)	600	600	0
12. Delivery, For 3 Miles of Haul	27,720	46,200	67
13. Subtotal:	105,768	152,748	44
14. Management: 10% of Subtotal	10,577	15,275	44
15. Total Cost:	116,345	168,023	44

1/ Yield (O.D. Tons/Acre Year): Sugarcane, 9.0; Energy Cane, 33.0

2/ Labor which is not included in other costs.

Total Cost/O.D. Ton: Sugarcane, $64.64
Energy Cane, 25.46

Total Cost/Million BTUs: Sugarcane, 4.31
Energy Cane, 1.70

TABLE 28. MEAN ANNUAL ENERGY INPUTS FOR FIRST-GENERATION ENERGY CANE PRODUCTION IN PUERTO RICO

Input	Unit	Units/Acre 1/	Energy/Unit 2/		Energy/Acre	
			BTU	Kcal	mmBTU/Acre	m Kcal/Ha
Fertilizer						
Nitrogen	lb	400	33,333	8,400	13.33	8,302
Phosphorus	lb	100	6,032	6,032	0.60	376
Potassium	lb	200	4,167	1,050	0.83	519
Sub-Total					14.76	9,197
Fuel (Distillate)	gal	64.00	138,690	34,950	8.86	5,527
Herbicides	lb	10.60	43,651	11,000	0.46	288
Insecticides	lb	2.25	43,651	11,000	0.10	61
Labor	hr	25.00	2,159	544	0.05	34
Machinery					3.37	2,101
Seed	lb	2,000	2,410	607	0.44	274
Total					28.04	17,482

1/ Alexander, et al (25, 46).

2/ Adapted from Warren, et al (47).

TABLE 29. ENERGY INPUT AND RECOVERY FROM ENERGY CANE PRODUCTION [1]

	Annual Energy Involvement		
Parameter	mm BTU/Acre	mm KCal/Ha	Bbl Oil/ha
Output [2]	279.12	173.80	44.40
Input	28.04	17.48	4.46
Balance	251.08	156.32	40.94
Output/Input	9.95	9.95	9.95

[1] Based on an annual dry matter yield of 33 OD tons/acre, less 640 lbs/OD ton as extracted fermentable solids.

[2] Steam recovery basis. Assumes alternate source of steam is an electric utility boiler having 85% efficiency using no. 6 fuel oil, and with 6.287 mm BTU/bbl of oil.

TABLE 30. TREATMENTS AND HARVEST DATES FOR THE SECOND GENERATION ENERGY CANE STUDY AT AES-UPR LAJAS SUBSTATION

Variety	Elemental N (lbs/Acre Yr)	Harvest Date, At Interval 1/		
		6 Months	12 Months	18 Months
PR 980	200	Feb. 1, 1981	Aug. 1, 1981	Feb. 1, 1982
	400	"	"	"
	600	"	"	"
US 67-22-2	200	"	"	"
	400	"	"	"
	600	"	"	"
B 70-701	200	"	"	"
	400	"	"	"
	600	"	"	"

1/ For Plant crop only.

TABLE 31. WHOLE CANE YIELDS FOR THREE VARIETIES RECEIVING VARIABLE N SUPPLY; 12 MONTH HARVEST; PLANT CROP

Variety	N Supply [1/] (Lbs/Acre Yr)	Tons/Acre, For – Millable Stems	Tops	Attached Trash	Detached Trash	Total
PR 980	200	98.5	10.1	2.3	7.9	118.8
	400	100.1	8.6	2.8	8.2	119.7
	600	94.9	11.1	3.9	8.2	118.1
	Mean	97.8	9.9	3.0	8.1	118.8
US 67-22-2	200	96.6	9.1	4.1	7.0	116.8
	400	101.3	13.4	6.7	8.9	130.3
	600	98.9	12.3	7.2	8.1	126.5
	Mean	98.9	11.6	6.0	8.0	124.5
B 70-701	200	88.6	8.1	2.6	7.9	107.2
	400	91.7	11.8	3.5	8.7	115.7
	600	88.2	12.0	3.2	9.3	112.7
	Mean	89.5	10.6	3.1	8.6	111.8

[1/] Applied in 4 increments at intervals of 3 months. The first increment was applied as a band beneath the seedpiece at planting. The N source was ammonium sulfate in a 16-4-8 fertilizer ratio.

TABLE 32. GREEN MATTER YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED AT 12-AND 18-MONTHS AFTER PLANTING; PLANT CROP

Variety 2/	Tot. GM (Tons/A), At — 1/			
	12 Months	18 Months	Tons Increase	% Increase
PR 980	110.7	135.7	25.0	22.6
US 67-22-2	116.5	164.4	47.9	41.1
B 70-701	103.1	135.1	31.9	30.9
Mean	110.1	145.1	34.9	31.6
	Millable Stems (Tons/A)			
PR 980	97.8	118.2	20.4	20.9
US 67-22-2	98.9	137.1	38.2	38.2
B 70-701	89.5	110.6	21.1	23.6
Mean	95.4	122.0	26.6	27.8
	Tops (Tons/A)			
PR 980	9.9	13.7	3.8	38.4
US 67-22-2	11.6	21.8	10.2	87.9
B 70-701	10.6	20.7	10.1	95.3
Mean	10.7	18.7	8.0	74.0
	Trash (Tons/A) 1/			
PR 980	11.1	23.3	12.2	109.9
US 67-22-2	14.0	26.9	12.9	92.1
B 70-701	11.7	21.1	9.5	81.2
Mean	12.3	23.8	11.5	94.4

1/ Excluding detached trash.

2/ Each figure is the computed mean of 4 replications and 3 N regimes.

3/ Includes both attached and detached trash.

TABLE 33. GM YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6-AND 18-MONTH INTERVALS; PLANT CROP

	GM Yield (Tons/A), At Month — 1/			
Variety	6	12	18	Total
PR 980	51.6	66.6	49.3	167.5
US 67-22-2	60.8	74.0	51.5	186.2
B 70-701	53.8	61.3	47.0	162.2
Mean	55.4	67.3	49.3	172.0
PR 980			135.8	135.8
US 67-22-2			164.5	164.5
B 70-701			135.1	135.1
Mean			145.1	145.1

1/ Includes millable stems, tops, and attached trash, but does not include detached trash.

TABLE 34. MILLABLE CANE YIELD FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6-AND 18-MONTH INTERVALS; PLANT CROP

	Millable Cane (T/A), At Month –			
Variety	6	12	18	Total
PR 980	34.9	49.0	33.5	117.4
US 67-22-2	33.8	51.4	32.5	117.7
B 70-701	33.4	41.7	32.5	107.2
Mean	34.0	47.4	32.7	114.1
PR 980			118.2	118.2
US 67-22-2			137.1	137.1
B 70-701			110.6	110.9
Mean			122.0	122.0

1/ Each figure is the computed mean of four replicates and three N regimes.

TABLE 35. TOTAL DRY MATTER YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6-AND 18-MONTH INTERVALS; PLANT CROP

	DM Yield (Tons/A), At Month — 1/			
Variety	6	12	18	Total
PR 980	9.8	13.2	13.1	36.1
US 67-22-2	11.4	15.8	15.1	42.3
B 70-701	10.8	14.7	14.7	40.2
Mean	10.7	14.6	14.3	39.5
PR 980			54.1	54.1
US 67-22-2			65.7	65.7
B 70-701			58.8	58.8
Mean			59.5	59.5

1/ Each figure is the computed mean of four replicates and three N regimes.

TABLE 36. DRY MATTER PRODUCTION BY THREE ENERGY CANE VARIETIES PROPAGATED WITH VARIABLE N SUPPLY; PLANT CROP, 18 MONTHS

Variety	N Supply (Lbs/Acre Yr)	Short Tons/Acre, For –				
		Tot. GM 1/	DM 1/	Det. Trash	Tot. DM 2/	% DM
PR 980	200	134.6	34.1	18.7	52.8	25.3
	400	138.8	35.8	19.2	55.0	25.8
	600	133.9	34.0	20.5	54.5	25.4
	Mean	135.8	34.6	19.5	54.1	25.5
US 67-22-2	200	153.7	42.0	19.5	61.5	27.3
	400	170.6	44.7	21.9	66.6	26.2
	600	167.8	46.3	22.8	69.1	27.6
	Mean	164.0	44.3	21.4	65.7	27.0
B 70-701	200	136.1	45.7	15.4	61.1	33.6
	400	134.9	39.9	16.7	56.6	29.6
	600	134.0	38.6	20.0	58.6	28.8
	Mean	135.0	41.4	17.4	58.8	30.7

1/ Excluding detached trash. 2/ Including detached trash.

TABLE 37. DRY MATTER YIELDS FOR THREE VARIETIES HARVESTED AT 12-AND 18-MONTHS INTERVALS; PLANT CROP

	Tot. DM (Tons/A), At —[1]			
Variety	12 Months	18 Months	Tons Increase	% Increase
PR 980	36.6	54.1	17.5	47.8
US 67-22-2	41.9	65.7	23.8	56.8
B 70-701	37.2	58.8	21.6	58.1
Mean	38.6	59.5	20.9	54.1

[1] Includes detached trash.

TABLE 38. TRASH YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6-AND 18-MONTHS; PLANT CROP

Variety	Trash (Tons/Acre), At Month — [1]			Total
	6	12	18	
PR 980	4.0	7.3	5.3	16.6
US 67-22-2	4.1	8.9	6.1	19.1
B 70-701	3.7	6.2	5.8	15.7
Mean	3.9	7.5	5.7	17.1
PR 980			23.3	23.3
US 67-22-2			26.9	26.9
B 70-701			21.2	21.2
Mean			23.8	23.8

[1] Each figure is the computed mean of four replicates and three N regimes, and includes both attached and detached trash.

TABLE 39. MEAN JUICE QUALITY AND SUGAR YIELD VALUES FOR THREE ENERGY CANE VARIETIES HARVESTED AT 12-AND 18-MONTH INTERVALS: PLANT CROP

Variety[1]	Harvest (Month)	Juice Quality Parameter –					TCA[2]	TSA
		Pol	Brix	Fiber	Purity	Rend.		
PR 980	12	11.2	12.4	16.3	88.7	9.6	97.8	9.4
	18	11.3	12.8	13.7	87.3	9.7	118.2	11.5
US 67-22-2	12	10.6	13.4	16.1	79.7	8.6	98.9	8.5
	18	10.2	12.8	13.9	79.1	8.6	137.1	11.7
B 70-701	12	5.6	7.9	20.6	70.7	3.6	89.5	3.2
	18	4.3	7.2	18.2	57.5	2.5	110.6	2.7
Grand Mean	12	9.1	11.2	17.7	79.7	7.3	95.4	7.0
	18	8.6	10.9	15.3	74.6	6.9	122.0	8.6

[1] Each figure is the computed mean of 3 nitrogen regimes. [2] Millable stems.

TABLE 40. MEAN BIOMASS YIELDS FOR FIRST AND SECOND GENERATION ENERGY CANE; PLANT CROP, 12-MONTH HARVEST

Generation	Tot. Biomass Yield (Tons/Acre Yr) Green [3]	 Dry	 Detached Trash	% DM	Stems/Acre (Thousands)
First [1]	74.8	25.6	4.4	28.3	65.5
Second [2]	110.1	38.6	8.2	27.5	60.9
Difference	35.3	13.0	3.8	-2.6	-4.6
% Change	47.1	50.7	86.3	-8.6	-7.0

[1] First generation figures are the computed mean for three varieties and two row spacings; plant crop only.

[2] Second generation figures are the computed mean for three varieties and three N regimes; plant crop only.

[3] Includes tops and attached trash but not detached trash.

TABLE 41. MEAN SUGAR YIELDS FOR FIRST-AND SECOND-GENERATION ENERGY CANE; PLANT CROPS

Generation	Average Annual Yield, For —		
	TCA	Rendiment	TSA
First (12 Months) 1/	74.8	6.0	4.5
Second (12 Months) 2/	95.4	7.3	7.0
Second (18 Months) 2/	122.0	6.9	8.6

1/ Each figure is the computed mean for three varieties (PR 980, NCO 310, and PR 64-1791) and two row spacings (50 and 150 cm).

2/ Each figure is the computed mean for three varieties (PR 980, US 67-22-2, and B 70-701) and three N levels (200, 400, and 600 lbs elemental N/acre year).

TABLE 42. PRODUCTION INPUTS AND COSTS FOR ENERGY CANE; 1980 AND 1982 1/

Input	Cost ($US/Year) 2/ First Generation	Cost ($US/Year) 2/ Second Generation	% Change Since 1980
Land Rental	10,000	10,000	0
Seedbed preparation	3,000	3,900	+30
Water	12,000	12,000	0
Water application	9,600	10,752	+12
Seed	3,000	3,000	0
Fertilizer	36,000	44,640	+24
Pesticides	5,300	6,572	+24
Harvest operations 3/	20,000	24,800	+24
Day labor 4/	6,048	6,754	+10
Cultivation	1,000	1,240	+24
Land rennovation	600	660	+10
Delivery	46,200	65,825	+24
Subtotal:	152,746	190,144	+24.4
Management	15,270	15,270	0
Total Cost	168,023	205,356	+22.2
Cost/acre	840.15	1,027.00	+22.2
Cost/Ton	10.12	9.33	-7.8

1/ Includes millable stems, tops, and attached trash, but excludes detached trash.

2/ Assumes a planted area of 200 acres, privately owned.

3/ Includes equipment charges, equipment depreciation, and labor.

4/ Labor not included in other costs.

TABLE 43. ANNUAL ENERGY INPUTS FOR PRODUCTION OF SECOND-GENERATION ENERGY CANE; PLANT CROP, 12 MONTHS, AVE. OF THREE VARIETIES

	Input Parameters			
Input	**Unit**	Units/Acre	BTUs/Unit	BTUs/Acre
Fertilizer				
N	**Lb**	400	33,333	13.33
P_2O_5	**Lb**	100	6,032	0.60
K_2O	**Lb**	200	4,167	0.83
Fertilizer Subtotal	-	700	43,532	14.76
Fuel (Diesel)	Gal	71	138,690	9.85
Pesticides	**Lb**	13	43,652	0.57
Labor	**Hr**	25	2,159	0.05
Machinery	-	-	-	3.71
Seed	**Lb**	183	2,410	0.44
Total	-	992	230,443	29.38

TABLE 44. ENERGY YIELDS FROM FIRST AND SECOND-GENERATION ENERGY CANE; PLANT CROPS

	BTUs/Acre Yr (x 10^6)		
Generation	Bagasse	Trash	Total
First	231	55	286
Second	336	117	453
% Change	45	111	58

TABLE 45. NET ENERGY BALANCES FOR PRODUCTION OF THREE SECOND-GENERATION ENERGY CANES; PLANT CROP, 12 MONTHS

	BTUs/Acre (x 10^6)			
Variety	Output	Input	**Balance**	**Ratio** (Output/Input)
PR 980	404.1	29.4	374.7	13.7
US 67-22-2	470.3	29.4	440.9	16.0
B 70-701	483.8	29.4	454.4	16.5
Mean	452.5	29.4	423.1	15.4

TABLE 46. ENERGY BALANCE AS A FUNCTION OF N SUPPLY; PLANT CROP

Lbs N/Acre	Energy Balance [1/] (Output/Input)
200	19.7
400	15.4
600	12.5

[1/] Mean of three varieties.

TABLE 47. ESTIMATED VALUES FOR HIGH-TEST MOLASSES AND FIBER FROM THREE ENERGY CANE VARIETIES PROPAGATED WITH VARIABLE NITROGEN; PLANT CROP, 12-MONTH HARVEST

		Yield/Acre Year		Value/Acre ($US)		
Variety	(Lbs/Acre Yr)	Tons DM 2/	Gal. HTM 3/	HTM 4/	Fiber 5/	Total
PR 980	200	34.9	2,133	1,621	1,841	3,462
	400	37.1	2,167	1,647	2,001	3,648
	600	37.7	2,208	1,678	2,029	3,707
	Mean	36.6	2,169	1,649	1,957	3,606
US 67-22-2	200	36.6	2,230	1,695	1,934	3,629
	400	42.2	2,556	1,943	2,235	4,178
	600	38.1	2,354	1,789	1,994	3,783
	Mean	39.0	2,380	1,809	2,054	3,863
B 70-701	200	33.4	1,237	940	2,123	3,063
	400	34.8	1,198	910	2,249	3,159
	600	35.6	1,357	1,032	2,243	3,275
	Mean	34.6	1,264	961	2,205	3,166

1/ Applied in 6 increments at intervals of 3 months. The first increment was applied as a band beneath the seedpiece at planting. The N source was ammonium sulfate in a 16-4-8 fertilizer ratio.

2/ Tons DM = tons Brix plus tons fiber (including tops and attached trash).

3/ Gal. HTM = (tons Brix) (0.85 recovery) (2000 Lbs/ton) ÷ 9.5 Lbs F.S./gal HTM.

4/ At $0.76/gal HTM

5/ At $80.00/OD Ton (4¢/OD lb).

TABLE 48. PERFORMANCE EVALUATIONS FOR THE M-C ROTARY SCYTHE OPERATING ON SORDAN 70A PLANTS OF VARYING MATURITY AND DEGREE OF LODGING

Crop Age (Weeks)	Estimated Crop Mass		Rotary Scythe Rating, At Lodging Status –							
	Tons/Acre	% DM	CU [1/]	NS	LL	ML	SL	LM	LMW	Mean
6	8-10	10	1 [2/]	1	1	1	1	1	1	1.00
10	16-20	24	1	1	1	1	1	1	2	1.14
14	20-24	30	1	1	1	1	1	2	2	1.29

1/ Abbreviations:
CU (Completely Upright)
NS (Normal Stand)
LL (Lightly Lodged)
ML (Moderately Lodged)
SL (Severely Lodged)
LM (Severely Lodged & Matted)
LMW (Severely Lodged, Matted, & Intermixed With Weeds)

2/ Equipment rating scale: 1 = Normal performance, operating as designed; 5 = faulty performance, unable to operate as designed.

TABLE 49. PRELIMINARY PERFORMANCE EVALUATIONS FOR THE M-C ROTARY SCYTHE-CONDITIONER OPERATING IN STANDS OF TWO NAPIER GRASS VARIETIES AGED SIX MONTHS

	Estimated Crop Mass		Equipment Operation		Performance Rating 1,2/						
Variety	Tons/acre	% DM	Tractor Gear (1900 rpm)	Mowing Height (in.)	Clean Cutting	Even Stubble	Conditioning	Plant Resistance	Crown Injury	Ratoon Regrowth	Total Rating
Merker	45-50	23-50	1	6-8	2.5	2.5	2.5	1.0	1.0	2.0	10.5
				2-3	1.0	1.5	1.0	1.0	2.0	1.0	7.5
			2	6-8	3.5	4.0	4.0	4.0	1.0	2.0	18.5
				2-3	2.5	2.5	3.0	3.0	2.0	1.0	14.0
PI 7350		40-45	1	6-8	1.5	1.5	1.5	1.0	1.0	2.5	9.0
				2-3	1.0	1.0	1.0	1.0	2.0	1.0	7.0
			2	6-8	3.5	4.0	4.0	4.0	1.0	2.5	19.0
				2-3	1.0	1.0	1.0	2.0	2.0	1.0	8.0

1/ **Implement rating:** 1 = Normal performance, operating as designed; 5 = faulty performance, unable to operate as designed.

2/ **Plant rating:** 1 = No apparent injury; 5 = severe injury.

TABLE 50. DRY MATTER YIELD FROM NAPIER GRASS FIELD PLOTS MECHANICALLY-HARVESTED AT 6 MONTHS OF AGE; FIRST-RATOON CROP.

Plot No.	Rotary Scythe Mowing Height (in.)	Area (Acres)	DM Yield [1] (Tons/Acre)	Crown [2] Damage
1	8-10	0.69	7.98	Nil
2	8-10	0.69	8.77	Nil
3	1-2	0.69	11.67	Nil
4	1-2	0.69	8.80	Nil

[1] Excluding approximately 20% of the total DM in the form of unraked residues. This material could not be windrowed with the available forage rake.

[2] Observations based on subsequent production of new shoots.

TABLE 51. PRELIMINARY PERFORMANCE EVALUATIONS FOR THE M-C ROTARY SCYTHE-CONDITIONER OPERATING AT TWO CUTTING HEIGHTS IN NAPIER GRASS AGED SIX MONTHS

Cutting Parameter			Fuel Expenditure —					
Height (in,)	Area (acres)	Time (min.)	Liters	Gallons	Gal/Hour	Gal/Acre	BTUs/acre 1/	Estimated Horsepower 2/
8-10	1.38	66.75	10.0	2.65	2.38	1.92	268,940	35.72
1-2	0.69	42.47	7.0	1.85	2.65	2.69	376,460	39.30
1-2	0.69	32.33	6.0	1.59	2.95	2.31	322,700	44.24
1-2 in. Combined	1.38	74.80	13.0	3.44	2.76	2.50	349,580	41.43
Combined Total	2.76	141.55	23.0	6.09	2.58	2.21	309,260	38.74

1/ Diesel fuel having a weight of 7.0 pounds/gallon and a heat value of 20,000 BTUs/pound.

2/ Taken from Nebraska Tractor Test Data for the project tractor (a Model 8700 Ford) using 0.06658 gallons/horsepower hour.

TABLE 52. DRY MATTER YIELD AND MOISTURE CONTENT VALUES FOR ENERGY CANE STUDY HATILLO; 15-MONTH HARVEST

	Short Tons/Acre, For –				
Treatment	Total Green Wt. [2/]	Dry Matter	Detached Trash	Total Dry Wt. [3/]	% DM
Control (Low Till) [1/]	107.2	26.3	11.3	37.6	24.5
Control (Sugar Corp.)	70.3	12.9	12.1	25.0	18.3
Unirrigated E. Cane [1/]	85.1	19.8	16.6	36.4	23.3
Irrigated E. Cane	110.9	26.0	16.0	42.0	23.4
US 67-22-2 (Irrigated)	150.1	28.5	23.7	52.2	19.0

[1/] Mean of two sites. [2/] Detached trash not included. [3/] Detached trash included.

TABLE 53. MOISTURE LOSS FROM STORED BALES OF SOLAR-DRIED NAPIER GRASS; VARIETIES MERKER (COMMON MERKER) AND PI 7350 [1].

Variety	Moisture Contents (%), At Day --													Mean
	0	2	4	6	8	10	12	14	16	18	20	22	24	
Merker	17.9	17.2	19.7	19.7	18.4	17.9	17.4	17.4	16.4	16.2	15.6	15.0	14.6	17.2
PI 7350	18.5	19.0	21.1	20.9	20.2	19.4	18.3	18.2	17.5	17.3	17.2	16.4	15.8	18.4
Mean	18.2	18.1	20.4	20.3	19.3	18.6	17.9	17.6	17.0	16.7	16.4	15.7	15.2	17.8

[1] Both varieties were mowed (conditioned) with a rotary scythe at 7 months of age. The material was solar dried in the field and compacted into 1000-1200 pound round bales. The bales were placed in an open-sided shed with approximately 20 inches of ventilation space between bales. Moisture determinations were made at 10 points within each bale, at depths of 10 to 24 inches, using a commercial hay moisture probe (Empire Corp.). Each figure is the mean of six replicates.

TABLE 54. MOISTURE CONTENT CHANGES FOR NAPIER GRASS THAT WAS SOLAR-DRIED, BALED, AND STORED OUT-OF-DOORS

	Moisture Content (%), At Day —						
Exp. No.	0	14	28	42	61	82	Mean
1 [1/]	36.6	32.6	22.9	21.6	23.2	21.5	26.4
2 [2/]	15.8	24.4	16.5	15.9	16.7	16.1	17.6

[1/] Consisting of two bales, partially dry when baled.

[2/] Consisting of 12 bales, fully dry when baled.

TABLE 55. MOISTURE CONTENT CHANGES IN VARIABLY-DRY NAPIER GRASS BALES STORED OUT-OF-DOORS 1/

Baling Moisture (%)	Bale Moisture Content (%) At Storage Day —						
	0	14	28	42	60	84	Mean
36.5	36.5	32.2	23.2	22.0	23.0	21.9	26.4
15.8	15.8	24.0	16.0	15.4	16.1	15.5	17.1
Mean	26.2	28.1	19.6	18.7	19.6	19.6	

1/ Harvested at 6 months of age.

TABLE 56. GREEN MATTER YIELDS BY FIRST-AND SECOND-GENERATION ENERGY CANE: PLANT CROP, HATILLO

Treatment	Tot. GM (Tons/A), At Month – 1/			Mean
	6	12	18	
Control 1/	30.8	76.4	89.9	65.7
E. Cane (1st Gen.) 2/	36.0	95.9	108.5	80.1
E. Cane (2nd Gen.) 3/	50.2	124.9	124.6	99.9
Mean	39.0	99.1	107.7	81.9

1/ Simulated PR Sugar Corporation, var. PR 980, unirrigated.

2/ Energy cane management, var. PR 980, irrigated.

3/ Energy cane management, var. US 67-22-2, irrigated.

4/ Detached trash excluded.

TABLE 57. MILLABLE CANE YIELDS BY FIRST-AND SECOND-GENERATION ENERGY CANE; PLANT CROP, HATILLO

Treatment	Millable Cane (T/A), At Month — 6	12	18	Mean
Control [1]	19.3	63.8	77.1	53.4
E. Cane (1st Gen.) [2]	24.0	82.6	98.3	67.8
E. Cane (2nd Gen.) [3]	34.7	96.0	109.0	79.9
Mean	26.0	80.8	94.8	66.9

1/ Simulated PR Sugar Corporation, var. PR 980,unirrigated.

2/ Energy cane management, var. PR 980, irrigated.

3/ Energy cane management, var. US 67-22-2, irrigated.

TABLE 58. DRY MATTER YIELDS FOR FIRST-AND SECOND-GENERATION ENERGY CANE; PLANT CROP, HATILLO

Treatment	Tot. DM (Tons/A), At Month – 1/			Mean
	6	12	18	
Control 1/	5.7	29.4	30.0	21.8
E. Cane (1st Gen.) 2/	5.9	32.8	37.0	25.2
E. Cane (2nd Gen.) 3/	8.8	50.5	49.6	36.3
Mean	6.8	37.6	38.9	27.8

1/ Simulated PR Sugar Corporation, var. PR 980, unirrigated.

2/ Energy cane management, var. PR 980, irrigated.

3/ Energy cane management, var. US 67-22-2, irrigated.

4/ Detached trash included.

TABLE 59. CANE QUALITY AND SUGAR YIELDS BY FIRST-AND SECOND-GENERATION ENERGY CANE; 18-MONTH HARVEST, PLANT CROP, HATILLO

		Quality Parameter —						
Treatment	Month	Pol	Brix	Fiber	Purity	Rend.	TCA	TSA
Control	12	7.6	9.7	11.7	78.5	6.1	63.8	3.9
	18	10.5	12.5	14.1	84.3	8.8	77.1	6.8
E. Cane (1st Gen.)	12	9.5	12.2	14.1	76.5	7.5	82.6	6.2
	18	10.3	12.0	15.6	84.7	8.5	98.3	8.4
E. Cane (2nd Gen.)	12	10.3	13.3	12.7	76.8	8.1	96.0	7.8
	18	10.1	13.1	11.6	77.6	8.4	109.0	9.2

TABLE 60. TRASH YIELDS IN FIRST-AND SECOND-GENERATION ENERGY CANE AT HATILLO; PLANT CROP

Treatment	Trash Yield (Tons/A), At Month – [1/] 6	9	12	15	18	Mean
Control [1/]	5.1	7.9	9.5	11.5	15.5	9.9
E. Cane (1st Gen.) [2/]	6.1	5.7	10.1	14.3	11.6	9.6
E. Cane (2nd Gen.) [3/]	6.2	11.9	23.3	31.2	29.1	20.3
Mean	5.8	8.5	14.3	19.0	18.7	13.3

1/ Simulated PR Sugar Corporation.

2/ Variety PR 980.

3/ Variety US 67-22-2

4/ Consists of combined detached plus attached trash.

TABLE 61. RELATIVE BIOMASS AND SUGAR YIELDS BY ENERGY CANE VARIETY US 67-22-2 AT LAJAS AND HATILLO SITES; 12 & 18 MONTHS, PLANT CROP

	Total GM (T/A), At —			
Month	Lajas	Hatillo	Tonnage Difference	% Difference
12	116.5	124.9	8.4	7.2
18	164.4	124.6	-39.8	-24.2
Mean	140.5	124.8	-15.7	-11.2
	Total DM (Tons/A)			
12	41.9	50.5	8.6	20.5
18	65.7	49.6	-16.1	-20.5
Mean	53.8	50.1	- 3.7	- 6.9
	Tons Cane/Acre			
12	98.9	96.0	- 2.9	- 2.9
18	137.1	109.0	-28.1	-20.5
Mean	118.0	102.5	-15.5	-13.1
	Tons Sugar/Acre			
12	8.5	7.8	- 0.7	- 8.2
18	11.7	9.2	- 2.5	21.4
Mean	10.1	8.5	1.6	15.8

TABLE 62. SUGARCANE CROSSES FOR BIOMASS; NOV.-DEC., 1979

Female Parent		Male Parent	Objectives
B 70-701	x	57-NG-54	Fiber only
NCo 310	x	US 67-22-2 [1/]	Fiber & Fermentable Solids
NCo 310	x	B 70-701 [1/]	Fiber & Fermentable Solids
PR 62-195	x	57-NG-54	Fiber & Fermentable Solids
PR 68-330	x	47-NG-54	Fiber & Fermentable Solids
PR 980	x	*S. spont.* Hybrid	Fiber & Fermentable Solids
PR 67-1070	x	*S. spont.* Hybrid	Fiber & Fermentable Solids
PR 64-1618	x	*S. spont.* Hybrid	Fiber Only

[1/] Field cross.

TABLE 63. TONS CANE PER ACRE AND TONS DRY MATTER PER ACRE FOR SIX F_1 PROGENY OF THE CROSS US 67-22-2 x B 70-701

Progeny	TCA 1/	TCA 3/ Index	% DM 1/	TDMA 2/	TDMA 3/ Index
PR 79-1-10	93.7	139.7	32.7	30.6	143.1
PR 79-1-5	83.7	124.7	34.0	28.4	132.8
PR 79-1-21	79.3	118.1	30.2	23.9	111.8
PR 79-1-22	76.2	113.5	27.9	21.2	99.3
PR 79-1-3	75.6	112.7	38.3	29.0	135.3
PR 79-1-11	71.2	106.2	33.1	23.6	110.1
US 67-22-2	67.1	100.0	31.9	21.4	100.0

1/ Data recorded at 12 months of age, plant crop.

2/ Determined for one sample consisting of 10 millable stems.

3/ Reference clone, US 67-22-2, = 100.

TABLE 64. GROWTH FEATURES OF THE TOP SIX F_1 PROGENY FROM THE CROSS US 67-22-2 x B 70-701

Progeny	Stem Characteristics [1]		
	Height (cm)	Diameter (cm)	No./Acre
PR 79-1-10	311	2.1	45,950
PR 79-1-5	270	2.0	40,936
PR 79-1-21	210	1.6	51,569
PR 79-1-22	300	2.0	36,181
PR 79-1-3	310	1.9	42,192
PR 79-1-11	260	1.8	45,518
US 67-22-2 [1]	250	1.8	32,982

[1] Data recorded at 12-months of age.

[2] Reference clone.

TABLE 65. QUALITATIVE VALUES FOR THE TOP SIX F_1 PROGENY OF THE CROSS US 67-22-2 x B 70-701

	Parameter —				
Progeny	Pol	Brix	% Fiber	Purity	% Sucrose
PR 79-1-10	5.7	8.7	21.6	64.0	3.24
PR 79-1-5	4.9	9.1	15.1	53.0	2.31
PR 79-1-21	4.6	10.7	14.7	43.0	1.67
PR 79-1-22	6.7	10.5	15.0	62.9	4.27
PR 79-1-3	7.5	10.3	20.7	70.0	4.99
PR 79-1-11	3.0	9.8	16.5	49.4	2.87
US 67-22-2	11.1	13.4	14.2	86.3	9.16
B 70-701	6.3	9.2	18.6	68.0	4.11

TABLE 66. SUGARCANE CROSSES FOR BIOMASS AND SUGAR; 1978 BREEDING SEASON

Cross Number	Cross	Second Selections
79-4	PR 67-245 x *S. sp.* RP [1]	5
79-12	US 67-22-2 x PR 68-3041 [2]	18
79-5	PR 68-330 x US 67-22-2 [2]	3
79-6	PR 67-1070 x US 67-22-2 [2]	4
79-3	F 160 x US 67-22-2 [2]	3
79-17	68-3041 x US 67-22-2	10
79-16	US 67-22-2 x F 160	2

1/ Being evaluated in 20' x 20' field-plot tests for biomass; two progeny had been crossed with conventional breeding canes during the 1981 cane breeding season.

2/ Being evaluated in 20' x 20' field-plot tests for both biomass and sugar.

TABLE 67. CANE CROSSES FOR BIOMASS; 1979 BREEDING SEASON

Cross Number	Cross	Breeding Line
80-1	PR 980 x *S*. *sp*. RP	F_1 *S*. *sp*. 1/
80-2	PR 64-1618 x *S*. *sp*. RP	F_1 *S*. *sp*. 1/
80-3	PR 67-1070 x S. *sp*. RP	F_1 *S*. *sp*. 1/
80-4	PR 68-355 x *S*. *rob*.	F_1 *S*. *rob*. 1/
80-27	PR 70-395 x PR 77-251-137	BC_1 *S*. *sp*. 2/

1/ Being evaluated in 20' x 20' field-plot tests for biomass; a few progeny had been crossed with conventional breeding canes during the 1981 breeding season.

2/ Being evaluated in 20' x 20' field-plot tests for both biomass and sugar.

TABLE 68. CANE CROSSES FOR BIOMASS; PERFORMED DURING 1980 BREEDING SEASON

Cross Number	Cross	Breeding Line
4	NCo 310 x US 67-22-2	BC_2 *S. sp.* 1/
10	NCo 310 x B 70-701	BC_1 *S. sp.* 1/
81-7	PR 69-3061 x F_1 (PR 980 x *S. sp.* RP)	BC_1 *S. sp.* 1/
81-29	PR 70-260 x PR 79-4-1	BC_1 *S. sp.* 1/
81-30	F_1 (PR 68-355 x *S. rob.*) x F_1 (PR 67-1070 x *S. sp.* RP)	F_1 *S. sp.* x F_1 *S. rob.* 2/
81-37	F_1 (PR 68-355 x *S. rob.*) x *S. sp.* RP	F_1 *S. rob.* x *S. sp.* RP 2/
81-28	F_1 (PR 67-1070 x *S. sp.* RP) x F_1 (PR 68-355 x *S. rob.*)	F_1 *S. rob.* x F_1 *S. sp.* 2/

1/ To be evaluated for biomass and sugar.

2/ To be evaluated for biomass.

TABLE 69. SUGARCANE CROSSES FOR BIOMASS; 1981 BREEDING SEASON

Cross Number	Cross	Breeding Generation
82-2	PR 62-195 x PR 79-4-1	BC$_1$ *S. sp.* 1/
82-23	IAC 51/205 x PR 79-4-3	BC$_1$ *S. sp.* 1/
82-30	IJ 76-424 x F$_1$ (PR 68-355 x 57 NG 54)	BC$_1$ *S. rob.* 1/
82-33	PR 67-1070 x F (PR 68-355 x 57 NG 54)	BC$_1$ *S. rob.* 1/

1/ To be evaluated for biomass and sugar.