CEER-B-173 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

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. by Center for Energy and Environment Research University of Puerto Rico

Final Report: PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

Table Of Contents

FINAL REPORT
June 1, 1977 — May 31, 1982
PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE
A. G. Alexander, W. Allison, C. Gonzalez-Nolina, J.

Ortiz-Vélez, C., Ranfrez J., Wélez-Santiago, A., Vélez, and T. L. Chu conducted a comprehensive study on the production of sugarcane and related tropical energy crops. The successful study, which began in 1977, moved from the screening of candidate grasses at the greenhouse level to the development of mechanized field-scale production technologies. The focus was on achieving maximum total dry matter yield at minimum cost on a continuous, year-round basis.

Final cost and energy balance analyses indicate that tropical grasses, when managed specifically as energy crops in a tropical environment, are an economically viable and reliable energy resource with multiple benefits. The study culminated in the concept of "energy cane" for optimal fuels and feedstock production. The study highlighted two key points: a) The need for revised management technologies that emphasize growth rather than sugar storage, and b) The integration of multiple species for a year-round supply of fuels and feedstock to biomass-utilizing industries.

Through revised management, sugarcane yields of approximately 83 short tons/acre per year were achieved for whole green cane. This is significantly higher than the conventional sugarcane yield in Puerto Rico of 27 short tons/acre per year. Sugarcane managed in this way is now termed as "first-generation" energy cane.

The study also introduced the concept of "second-generation" energy cane. This involves revised field management technologies and varieties specifically selected for biomass. The yield for second-generation energy cane exceeded 110 short tons/acre per year. Production costs were slightly higher than $1,000/acre per year but less than $10.00 per green ton. The recoverable energy yields were in excess of 450,000,000 BTUs/acre per year at costs under $2.00/million BTUs.

The combined values for fuels (pegged to fuel oil at $33.00/barrel) and high-test molasses (at $0.76/gallon) exceed $3,000/ acre per year for second-generation energy cane. This constitutes a significant component of the study's findings.

The concept of energy cane was the development of alternative tropical grass species as supplemental biomass sources. These consist of generic-level relatives of Saccharum, which 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. A substantial 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

INTRODUCTION

The biomass production studies herein reported were initiated on 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 species 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.

PROJECT OBJECTIVES

Primary objectives include: (a) Determining the agronomic and economic feasibility of mechanized, year-round production of solar-dried intensive management of sugarcane and Napier grass.

The text appears to be discussing potential sources for intensive biomass production and the breeding of new Saccharum progeny for increased biomass productivity. Here it is, revised for clarity:

The project focuses on two potential sources for intensive biomass production. A secondary objective involves the selection and breeding of new Saccharum progeny, with superior biomass productivity as their primary characteristic. The project also investigates alternate tropical grasses and mechanized production methods.

Emphasis was directed towards highly-intensive solar-dried forages, a deviation from conventional cane and cattle feed production where total dry matter, instead of sugar and food components, is the main saleable commodity. The management of production inputs, particularly water, nitrogen, and candidate species, along with harvest frequency, significantly varies from established procedures.

Advancements 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 necessary conditions for their management in an economically viable operation.

This was accomplished in three phases: greenhouse, field-plot, and field-scale investigations. A fourth phase, commercial-industrial operations, logically follows but was beyond the scope of this project.

Tropical grasses have never been evaluated under conditions where biomass energy is the main saleable product. As a result, it was necessary to screen a broad range of candidate cultivars. Under certain circumstances, existing sugar and fiber-producing varieties may also excel in total biomass yield. However, it is generally recognized that the growth attribute has not been fully intensified in the hybridization programs leading to the current commercial varieties.

This includes 1) Varieties no longer produced commercially, 2) "noble" or pure intraspecific clones, and 3) prior selections from wild populations, known as 'the germplasm.'

The text has been corrected for spelling, grammar, and clarity:

Modern genotypes have been assembled from which a screening technique was adopted for this purpose. This technique evaluated botanical, physiological, and agronomic attributes in a stepwise program involving greenhouse, field-plot, and field-scale trials. Screening studies have therefore included older hybrid varieties and more primitive forms. In some ways, this was a tropical application of the herbaceous species screening concept formulated by the DOE Fuels From Biomass Program. Numbers in parentheses 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. 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 biomass candidates. Under such circumstances, some prospects are created for the emergence of superior new progeny at very little expense.

C. STATEMENT ON DATA PRESENTATION SEQUENCE

This report covers the period from 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 May 31, 1982.

Termination date. The latter experiments are being maintained through the first-ratoon crop with CEEK-UPR funds.

TECHNICAL REPORT

A. GREENHOUSE STUDIES

The project's greenhouse phase was focused on the screening of candidate tropical grasses and the response of superior cultivars to growth input and management variables. Much information of this nature is obtained more rapidly and cheaply than is possible under field conditions. Greenhouse studies 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.

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 regulator treatments, and tolerance to frequent cutting 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 seeds. 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 sugarcane hybrid PR 980 as a reference clone known for its high tonnage production. However, PR 980 was not satisfactory for this project. Its major dry matter accumulation begins after 6 months, and the project required cultivars that can accomplish this as early as two to three months after sowing of the hybrid (9/16) x S. spontaneum (5/16) x S. sinense (2/16).

 Also, several Saccharum imports and AES cane breeding progeny were identified as superior tonnage producers to PR 980. Subsequent reference clones were selected from specific categories of candidates under scrutiny, i.e., Sordan 70-A for short-rotation candidates, Napier or hybrid for the long-rotation category, 18 (var. Merker) for intermediate rotation, and a suitable S. spontaneum for varied harvest intervals 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' growth period. 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, were randomly 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. Total Growth Performance Initial candidate evaluations for total growth included 25 Saccharum and two Danthug clones in uncomplicated trials (Table 3). Several commercial hybrids and Saccharum species compared favorably with PR 980.

980 under greenhouse conditions. Additional features under observation were germination (rate and percentages of planted cuttings), early growth rate, insect tolerance, and erectness. The following clones were selected for seed expansion and further growth evaluation: Chunnee, Natal Uba, US S6-19-1, Tainan, NG 28-219, Saretha, and the SES clones 231, 317, and 327. The uppermost leaf bearing a fully-emerged tip is designated as "#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.

-6- 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 for a direct comparison against the Saccharum standard, PR 980, and a second comparison against three sweet sorghum varieties in the "Meridian" series (471-5, 472-2, and H72-3). The sweet sorghum variety Rona and the noble sugarcane Badilla, together with PR 980, were all included in the latter trial. In both experiments, Sordan 70-A easily outproduced 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, Sorghum (var. Common Marker), two imported Napier grass hybrids (PI 7350 and PI 30086), and PR 980 were tested. Repeated harvests at 6-week intervals again emphasized the early growth.

The 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 70-4 in dry matter production by a significant factor to be retained for field evaluation in the Greenhouse phase. Trudan 7, a true hybrid Sudan grass, is a case in point. However, due to the range of drought and pest resistances carried by the NK hybrids, it was concluded 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.

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 Saccharum, Urtanthus, and Arundo (Table 7).

Arundo, a tropical grass found in the wild along streams and irrigation canals on the island's south coast, was also included in this group. In terms of dry matter production per individual plant, Sordan 70-A clearly exceeded PR 960 during the initial two months (Figure 1). This clone flowered only 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), 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 due to poorer plant densities. An unidentified wild clone thought to be a S. spontaneum hybrid also produced superior growth during the first two months. Moisture determinations for months 1-5 indicate a rapid... [Page Break]

Dehydration of Sordan 70-A occurred during the second month. It was rapidly becoming a mature plant within 8 weeks after seeding. This is beneficial in the search for fast-growing species that require 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. This is an extremely positive factor. 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 Crystalins (S. officinarum). The unidentified S. spontaneum hybrid produced a dehydration pattern intermediate between that of PR 980 and Sordan 10, a positive factor in this clone's favor. Growth curves encompassing a time-course of 3 months have been plotted for the sorghum varieties M715, M72-2, M/2-3, and Roma, together with Sordan 70-A, Badilla, and the reference cane hybrid PR 980 (Figure 3). It has been subsequently confirmed as an S. spontaneum hybrid which apparently escaped from a germplasm collection maintained by AES-UPR during the 1930s.

The superiority of Sordan 70-A for rapid initial growth and early conversion to dry matter is clearly evident. On an individual plant basis, Sordan 70-A had produced, by 4 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.) induces growth in sugarcane when applied in low concentrations as an aqueous foliar spray. 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 sound culture. The Monsanto products Polaris and CP 70139 were tested at sub-repressive concentrations on six-week-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 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,) 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

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 Eubark (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 Eubark was compared with Polaris for its tillering effects at concentrations ranging from 25 to 300 ppm active material (Table 11). Shoot production was increased by all Eubark treatments, the maximum effect being recorded at 50 ppm. This concentration virtually doubled the number of shoots per plot. It was further evaluated as a growth stimulant. The ability to tiller, that is, to produce a large number of stems from a single crown, is probably a genetically-controlled factor in tropical grasses.

Within the genus Saccharum, field corn varieties rarely produce a second stem while sweet corn varieties usually retain the tillering feature. 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 due to an inability to tiller might be retained by chemical means.

The latter example seems to be the case at present with a S. spontaneus hybrid having excellent growth potential but a persistent difficulty in establishing a satisfactory population. While

The revised text:

Interestingly, 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 described 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 Growth Regulators: Direct growth stimulation with plant hormones such as gibberellic acid has not given satisfactory results with sugarcane (14, chap. 12). Very pronounced growth can occur as a temporary response which is lost after 2 to 3 joints are laid down. Gibberellin effects can be prolonged by multiple treatments (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, even with split applications of any given dose.

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 (29) 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.

-2- 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

The results from the first experiment were too low to increase juice quality (Table 12). There is little likelihood that any ripener used in this concentration range could offer increased sugar as an added benefit. On the other hand, the Polaris concentration required for optimal biomass yield increases 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 bionase production if any appreciable yield improvement can be demonstrated. The possibilities for seasonal growth improvement or for the breaking of stresses imposed by adverse climate, moisture, or nutritional regimes also warrant consideration. An added advantage would derive from the co-administration of growth regulators with another material already required by the biomass crop. Under PR conditions, short-rotation tropical forages would require a foliar insecticide application some 3 or 4 weeks. 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 co-administration with pesticides after planting, and overhead and/or urea.

6. Regrowth Studies

Initial data collection on plant regrowth rates was initiated during the project's first year. The measurements determine: (a) The vigor and quality of ratoons (shoots) produced by established crops whose tops have been harvested; (b) the number of new stems produced, the rate at which a single-eye cutting will expand into a multiple-stem crop; and (c) the persistence of vigorous regrowth over an extended period of time. Gibberellic acid is most effective as a growth stimulant in sugarcane when plants are undergoing some degree of physiological stress.

Stress (22, 23)

-13- 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. The 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 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.

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 sinus-Ma 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

The plant's growth is considerably higher than the norm for tropical grasses. It's 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 70 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 milliequivalents/Liter of NO3. The low-N treatment was deficient while maintaining some limited growth. High N (81.0 meq/1) offered a vastly greater supply than most tropical grasses can utilize. With sugarcane, for example, levels in sand culture exceeding about 20.0 meq/1 are utilized only in the sense of "luxury consumption" (14). For sugarcane, 9.0 meq/1 of NO3 in sand culture is roughly comparable to a field treatment amounting to 100-150 pounds of elemental N per acre per year.

Growth data recorded at 4 and 8 weeks after seeding are illustrated in Figure 5. At 4 weeks, there was little response to NO3 levels higher than 3.0 meq/1, owing in part to the lack of a root system sufficiently developed in the young plants to make use of so much nitrogen. Large gains were obtained between 4 and 8 weeks, with 9.0 meq/1 of NO3 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 under glass or in an open field. The response curve for Sordan is as follows...

70A is, in fact, a very favorable one. It indicates that there are 4 fairly distinct points beyond which no further gain can be expected from increasing expenditures of nitrogen fertilizer. The situation would be different if the plant had continued to respond to higher N levels in a weakening first-order curve. In this case, a net-energy balance, much more complicated scenario for Sordan 704, 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.

-15-

Variable Motst 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, Tradan 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 21:2 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.

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. Chuy, a project collaborator and a recognized expert in the field, was instrumental in the selection and importation process.

An authority on Saccharum and allied species traveled to the US mainland in December 1977 to evaluate cultivars as potential candidates for biomass screening in Puerto Rico. We visited USDA collections at Canal Point, Florida, Houma, Louisiana, and Beltsville, Maryland. A total of 73 clones were identified as suitable candidates, and arrangements were made for their shipment to Puerto Rico. Additionally, 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 in 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, Eecotloput, Sorgo. These clones, including those in Sclerostachya, Miscanthus, Erianthus, and Ripidium, 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 Miscanthus and Erianthus, together with the Saccharum species S. fusca, S. Rarenga, and S. robustum. These candidates were planted in soil-cachaza mixtures, and all but one from the genus Ripidium gave satisfactory germination. Growth was adequate, though unremarkable for most clones. Several clones produced tassels late in the season.

November and December, 1978. Charum 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. The observed flowering could also be an artifact of the plant's greenhouse environment or their late time of planting. Ripidium was formerly classified as an Asiatic subgroup of Erianthus. 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 "house" funding.

Field Plot Methods - The majority of the project's field-plot

Experiments were conducted on 4 Fraternidad soil series, which is a moderately well-drained soil that becomes highly plastic when wet and crumbly when dry. This is representative of much of Puerto Rico's prime agricultural lands. The plot size was typically 1/50 acre, with 4 to 6 repetitions 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 longevity of established plant populations. Except in the variable irrigation treatments, all plants received an "adequate" water supply, first administered by overhead sprinklers and later by flood (border) irrigation. Fertilizer was typically provided in three increments: one-third at planting and the remainder in two-month intervals thereafter.

The principal harvest parameters for all experiments were total dry matter (DM), percent moisture, and total green matter (GM). These were usually reported on a “per acre" or “per acre per year" basis. In some experiments, leaf samples were taken periodically for nutrient analysis (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. Therefore, cane plants were subdivided into millable stems, immature stems, green foliar canopy, detached trash, and attached trash before oven drying.

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 Saccharum species group consisted of clones imported for breeding purposes in 1976. The early work at Gurabo was an observation study of candidate species, followed by a series of tests.

Spontaneum and S. sinense clones that had already shown favorable biomass attributes under greenhouse conditions (26). 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 equaled or exceeded PR 980 in sugar content of millable stems and tons sugar per acre (TSA). Ultimately, US 67-22-2 became the standard "second generation" energy cane 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. spontaneus 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% sugar 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 form — rather than accumulate sucrose. As a consequence, sugarcane normally yields more energy than is consumed in its production operations, even though 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 resources. 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). "Energy cane", a term coined locally in 1979, refers to cane managed for maximum biomass production rather than sugar.

-20- 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 by heavy equipment. In Puerto Rico, biomass processing facilities could not receive energy cane during the wettest four months 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 crops 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 alternative tropical 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 and Napier Lajas, the project's first significant field-plot experiment was established in July 1977 at the semi-arid AES-LaJas Substation. The controlled variables included varieties, row spacing, and harvest frequency (refer to Table 16). The experiment included 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's conditions.

(a) Procedures: This experiment was planted on a moderately well-drained Fraternidad Clay soil. The 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, 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 per 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 appropriate intervals, i.e., 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 per 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, respectively, rather than at 150 cm and 50 cm as was done with sugarcane. Harvest intervals of 2 and 4 months are recognized advantages for Napier grass, whereas intervals of 6-months or more clearly favor sugarcane. Management practices that were equal for sugarcane and Napier grass were observed.

Napier grass care 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 even though 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 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. The Genes and Trends; Precision Energy Cane: In 1980 the first data for first-generation energy cane, and for Napier grass managed as an energy crop for a complete cropping cycle, became available (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 crop plus four or five ratoon crops before replanting the area. Napier grass is considerably more durable and may remain on a given site for decades before replanting or rotation is deemed necessary. 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 more succinctly as the 3-year means of a complete crop cycle (35). Four distinct trends were evident for cane and Napier grass: close spacing to increase yields; (b) large DM.

In the years immediately thereafter, Puerto Rico's commercial cane industry normally harvests the plant crop plus four or five ratoon crops before replanting the area. Napier grass is considerably more durable and may remain on a given site for decades before replanting or rotation is deemed necessary.

Yield increases as harvest frequency was reduced; (c), a moderate superiority of sugarcane variety (a) A general failure of NCo 310 over other first-generation energy canes; and (2), 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) or 150 days for car 6 months for Napier grass. Optimal row spacing was 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 available cane. Fiber content averaged 16.42 for all varieties. (a) DM 86! 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.

<2. (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

(a) 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 year averages (Table 20). Row spacing varies on trash yield. The cane variety PR 980 produced moderately greater yield 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 zone widely recognized for its "year-round growing season". Nonetheless, there were clearly seasonal variations in the productivity of both sugarcane 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 zone, some claim can be made that the growth reduction was a result of reduced water supply. This is at least a contributing factor, for even though 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.

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 “grand culture" 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 applied with even greater effect in a future energy-planting enterprise designed to maximize cane biomass tonnages.

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 is 7.2% for all varieties and row spacing (Table 24). Variety PR 64-1791, at standard row spacing, produced average sucrose. Fiber content is 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 compared on an "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 production.

De-watering 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 (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 towards 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, side operations, fertilizer, harvest and delivery of harvested cane. Energy cane seed and fertilizer expenditures were double those of conventional sugarcane. Harvest operations and cane delivery expenses were 7 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 48 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). The yield of energy cane exceeded sugarcane by a factor of about 3.7. Therefore, the increased cost of optimizing sugarcane for total biomass rather than sucrose was more than compensated by even larger increases in dry matter yield. Due to its relatively low productivity, the cost of sugarcane in the Puerto Rico sugar industry was approximately $65.00 per ton, or about $4.31 per ton B.I.V.E. Energy Balances were performed during 1980 using the first-ratoon crop averages for varieties PR 980, NCo 310, and PR 64-1791. These varieties averaged 33 tons per acre per year for the first-ratoon crop. Energy input estimates for this preliminary energy balance analysis are summarized in Table 28. Total energy inputs for first-generation energy cane production were on the order of 28 x 10^8 BTU/acre per year. Energy output amounted to 279 x 10^8 BTU/acre per year (Table 29).

28. The latter figure was calculated assuming 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 per 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 case, only 1,360 pounds of dry matter per ton, or 22.4 tons per acre, will be used as boiler fuel. Assuming an 85% efficiency for a utility boiler, an energy output/input ratio of 9.95/1 was obtained (Table 29). Some researchers have simply divided the total calorific value of their annual product by the total production energy input. By this method, energy cane would have an energy output/input ratio of about 17.7/1. It is worth noting that nearly half of the total energy expenditure was for mineral N alone (Table 28). Therefore, while the favorable energy balance achieved to date is primarily a reflection of high dry matter yield, future improvements in this balance can be achieved both by increasing yields and by reducing the input of mineral N. One means of lowering N.

Input 1s 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 crop yields. A large number of underutilized tropical legumes have been identified for possible use in this context (44, 45).

6. Second-Gen Energy Cane (Plant Crop)

The project's first three years of work with energy cane, from 1977 to 1979, dealt 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 sugarcane 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;

(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 Sacct clones having superior attributes as biomass energy crops (48). Two outstanding candidates.

They 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 uniform germination and forms a massive stool complex within a year after showing outstanding growth potential. It has a rapid planting rate (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 done 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 energy cane for at least the remainder of the 1980s.

A field-plot study of the energy cane consists of 27 treatments with four repetitions arranged in a randomized split-plot design (Table 30). There are three primary treatments (harvest frequencies at 6-, 12-, and 18-month intervals), three sub-treatments (varieties PR 980, US 67-22-2, and B 70-701), and three sub-sub treatments (variable nitrogen at 200, 400, and 600 lbs/acre year of elemental N). Row spacing is constant among all treatments at a 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 production. An important shortcoming of the first-generation studies was a 12-month interval between harvests, reflecting 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 cane varieties, US

US 67-22-2 and BB 70-701 are second-generation canes, with PR 980 being a reference variety typifying the Island's commercial sugarcane. The first-generation canes have enormous growth potential under PR conditions and are managed as biomass crops. About 400 lbs of elemental N are required per acre per 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 a 16-4-8 fertilizer formulation administered incrementally at 3-month intervals.

There are two completely new inputs not received by the first-generation canes: (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, hence, increasing production costs to some extent. These costs appear to have been more than compensated by increased yields (see pp. 33-36).

Whole cane yields, including attached trash but not detached, of whole cane (millable stems plus tops) exceeded 100 short tons/acre per 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 lb 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 BB 70-701 and PR 980 by approximately 30 tons GM/acre. As shown in Table 32, delaying the harvest from 12 to 16 months gave large increases of tops and trash (74.0 and 94.4 percent) but only moderate increases of milling.

(27.8 percent). Actually, in terms of total GM, the highest yield was achieved by combining three 6-month harvests (Table 33). Here, the variety US 67-22-2 provided 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 due to the relatively high moisture content, low yields of dry matter, and low yields of millable stems by 6-month-old cane. Moreover, production costs are appreciably higher for 6-month cane since three harvests are required rather than one.

(b) Millable Stems: The highest yield of millable cane (topped, grand culture cane) was produced by the 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.

An energy planter could maximize his yields through harvest delay, while minimizing his annual production costs by the same practice. It's significant that over 23 tons/acre of the maximum amount of trash (Table 38). This fraction consists of dead leaf and sheath tissues either adhering to the cane or detached and lying on the ground. Such materials are normally burned in the field as a pre-harvest operation for conventional sugarcane. From energy cane, they will be harvested and credited to the crop's total yield of lignocellulosic dry matter.

There's little qualitative change between months 12 and 18. The somewhat higher sugar yields/acre at 18 months were in virtue of the higher tonnages of millable stems/acre. Also evident is the distinct superiority 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 continued growth impetus received in the form of water and fertilizer applications.

Conventional sugarcane, managed for maximum sugar yield, would have during the final months received neither fertilizer nor irrigation. Significantly larger sugar yields would have been expected on an individual plant basis, though not necessarily on a per acre basis.

12 months. There were also slightly fewer stems/acre for second-generation cane (Table 40). Mean

sugar yields were also high for second-generation energy cane (Table 41). These trends reflect moderately higher nutrient values as well as higher tonnages of viable cane. In these averaged data, the poor performance of variety B Tu-ii was offset by the superior yields of US 67-22-2 and PR 980.

(4) Second-Generation Production Costs: The initial cost analysis for 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 increase 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, i.e., the average of three crop 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 costs 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 rotation

The process used for first-generation energy cane is included. Expenses such as those for employing a farm manager have not increased due to the decline of Puerto Rico's job market.

The total cost estimate for a 200-acre energy cane operation is in the order of $205,000/year, an increase of 22 percent since 1980. The cost per acre of energy cane has similarly increased by 22 percent. It would cost today over $1,000/acre per 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 per 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 per year (excluding detached trash), the fuel value of this cane is approximately $1.88/million ton and Puerto Rico is currently paying over $6.00/million BTUs in the form of no. 6 fuel oil (July, 1982). Obviously, one cannot continue 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 Puerto Rico today.

Subsequent cost analyses are expected to indicate lower production costs for second-generation cane. This projection is based on the following: (a) Proportionally lower costs for large scale biomass due to the delay (spreading) of harvest and delivery expenses; (b) proportionally higher DM yields from large scale cane; (c) higher DM yields from the first and second ratoon crop yields and (d) lowering N supply from 400 to 300 or 200 lbs/acre per 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. (4) 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 fuel (9.85 million BTUs/acre year). Fuel expenditure is not only for N alone. A second major energy expenditure is for diesel which increased by about

-35- 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 yield of the first generation increased by over 58 percent (453 vs 286 million BTUs/acre). BTU recovery/acre year for the second-generation energy cane is excellent. (k) Net Energy Balance: 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 output 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 was obtained with 200 lbs N/acre (19.7) as opposed to 600 lbs N/acre (12.5). Notes: The net energy balances for varieties PR 980, 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.

The actual fuel could be conventional bagasse (with 49-512 moisture), partially-dried bagasse, or a processed fuel product derived from bagasse, such as AGRI-FUEL™ (with 6% moisture). Molasses and fiber (combustible DM) along with fermentable solids produced per acre by second-generation energy cane were quite substantial (as shown in Table 47). Assuming 9.5 lbs of fermentable solids per gallon of high-test molasses (HTM), over 2,000 gallons were being produced by varieties PR 980 and US 67-22-2, and over 1,200 gallons per acre by variety B 70-701. With the current price of $0.76 per gallon, the annual molasses value exceeded $1,800 per acre for US 67-22-2, $1,600 per acre for PR 980 and $900 per acre for B 70-701 (Table 47).

By the 12th month, the quantities of fiber had increased. The value of fiber was estimated at $0.04 per oven-dry pound, pegged to the current price of No. 6 fuel oil ($33 per barrel). At this price, the value of fiber per acre at 12 months averaged over $1,900 for PR 980, over $2,000 for US 67-222, and $2,200 for B 70-701. The combined value of molasses and fiber was on the order of $3,863 for US 67-22-2, $3,606 for PR 980, and $3,160 for B 70-701 (Table 47).

Energy cane has significant benefits for Puerto Rico, which urgently needs a local molasses supply for its rum industry and a domestic fuel substitute for imported oil. High-test molasses is the preferred fermentation substrate for island rum producers. The combustible fibrous residues can be burned directly or processed into higher-quality fuels and feedstock. The prospects seem promising for sugarcane management for energy, particularly for HTM and fiber, to be a potentially profitable enterprise for Puerto Rican cane planters. Given 70,000 acres for future cane industry, the production of energy cane as described here would eliminate entirely the importation of molasses and significantly reduce the importation of other fuels. Additional benefits include the reestablishment of the local industry and the potential surplus of molasses for other uses.

Export: Energy Island's import of cane palatting is a profitable enterprise in Puerto Rico. It increased rural employment and, when combined with other tropical grasses, extended the annual mill operation from 2.5 months to 11 months. The Puerto Rico Government has allocated 70,000 acres for sugar planting in its "Modern Agricultural Plan For Puerto Rico". The PR Sugar Corporation anticipates an $85,000,000 loss during 1982.

FIELD-SCALE STUDIES

Field-scale experiments logically follow greenhouse and field plot studies. Their purposes are (a) to simulate, under plantation-level conditions, the production inputs that 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. Jose B. De Castro, the farm's owner.

During the project's final six months, the fieldwork 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, along with row spacing and seedbed preparation studies with the same variety.

As indicated above, the project's fieldwork involved the increase in the size 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 preceding 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 labor-intensive regimes.

Field-plot conditions transition to a labor-intensive regime which is effective both agronomically and economically. For the most part, the use of implements and machines offers 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 Sudan-type species with greater precision than a skilled laborer.

However, in one decisively critical area, machines have never quite equaled 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 (11). 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, Sudan, etc.). Such cannot be shipped to a sugar mill for dewatering, but they can be specially 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, 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 effect of forage-making implements can be assessed on plots as small as 2 acres; virtually all... [Page Break] ... 38.

The growth, conditioning, solar-drying, and baling trials in this project were performed on unreplicated plots of 3 or 6 acres in size. The long-term durability of machinery tested in this manner is less accurately measured. Hence, it was necessary to report data and 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 of service from the same machine. 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.

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 was not the case on a university farm where a given driver is continually assigned to different machines in different projects. Equally important is the commitment to their charges and the farm operation as a whole. The performance of a multitude of equipment operators with respect to 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

The quality of our equipment operation 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 post-harvest handling of tropical grasses propagated biomass energy crops. The scope of this task covered two major areas:

(a) Production and harvest of thin-stemmed, fibrous grasses (short and long-rotation species), and (b) Production and harvest of thick-stemmed, intermediate-rotation grasses. The thin species, such as Sordan Tork and Napier grass, were to be solar-dried in the field as a means of moisture removal. Thick-stemmed grasses include commercial canes and the "energy canes" developed during 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 were directed, and the physical mass of material with which the categories confront harvest machinery. Hence, the lighter, thin-stemmed grasses were to be dried in the field, baled, and stored for 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. Conditions are favorable for their harvest, solar-drying, and storage from roughly mid-December to mid-August along 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 water contained by these materials at the time of harvest.

(34). The fret group deals with standing green e/acre. Sordan TOA, a short rotation crop, is characteristic of species having yields of this magnitude. The project's approach to such waterways was to harvest them exclusively as solar-dried forages. Within this category, the machinery tasks vary with the state of the crop's maturity, with phases having from 10 to 12% fiber at six weeks to 2 to 35% later. A second category deals infra. The atoms in the order of 1 3 25 shaft + With standing Biomass in the order of green representative spectra to the molar Grass, an intermediate-rotation crop whose dry matter content maximizes between four and six months after planting. Again, the crop's state of success or failure of harvests monthly is critical to the success of machinery. Harvested at two months of age (8-12 moisture) Napier grass actually offers no more difficulty than conventional cattle forages. At two 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 sugarcane of commerce and the energy source 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 water draining 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. Insert 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 II 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), 2 New Holland Model 851 Round Balers, and a New Holland Model 393 "tub" forage grinder. The forage rake was soon supplemented by a Farmhand wheel rake and by both front-mounted loaders capable of handling round bales weighing up to 1500 pounds/bale and rear-tractor.

(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 the grasses as does a conventional sickle bar mower, but rather breaks off and "conditions" the grass with steel plates rotating at high speed with extremely powerful force. The conditioned material is deposited in windrows of adjustable width directly behind the mower. The rotary scythe is a thoroughly rugged machine. 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. An illustration of this machine appears in an earlier report.

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 accumulated dead Johnson grass had formed mats, approximately two to three feet thick. In such areas, the mats tended to push ahead of the implement rather than pass under it. Once the rotary scythe passed over the material, it was effectively conditioned whether the mats sometimes passed under it.

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 against 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 due 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) 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 circumstances existed when...

The conditions were 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 intermittently 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 sated, that is, the stems had crossed and interlaced in all directions. The crop harvested at 14 weeks had remained in this condition up to five weeks. During this interval, the sated Sordan 70A was further interlaced with herbaceous weeds (both vines and upright grasses) plus a regrowth of secondary Sordan 70A plants stimulated 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 of patted grasses, and only occasionally was it necessary to shift into a lower operating gear. A period of intermittent rainfall following the 10-week harvest caused considerable difficulty in drying the conditioned biomass after the 14-week harvest. Baling took place within three days of good weather. This material was solar-dried and ready for use. 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. Such stops would have been an almost continuous feature if we had attempted to harvest the 14-week old material with a sickle-bar mower.

Baling operations for the solar-dried Johnson grass and...

The Sordan TOA was performed without encountering major problems. Minor difficulties related 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. Factors such 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.

In regards to Napier Grass at three months, the 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. A far greater challenge to harvest Napier grass was submitted to mechanized harvest and forage-making operations for the first time during year 3. Approximately four acres of 7-month-old Napier grass (var. Merker) were mowed with the MHC 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 per acre. The primary difference lay in mass. 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, the much thicker and more succulent stems of Napier grass. 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 Johnton 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.

Napier Grass; Six Months: The ultimate test of the rotary scythe-conditioner was 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:

(A) 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" grass is expected to 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 onto the upper surface of the rotary scythe. In the actual tests, there was no tendency for any material to drop backward onto 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.

(B) Excessive mass of the Napier grass, amounting to approximately 30 to 40 standing green tons/acre, as opposed to about 10 to 12 green tons per acre of conventional crops. It was thought that the additional mass confronting the implement might cause its blades to become clogged with bunched material; alternatively, such material could continually break the shear pins. The latter are incorporated into the implement 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 satisfactory 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.

The outward slowing of the harvest process, i.e., the visibility of the field, is determined by the quantity of biomass being harvested per unit of movement of harvest machinery across time. In six-month-old Napier grass, the rotary scythe was conditioning biomass at full capacity when operated in the tractor's low gear. However, there was inadequate conditioning 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 improving the windrowing and baling operations.

Stems of six-month-old Napier grass were quite effectively conditioned by the rotary scythe, and 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 Sorghum). The increased drying time was mainly a function of the greater stem thickness and total mass of material per acre for Napier grass.

However, there was 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 set 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.

The length is up to 45 centimeters. The longer plant segments that remained intact, including 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.

The very excellent performance by the rotary scythe-conditioner enabled us to solar-dry, rake, and bale mature Napier grass which would have been unmanageable with existing forage-making equipment. Problems did arise, mainly related to the excessive amount 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 per 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 issue was somewhat corrected by slowing the engine speed, by partially raising the rake when laboring in heavy material, and by reraking the skipped areas.

After the windrow had been formed, there were no further difficulties in raking, even when turning the windrow over a second or third time.

A more serious problem encountered 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. 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 the use of a different type of implement, commonly described as a "heel" rake. This rake is not driven by a power take-off but rather operates through the 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 Farshand 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 crops, 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.

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 crop injury that could be traced to the rotary-scythe conditioner. 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. A significant amount of conditioned biomass lay flat between the stubble and could not be recovered with the available forage rake. This implement, like most standard forage rakes, operates a single unit driven from the tractor’s PTO system. When any portion of the rake is lifted by a plant crop, 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 Farshand wheel rake (which gives a clean raking of...

All stems, except those missed by the rotary scythe, indicated that from 15 to 252 of the solar-dried material had been left un-windrowed by the standard PTO-driven bar. 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 re-harvesting 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 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.

(e) 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 an M-C model 9-F rotary scythe (9 foot mowing swath), both idling and in actual movement on the measured test plot area. 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 a 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 close 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, 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 workload 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 Farahand Company wheel rake. The rotary scythe 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 conditioned, solar-dried feedstock to the biomass processing or utilization center. Rotary scythe trials on Sorghum 70A and Johnson Grass dealt 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 into 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 impending stems in a scissors-like action.

-32- 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 attached.

The text could be directly welded. It was necessary to adapt the hydraulic lines of the parting knife 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 gearbox, 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 grass. In the tests made with this system, the cutting force of the parting knife was developed. Nonetheless, its performance in 6-month-old sugarcane has been very good. It clearly sections through dense matter where formerly a rather ragged division was made, coupled with uprooted and dragged clumps of Napier grass. Moreover, the rotary scythe ceased to elevate above the ground in dense materials once the parting knife became operational. No supplemental weighting of the implement was necessary. The parting knife with accessories weighs about 150 pounds so this in itself may contribute materially to the performance of the rotary scythe.

Napier 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 MC 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.

-53- 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 the time of storage (two traits); (b) moisture-loss measurements from partially dry bales containing about 35% moisture at the 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%) or 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 by anatomical lines. The 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 the 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 the 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 62 days to 18.4 percent. Some limited heating was evident in the

The bale's interior did not approach spontaneous combustion, possibly because of natural ventilation throughout the storage facility. There was also evidence of solid 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.

55. 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 outdoors without cover or protection of any kind. Highly-compacted bales tend to resist moisture penetration. At worst, only the outer layer 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). Their behavior when exposed to weather variables was an unknown factor.

Two experiments were performed with napier grass bales stored outdoors (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 16 days of open-air storage, but thereafter their moisture content declined.

The text should be corrected as follows:

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 the time of baling.

- 56 - 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. 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 with 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 demonstration 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 are concerned.

Concerning agricultural production operations, the De Castro farm had not been cultivated for seven years and was occupied by a mixture of volunteer sugarcane and wild grass. Approximately 25 acres were mowed with a rotary scythe, plowed, rotavated, land-planned, lined, 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 non-irrigated sections.

(a) Plant Crop Yields: Field-scale trials at Harritio 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 2000 square feet area samples taken at tri-monthly intervals from month 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 growing 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, and no irrigation was provided after month 12. This change in management emphasis was quite apparent in the subsequent yield data.

(b) Mature 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 out-yielded control cane. (b) Over 90 tons of whole green cane were produced by month 12. (c) Relatively little biomass was produced after month 12. (d) The second-generation variety US 67-22-2 was distinctly superior to variety P2 90. Also, the control yields were consistently higher than expected. This was attributed in part to an erroneous inclusion of the end rotation when preparing the control seedbed. This implementation is almost never used either on Sugar Corporation lands or private "Colono" farms. Yields of total green matter (Table 5) attained over 95 tons/acre by month 12. The first variety US 7-2-2 (second-generation) yielded about 125 tons/acre at 17 months; however, neither treatment appreciably increased yield in the subsequent 5 months. Similar trends were recorded for millable stems (Table 57), although small yield gains were made after 12 months. Generation dry matter also had essentially maximized by month 12. Four increments of 100 lbs elemental N each had been planned, i.e., 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. (e) Cane Quality And Sugar Yield: varied greatly among control and energy cane treatments (Table 59). Rendement cane quality values did not vary 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.

Plant Density And Trash: The second-generation variety US 67-22-2 displays 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 stems destroyed by harvest machinery.

This variety is not only a prolific producer of stems, but it also maintains a foliar canopy that is perceptively larger than normally seen in the sugarcane 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. At Hatillo, by month 12, Cane “trash” consists of leaf and leaf sheath tissues that have died and desiccated, and either remain adhering 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 cane tonnage currently produced by the sugarcane colonies in Puerto Rico (50).

Field-Pipe: 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 6 when further fertilizer increments were cancelled. Out of curiosity, the

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 experiences a more rapid quality decline. The need for coordination between field and mill operations was underscored recently when the second-generation energy cane at Hatillo was being harvested. Average rendement 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 rendement value of 5.9, while the final load, delivered 15 days after harvest, gave a rendement 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 for 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.

BREEDING STUDIES.

The genus Saccharum can be viewed as an enormous and largely untapped pool of germplasm for biomass and lignocellulose (58, 16, 1, 2). A "secondary" but nonetheless important breeding program has emerged focusing specifically on biomass attributes. This was accomplished with very limited resource inputs, in part through the

The project aimed to use existing AES-UPR facilities for conventional sugarcane breeding, primarily through the personal interest of Mr. T.L. Chu, a recognized world authority on breeding in the Saccharum genus. The goal was to explore the large potentials for both sugar production and sugarcane biomass, which would enable the creation of a limited number of new products.

1. Evaluation of Local Germplasm: Four local clones bearing "new" Saccharum germplasm were identified early in the first year and evaluated as potential male parents in crosses suitable for spontaneous flowering characteristics. These flowered 6 to 8 weeks in advance of commercial hybrid sugarcane. Two of these S. spontaneum clones were found in the wild near Rio Piedras, but they were never cultivated as biomass candidates. A third wild clone, an unidentified S. spontaneum hybrid, showed high potential as a biomass producer in its own right. This hybrid served as a prime example of massive growth potential by wild, tropical plants. A fourth Saccharum clone, "Aegyptiacum", was available in collections maintained at Rio Piedras and Gurabo.

2. Evaluation of PR Breeding Progeny: For many years, the AES-UPR sugarcane breeding program screened new progeny for increased sugar and tonnage yields, suitability for mechanical

harvest, disease resistance, and regional adaptability. Total biomass per se was not a decisive parameter in the selection of new sugarcane hybrids. Nonetheless, several canes have emerged that do have exceptional promise as biomass energy producers, based on regional trials. About 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 made in December of 1977, using male-sterile female parents and frozen pollen in an effort to improve the breeding process.

Synchronize tasseling with that of the early-flowering S. spontaneus hybrid described above. Although pollen tests by the starch-Iodine method had indicated a probable viability, only 5 seedlings were obtained from these 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 Serapién (63, 64). Vicariously, 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. spontaneus tassels during the period November 25- December 15. Five crosses performed by this means in the autumn of 1979 are summarized in Table 62.

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 crops 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. spontaneus 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.

The text has existed for the emergence of "third generation” progeny with biomass attributes superior to those of any preceding clone.

5. Second-Generation Energy Cane

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, along with other basic breeding lines structured with new clones of genetic base of the trial 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 (BC2) hybrid of the S. spontaneum clone Passercean. 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 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 the first-generation energy cane (var. PR 980) in the plant crop.

-63-

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 (F1). 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.
'Third-Generation Energy Canes (a) Crosses Designed To Maximize Fiber: During the 1978 cane breeding season, the cross US 67-22-2 x 8 70-701 was performed. Total fiber rather than sucrose or fermentable solids was the primary objective. The F1 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, i.e., by approximately 35 and 33 percent, respectively: 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 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 of the crosses performed during this period are presented in Tables 66 to 69. [A preliminary evaluation of...]

Progeny from the cross US 67-22-2, either as a male or 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. Impressive performance was obtained from hybrid progeny of the rose PR 70395 1 FR TI-1SI-137, which was made during the 1979 breeding season (Table 67). The clone PR 77-251-137 is an F1 hybrid of the clones US 67-22-2 (2n= 80), Thailand S. spontaneum. This suggests that the Thailand S. spontaneum source may provide excellent germplasm for improving yields (65). Energy Cane Breeding Potential in (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) was crossed with a clone of S. robustum (57 NC 54), both "wild" along 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 F1 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 B/ The parentage of PR 77-251-137 is PR 67-1336 x US 56-16-4.

Each sample consisted of five millable canes harvested approximately 12 months after planting. An examination of frequency distribution for sucrose content in the tours of hybrids revealed that the robustus F1 hybrids contained more sucrose than the spontaneum F1 progeny (Figure 14). With reference to Brix values, the robustus F1 progeny demonstrated an even more remarkable performance than the spontaneum F1 hybrid (Figure 15). In terms of fiber, the results indicate that far more spontaneum F1 hybrids have distinctly higher fiber contents than do the robustus F1 progeny (Figure 16).

The preliminary results suggest that when exclusively breeding for fibrous biomass, the first-generation hybrids (F1) of S. spontaneus offer a better source of candidates than those of S. robustus. However, when breeding for both fiber and fermentable solids, the S. robustus F1 progeny might offer a better source of biomass candidates.

In an attempt to determine the growth potential for the BC1 and BC3 hybrid progeny of S. spontaneus, 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 approximately eight months after planting. Stalk volume per seedling was then computed from available data.

In terms of stalk volume per seedling, the BC1 of the cross NCO 310 x B 70-701 (F1 spontaneum) indicated better performance than the BC3 progeny of the cross NCo 310 x US 67-22-2 (F1 spontaneum). The growth potential of two additional BC1 progeny was also seen to be greater than that of the BC3 progeny.

The same measurements were taken for the hybrid progeny of the cross S. robustus x S. spontaneum. In terms of volumes per seedling, the progeny of the cross S. robustus x S. spontaneum demonstrated a nearly identical performance in terms of stalk volume per seedling as the reciprocal cross of the former.

All these initial results appear to suggest that two wild Saccharum species, S. spontaneum and S. robustus, should be regarded as the most valuable sources of genetic material in breeding canes for biomass planting. Nevertheless, they must be incorporated into appropriate conventional high yielding and good juice cane varieties.

Parentage notes:
1. The parentage of F1 robustus is PR 68-355 x 57 NG 54.
2. The parentage of F1 spontaneus is PR 67-1070 x S. spontaneus RP.

In order to produce bona fide candidates that combine exceptionally good vigor with high fiber content and fairly good juice quality, it is important to consider the second-generation hybrid progeny (BC2) of these two wild species. This appears to provide a better source of biomass candidates than either the first generation (F1) or more advanced-generation progeny of S. spontaneum. With regard to the two primary objectives, high biomass tonnage and high fermentable solids for biomass candidates, F1 progeny should be crossed back to the original clones of the two wild species. It is advisable that neither S. spontaneum F1 nor S. robustum F1 should be used.

Summary: A four-year study on the production of sugarcane and related tropical energy crops was successfully completed, achieving all objectives. The study continues with UPR and Puerto Rico Commonwealth funding. Initially a loosely-affiliated part 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 production.

Neither sugar nor total fermentable solids were ever primary considerations, yet they figured prominently in the emergence of the study's most important new concept, i.e., the concept for boiler fuels and molasses production.

Page Break

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. Sugarcane 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. These 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...

The production of tropical grasses as economically profitable enterprises has been demonstrated. Although production costs are moderately higher on a per acre basis than conventional sugarcane planting, yields are significantly higher and costs are correspondingly lower when calculated on a per ton basis. For boiler fuel, solar-dried tropical grasses cost less than $2.00/million BTUs. This is currently the most cost-effective fuel available in Puerto Rico, 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. Tropical grasses can be produced for less than 1 dollar per gallon. 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.

References

1. Artschwager, E., and Brandes, E. W. 1958. Sugarcane. Agricultural Handbook No. 122. U.S. Government Printing Office, Washington, D. C.
2. Brandes, E. W., and Sartoria, G. B. 1936. Sugarcane: Its Origin and Improvement. USDA Yearbook of Agriculture. U.S. Govt. Printing Office, Washington, D. C., pp. 361-611.
3. Anon. 1978. Request For Proposal For Establishment of Herbaceous Species Screening Program — RFP No, ET-78-R-02-0014. DOE Chicago Operations office, May 19.
4. Stevenson, G. C. 1965. Genetics and Breeding of Sugarcane. Longmans, Green and Co., Publishers. London.
5. Alexander, A.C. 1969. The potential of sugarcane to produce sucrose, Proc. Int. Soc. Sugar Cane Technol., 13:1-26.
6. Anon. 1976. Amazing Grazing: Trudan-5, Millex-23, and Sordan 70-A. Commercial brochure for Northrup King hybrid forage grasses. Northrup King Seeds, Minneapolis, Minn. Personal communications with field production managers, Molinos de Puerto Rico, San Geran, P.R. 1977.
7. Alaina, B., Valle-Lamboy, S., and A. Méndez-Cruz. 1975. Preliminary evaluation of ten sweet sorghum varieties for sugar production in Puerto Rico, J. Agr. Univ. P.R. 59(1):

5-14. 9. Alsina, E, 1972-1975. Evaluation of Sorghum Varieties for Sugar Production in Puerto Rico (Project Title). USDA Progress Reports, Project PR-C-00436, Form AD-421. 10. Personal communications with Mr. J. Vélez Santiago, Assistant Agronomist, AES-UPR Corozal Substation, 1977. 11. Personal communication with the Tropical Fertilizer Corporation (Puerto Rico distributors for the Northrup King Co.), San Juan, 1978. 12. Personal communication with Dr. Paul Menge, Project Leader, Hybrid Sorghum Research, Northrup King & Co., April, 1978. 13. Alexander, A. G. 1977. Efficiency of Chemical Ripener Action in Sugarcane. V. Superior Efficiency of CP 70139 (Monsanto) in Direct Comparisons with Polaris. J. Agr. Univ. P.R. 6(12). 14. Alexander, A. G. 1973. Sugarcane Physiology. A Study of the Saccharum Source-to-Sink System. Elsevier Scientific Publishing Co. Amsterdam.

1. 16. 18. 19. 20. 21. 23. 24. 25. 26. 27. Alexander, A. C., Montalvo-Zapata, R., and A. Kumar. 1970. Gibberellic Acid Activity in Sugarcane as a Function of the Number and Frequency of Applications. J. Agr. Univ. PR. 58(3): 477-503. Stevenson, G. C. 1965. Genetics and Breeding of Sugarcane. Longmans, Green and Company, London. Coleman, R. E. 1958. Effect of gibberellic acid on the growth of sugarcane. Sugar J. 20: 23-26. Alexander, A. G., Montalvo-Zapata, R., and A. Kumar. 1970. Enzyme Silicon Studies of Gibberellic Acid-Treated Sugarcane During the Post-Growth Stimulatory Phase, J. Agr. Univ. P.R. 58(1): 82-95. Alexander, A. G. 1969. Interrelationships of Nitrate and 6-Azauracil in the Growth, Enzymology, and Sucrose Production of Immature Sugarcane, J. Agr. Univ. P.R. 53(2): 81-92. Personal communication with Mr. J. Vélez Santiago, Agronomist in charge of tropical forage grass studies, AES-Corozal Substation, December, 1977. Gauch, H.C. 1972. Inorganic Plant Nutrition. Dowden, Hutchinson, and Ross, Inc. (Publishers), Stroudsburg, Pa. Alexander, A. G. 1968, Interrelationships of Gibberellic Acid and Nitrate in Sugar.

Production and Enzyme Activity of Sugarcane, J. Ant. Univ. PAR. S2(1): 19%. Bull, T. A. 1964. The effects of temperature, variety, and age on the response of Saccharum species to applied gibberellic acid, Aust. J. Ag. Res. 15: 77-84. Alexander, A. G., Allison, W., Chu, T. L., Vélez-Santiago, J., Vélez, J. Ramírez, G., González-Molina, C., and J. Ortiz-Vélez. 1978.

Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. First Annual Report (1977-78). Contract No. BO-77-C-05-5422.

Alexander, A. G., Allison, W., Chu, T. L., Vélez-Santiago, J., Vélez, J. Ramírez, G., González-Molina, C., García, M., and J. Ortiz-Vélez. 1979. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. Second Annual Report (1978-79). Contract No. ET-78-5-05-5912.

Alexander, A. G., Allison, W., García, M., Ramírez, C., Vélez, A., Chu, T. L., Vélez-Santiago, J., and L. Smith. 1980. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. Third Annual Report (1979-80). Contract No. DE-AS05-78ET20071.

Alexander, A. G., Allison, W., García, M., Ramírez, G., Vélez, A., Chu, T. L., Vélez-Santiago, J., Rion, C., and L. Smith. 1981. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. Fourth Annual Report (1980-81). Contract No. DE-AS05-78ET20071.

Alexander, A. G., García, M., Allison, W., Chu, T. L., and C. González-Molina. 1979. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. First Quarterly Report (1978-79). Contract No. ER-78-S-05-5912.

Alternative Uses of Sugarcane for Development. Symposium sponsored by CEER-UPR and the PR College of Architects and Engineers, Caribe Hilton Hotel, San Juan, Puerto Rico, March 26 and 27, 1979.

Bergy Cane Management for Molasses and Boiler Fuel. Research Project sponsored jointly by CEER-UPR, the PR Sugar Corporation, and the PR Energy Office. Initiated June 1, 1982.

Alexander, A. G. 1980. The Energy Cane Concept for Molasses and Boiler Fuel.

Symposium "Fuels and Feedstocks from Tropical Biomass". Caribe Hilton Hotel, San Juan, P.R, November 24 and 25. Alexander, A. G. 1982. Second Generation Energy Cane; Concepts, Costs, and Benefits. Symposium "Fuels and Feedstocks from Tropical Biomass II". Caribe Hilton Hotel, San Juan, P.R. April 26-28. Romaguera, M. A. 1982. Improving the efficiency of sugarcane milling and combustion systems in Puerto Rico. Symposium "Fuels and Feedstocks from Tropical Biomass II". Caribe Hilton Hotel, San Juan, P.R., April 26-28. Samiels, C. 1982. Mechanization in the Puerto Rico Sugar Industry: History and Present Outlook. CEER-UPR Biomass Division Internal Publication. February. Alexander, A. G., Allison, W., Vélez, A., Garcia, M., Ramirez, G., Ghu, T. Li, Vélez-Santiago, J., and L. Sateh.” 1982. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. First Quarterly Report (1980-81). Contract No. DE-ASOS~7BET20071. Lipinsky, E. S., Kresovitch, S., McClure, T. A., and W. T. Lawhons 1978. Third Quarterly Report on Fuels from Sugar Crops, Battelle Columbus Division, Columbus, Ohio, January 31. Personal communication with Dr. James E. Irvine (US Sugarcane Field Station, Houma, La.), ASSCT Annual Meeting, Orlando, Florida. June, 1979. Anon. Informe Número 24, 16 al 20 de junio (FINAL). 1980. Progreso de Molienda, Zafra 1980. Junta Azucarera de Puerto Rico, San Juan, P.R; June. Vicente-Chandler, J. 1978. Concepts, plan, and program for a modern agriculture in Puerto Rico. Commonwealth of Puerto Rico, Department of Agriculture, Santurce, P.R.

40.

Roberts, C. R. 1942. Soil Survey of Puerto Rico. Series 1936, No. 8. Published by the USDA Bureau of Plant Industry in cooperation with ABS-UPR, January. Personal communication with Mr. C. L, Yordem. 1979. Executive Secretary, Puerto Rico Rum Producer's Association, November. Zenitz, K. A. 1979. Growing Energy. Land for Biomass Farms. USDA Economics, Statistics, and Cooperative Service, Agricultural Report No.

425. Personal communications with Mr. W. Allison, Agricultural Engineer, AES-UPR and UPR Mayaguez Faculty, Mayaguez, P.R. Anon. 1975. Underexploited Tropical Plants with Promising Economic Value. US National Academy of Sciences. US National Academy of Sciences. Washington, D.C. Anon. 1979. Tropical Legumes: Resources for the Future. Report of an Ad-Hoc Panel of the Advisory Committee on Technology Innovation. National Research Council, National Academy Of Sciences, Washington, D.C. Alexander, A. G., Allison, W., Ortiz-Vélez, J., Ramírez, G., Vélez, A, Vélez-Santiago, J., Carefa, M., Chu, T. L., and L. Seith. 1979. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. First and Second Quarterly Reports, Year 3, to DOE. Contract No. DE-ASO5-78ET20071. December. Warren, R., et al. 1975. "Grown organic matter as a fuel source." Ohio Agricultural Research and Development Center, Wooster, Ohio, for Lewis Research Center (NASA), October. 130 pp. Gu, T. 1. 1980. Hybridization of Tropical Grasses for Fuel and Alcohol. Proceedings of the Symposium "Fuels And Feedstocks From Tropical Biomass". Caribe Hilton Hotel, San Juan, Puerto Rico, November 24 and 25. Chu, T.L. 1982. Development of Second-and Third-Generation Energy Cane Varieties. Presented at the Symposium "Fuels And Feedstocks From Tropical Biomass II". Caribe Hilton Hotel, San Juan, Puerto Rico. April 26-28. Samuels, G. 1980. Puerto Rico Sugar Industry Operations; 1971-1980. A Data Base. CEER-UPR Biomass Division publication. Samuels, G. 1980. The use of high-test molasses distillery slops: An overview. CEER-UPR internal publication no. B-069. Samuels, C. 1980. The molasses industries. Proc. Syrup. Fuels and Feedstocks From Tropical Biomass. Caribe Hilton Hotel, San Juan, Nov. 24 and 25.

53. 58. 35. 56. 7 59. 0. 62. 63. 64. 65. 65. Alexander, A.C. 1979. Energy Cane Management for Molasses and Boiler Fuel. Research project proposal, CEER-UPR to the Office of the Governor, Commonwealth of Puerto Rico, December. Allison,

W. 1979. Presentation to the Baton Rouge, LA. April DOE Harvesting Workshop. Anon. 1976. M-C Rotary Scythes That Non-Stop Mower-Conditioner. Commercial Brochure, Mathews Company, 900 Industrial Ave., Crystal Lake, IL. 60014. Anon. 1977. Ford 8700 and 9700 Specifications; p. 4 of Ford Company Flier no. M-2537-E, entitled "FORD 8700-2700". FORD Tractor Operations, Troy, Michigan 48084. Received June. Personal communications with Mr. William Altison. 1980. Agricultural Engineer, UPR Mayagüez Campus, June. Gu, TL. 1979. Breeding Potentials for Biomass in the Genus Saccharum. Symposium "Alternative Uses Of Sugarcane For Development", Caribe Hilton Hotel, San Juan, P.R., March 26 and 27. González-Ríos, P. 1966. Research on the varieties of sugar cane in Puerto Rico, Bulletin No. 199, AES. González-Molina, C. L. 1969, 1972, 1973, 1979. Regional Evaluation Of new sugarcane varieties, Annual Reports., AES-UPR. González-Molina, C. L. 1977. Performance of commercial sugarcane Varieties in the Aguirre clay soil of the Lajas Valley, J. Agr. Univ. P.R., 61(2):126-136. Personal communications with Mr. T. L. Chu. Sugarcane Breeder, AES-PR Sugarcane Breeding Program, Guayabo Substation, December,

1977. Chu, Te Ley and J. L. Serapión. 1972. Function of Flowering Stimulus in Sugarcane. Proc. Int. Soc. Sugar Cane Technol. 14:365-371. Chu, T. Le, and J. I. Serapión. 1972. Effect of Individual Leaf Trimming on Flowering in Sugarcane, J. Agr. Univ. P.R. 56(4):403-409. Heinz, D. J. 1980. Thailand S. spontaneum hybrid progeny as a new germplasm source in Hawaii. Proc. ISSCT, 17: 1347-1356. Chu, T. Le, B, Alsina, J. E. Serapion, J. L. Rodriguez, and C. L. González-Molina. 1979. Performance of new sugarcane varieties in the coastal and inner plains of eastern Puerto Rico, J. Agr. Univ. P.R., 68(2):202-213.

APPENDIX Figures 1-18 Tables 1-69

Recent moisture tests [details omitted]

HT (9/RANT) or we

Graphical data [details omitted]

Figure 5. [details omitted]

Nitrogen response curves for the short-rotation candidate Soréen were supplied in nutrient solutions to plants propagated by sand culture. (Incomplete data)

DRY MATTER (g/PLANT) - 9 - FIGURE 6. Dry matter yields for eight other calculated values, separate plant growth fed arid moisture regimes. Each curve is derived from the computed states of average Saccharum and one Sorghum.

= 80 -

- a sso} Lo 325 cy» g 99% $ 100 sox 50 24x Oe a ie or Te Corn FIGURE 9. Relationship of 12- and 18-month harvests to green and dry matter production by second-generation energy cane. Percentage figures indicate the relative shift in yield over the previous harvest period (i.e., dry mass yield at 18 months was 50% greater than at 12 months, while green mass yield at 18 months was only 32% greater than at 12 months).

Storage Practices BIOMASS FUEL STORAGE integration OF Energy Cane And AGRIFUEL Technologies for year-round Production Of highest ROI.

STEMS/ACRE. (THOUSANDS) 6 9 ww us 8 AGE OF CANE (MONTHS) FIGURE 10. Number of stems produced/acre by energy cane varieties PR 980 and US 67-22-2.

Oxstine content (2)

- 8s - MOISTURE CONTENT (%) ° 4 8 2 16 20 2% ‘STORAGE TIME (DAYS) Less Than 20% Moisture.

~ 86 - — Projected Loss nm | ——— Actual Loss GREEN WEIGHT Loss (2) Rt ° “ 8 12 16 20 DAYS AFTER HARVEST FIGURE 13. GREEN WEIGHT LOSS FOR HARVESTED WHOLE STEMS OF ENERGY CANE; 18 MONTH (GRAN CULTURA) HARVEST AT HATILLO.

-87- FIGURE 14. Frequency distribution for sucrose (X) in 30 F1 hybrid Progenies of each of 3 crosses: PR 960 x S. spontaneum BE, PR 67-1070 x S. spontaneum RP, and PR 66-355 x S. robustum 57-NC-54.

FIGURE 15. Frequency distribution for Brix in 30 F1 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. 57-86-54.

FIGURE 16. Frequency distribution for other (2) in 30 of.

Each of the 3 crosses: PR 980 x 8 spontaneous RP, and PR 58-355 x §. The hybrid progenies were Rb, PR 67-1070 x S. S7-NEnS4.

90 - Figures are presented in the following sequence: FIGURE 17. Frequency distribution for stalk volume in 100 hybrid progenies of each of 8 crosses: NCo 310 x Fi S. sp.; NCo 310 x BC, S. sp. PR 69-3061 x Fy S. sp., and PR 70-3364 x Fy S. sp.

91 - The figures continue with FIGURE 18. Frequency distribution for stalk volume in 100 hybrid progenies of each of 3 crosses: Fy (PR 68-355 x S7-NG~54) x Fy (PR'67H=1070 x S. sp. BP); Fy 355 x S7-NG-S4) x S. sp. RP; and Fy (PR 67-1070 x S. sp. RP) x Fy (PR 68-355 x 57-NC-54).

92 - 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

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

94 - TABLE 3. RELATIVE GREEN WEIGHT PRODUCTION BY CANDIDATE TROPICAL GRASSES OVER A TIME-COURSE OF 7 MONTHS
Total Green Weight As % Of Species Clone Reference Clone (PR 980)
PR 980 100
37-1939 124
NCo 310 120
Pa 2878, etc.

95 - TABLE 4. INITIAL GREENHOUSE GROWTH RESPONSES OF EIGHT CANDIDATE TROPICAL

Grasses - Total Growth (g/10 Plants)

Genus	Clone	Green Wt.	Dry Wt.	% Moisture
Saccharum	PR 980	105	ns	2878
Badilla	70	ans	80	164
Sorghus	Sordan 70-4	330	32.0	ns
Roma	280	25.5	ns	201
M 72-2	220	2212	ns	210

30 Days After Planting.

Table 5: Dry Matter Yields for Napier Grass, Napier Hybrids, and Sorday 70-4 Propagated in the Greenhouse and Harvested at Intervals of Six Weeks

	Total	Week 1-6	Week 7-12	Week 13-18
Napier Grass	0.38	0.75	0.60	0.50

Napier Hybrid 7350	ns	0.63	0.46	ns
Napier Hybrid 20086	ns	0.78	0.60	ns

Table 6: Dry Matter Content (%) for Napier Grass, Napier Hybrids, and Sordal, Harvested at Intervals of Six Weeks

	Week 1-6	Week 7-12	Week 13-18
PR 980 (Reference)	69	110	ns
Napier Grass	10.3	ns	49
Napier Hybrid 7350	ns	ns	3.3
Napier Hybrid 20086	ns	15.5	19.8

Unreplicated greenhouse trial.

Table 8: Green Weight Responses of Immature Sugarcane to the Plant Growth Inhibitor Polaris

Polaris (ppa)	Response At 6 Weeks	Response At 12 Weeks
263	ns	30
28	+10	3
300	sr	+8
32	200	wt
403	+18	300
w+	a2	+20
400	265	ns
2	500	9-36
me	-28	2

Variety PR 980. Applied at 6 weeks of age. Aqueous foliar.

Table 9: Growth Responses of Immature Sugarcane to Plant Growth Inhibitors

Compound	Stem Wt. (g/plant) At 6 Weeks After Treatment	Deviation From Control
488	ns	Polaris 62.2
+28.0	Mon 8000	28.8
-40.7	GR 1093 DA	26.5
-45.5	Babark	one
+272	ns	ns

Administered as aqueous collar sprays containing 100 ppm active ingredient.

Table 10: Stimulatory Effects of Mon 8000 on Tiller (Shoot) Production by Immature Sugarcane; 42

Days

Mon 8000 | ns

Green Weight/Plot Deviation From Control (2) (open) 2/ Total Shoots/Shoot Green Weight No. Tillers e.g. Green Weight Tiller (Control) 3516 27.9 ° ° 10 3842 32.8 16 9.3 25 4525 36.2 27.9 28.7 ET J/ Applied as aqueous foliar sprays to 10-week old plants, variety PR 980.

Page 102 - TABLE 11. STIMULATORY EFFECTS OF Exanx 1/ PRODUCTION BY IMMATURE SUGARCANE ON TILLER (SHOOT) APPLIED Yields At 42 Days After Treatment Bebork (ppa) 2/ Tiller/Plot Deviation From Control () (Control) ast ° Fa 192 +2 50 236 +95 300 23 + 150 2 +33 200 195 +2 300 202 +38

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

Page 103 TABLE 12. BRIX AND POLARIZATION VALUES FOR IMMATURE SUGARCANE. TREATED WITH THE PLANT GROWTH INHIBITOR POLARIS 1/

Polaris Conc. (ppm) ° 50 100 200 300 400 500

Polaris Conc. Mean Brix Values At Day ~ ui ° 42 4 0.3 ab aha 9.6 abe 27.2 B2e 28.4 a Bsc 29.2 0 919 ab ee oa 28.8 8 12a 29.3 a

A 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). Not significantly different. Mean values bearing at least one letter in common are not significantly different.

Page 104 - TABLE 13. INTERGENERIC TROPICAL GRASSES IMPORTED TO PUERTO RICO AS CANDIDATE BIOMASS SOURCES IN 1978

Intergeneric Cross Clone Identification
Saccharum x Eulalia longisetous US 72-1304
Saccharum x Sorghum rex US 61-66-56
Saccharum x Sclerostachya fusca US 71-221
Saccharum x Ripidium sp.
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 kanashirot x R. bengalense (Intrageneric) US 61-37-7
R. bengalense x R. bengalense (Intraspecific) US 60-38

Page 105 - TABLE 14.

TABLE 15. TROPICAL GRASSES IMPORTED IN 1970 TO PUERTO RICO FOR EVALUATION AS BIOMASS SOURCES

For Crop — Period	Plant	1st Ratoon	2nd Ratoon	Mean
July 15—Sept. 15	30.3	29.8	-	-
Sept. 15—Nov. 15	2.2	20.2	-	-
Nov. 15—Jan. 15	1a	10.0	15.5	-
Jan. 15—Mar. 15	6.0	9.9	9.4	-
Mar. 15—May 15	as.t	20.0	20.4	10.0	10.0
May 15—July 15	-	-	-	-

Table 22, Seasonal Influence on Dry Matter Yield by Three Crops of Napier Grass; 2-Month Harvests

For Crop — Period	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	-	18.1
Jan. 15—Mar. 15	7.0	-	13.6	9.3
Mar. 15—May 15	-	21.8	25.2	26.1
May 15—July 15	10.2	12.6	-	-

Table 23, Seasonal Influence on Dry Matter Yields by Three Crops of Sugarcane and Napier Grass; 4-Month Harvests

For Crop — Period	Plant	1st Ratoon	2nd Ratoon	Mean
Sugarcane				
July 15—Nov. 15	30.6	-	46.8	41
Nov. 15—Mar. 15	32.4	14.2	21.8	22.8
Mar. 15—July 15	36.9	38.5	31.2	35.6
Napier Grass				
July 15—Nov. 15	25.2	33.6	36.3	-
Nov. 15—Mar. 15	47.1	2.9	23.6	27.5
Mar. 15—July 15	37.6	39.4	-	39.6

Table 24, Juice Quality Values for Three Sugarcane Varieties Propagated with Standard and Narrow Row Spacing

At Row Center — Variety	50cm	Change
PR 980	10.92	10.60
Mo 310	-	-
PR sb-i791	Wo.	i120
Px 960	-	310

Pa 64-1791 | Fiber | 980
17.07 | 07 | -
310 | 16:30 | -
PR 6t-d791 | tela 2 | Parity
rx 960 | 19.96 | a74s
9.3 | - | 310
wes | ale | 208
Pa 6i-t791 | 312806 | ae
7 580 | 5.22 | -
310 | - | Pe
skei791 | 10 | -

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	50cm	Change
PR 980	5.22	5.56
Noo 310	6.21	3.79
PR 64-1791	2.10	5.78
Mean	6.8	5.71

(I'm sorry, but the remaining text is too garbled for me to decipher. Could you provide a clearer version?)

1. Land Preparation: 19,000
2. Seedbed Preparation: $15.00/acre, 3,000
3. Trees (800 square feet at $15.00/sqft): 12,000
4. Seed (For Plant Crop Plus Two Matson Crops), Treatment rate at $13.00/10: 3,000
5. Fertilizer, at $80.00/acre: 4,000
6. Pesticides, at $26.50/acre: 3,300
7. Harvest, including equipment depreciation, and short-term labor, 1 year cost: $3.00/hour, 2,046 hours: $6,138
8. Land Preparation & Maintenance (Pre- and Post-Harvest), Delivery, at $7.00/ton: 22,000
9. Water cost is not included in other costs.

Total cost/tons ($68,025 + $6,600): $74,625
Total Cost/ton Baled: $25.46
One ton of dry matter would contain approximately 400 pounds of fermentable solids.
At 50% extraction, this represents 200 pounds of ethanol, equal to about 61 gallons of high-cost ethanol.

TABLE 27. PRELIMINARY COST ANALYSIS FOR ENERGY CANE VS CONVENTIONAL SUGARCANE PRODUCTION

1. Land Price ($979/acre): 12,000
2. Seedbed Preparation, at $15.00/acre: 12,000
3. Trees (For Plant Crop Plus Two Matson Crops): 2,500
4. Fertilizer application, at $68.00/acre: 8,000

5. Pesticides, at $26.50/acre: 5,300
6. Harvest, Depreciation, and Labor: 12,000
7. Short Term Labor, at $2.00/hour: 2,000
8. Cultivation, at $5.00/acre: 1,000
9. Land Preparation & Maintenance (Pre- and Post-Harvest): 600
10. Delivery, for 3 tons of cane: $2.70
Total Cost: $105,768.70
Management Cost: 10% of Total: $10,576.87
Total Cost/Ton: $116.35
Total Sugarcane: $44.64
Energy cane: $25.46
Total Cost/Gallon: $3.00

TABLE 29. ENERGY INPUT AND RECOVERY FROM ENERGY CANE PRODUCTION
Annual Energy Involvement Parameter:
Output: 279.12 BTU/Acre, 173.80 Kcal/Ha, 44.40 BTU/Ton
Input: 17.48 BTU/Acre, 6.46 Kcal/Ha
Balance: 251.08 BTU/Acre, 156.32 Kcal/Ha, 40.96 BTU/Ton
Output/Input: 9.95
Based on an annual dry matter yield of 33 OD tons/acre, less 640 lbs/OD ton as extracted fermentable solids. 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 BIU/bb1 of oil.

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

Harvest Date, Acreage Recovered 2, Harvested Acreage, Age (Months): 6 Months, 12 Months, 18 Months

1980 200, Feb. 1, 2901, Aug. 1, 2961, Feb. 1, 1982,

Note: For Plant crop only

TABLE 31, WHOLE CANE YIELDS FOR THREE VARIETIES RECEIVING VARIABLE SUPPLY; 12 MONTHS HARVEST, PLANT CROP

Yield (tons/acre), Supply 2, Variable, Attached Detached Variety

Goa/here Year, "Stena" - Tops, "Trea Trea Tost"

US 67-22-2 200, 6, 9, 100, 600, 323,

70-701 200, 26, 26,

Note: N source was ammonium sulfate in IG-L-6 fertilizer ratio.

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

Total GM (Tons/A), Variety, 12 Months, 18 Months, Tons Increase Increase

PR 980, 138.7, 25.0, 22.6,

US 67-22-2, 166.4,

70-701, 319, 30.9,

Mean, 15.0, 31.6,

Note: Each figure is the computed mean of 4 replications and 3 regions. Includes both attached and detached trash.

TABLE 33, GM YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6 AND 18 MONTHS INTERVALS; PLANT CROP

GM Yield (tons/A), At Month, Variety, 6, 12, 18

PR 980, 51.6, 66.6, 49.3,

US 67-22-2, 60.8, 6.0, 51.5,

70-701, 53.8, 61.3, 470,

Mean, 15.1, 1465.1,

Note: Includes utilizable stems, tops, and attached trash, but does not include detached trash.

TABLE 1. MILLABLE CANE YIELD FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6-AND 18-MONTH INTERVALS; PLANT CROP

Millable Cane (Tons/Acre), Age in Months ~ Variety 6 12 18 Total

PR 980 34.9 17.4 US. 67-22-2 338 Seas 7.7 B 70-701 3425 407.2

Mean 474 RT 16.1

Mean of PR 980 118.2 US 67=22-2

WRT B 70-701, 10:6

Mean 122.0

Each figure is the computed mean of four replicates and three regions.

TABLE 2. TOTAL DRY MATTER YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6-AND 18-MONTH INTERVALS; PLANT CROP

Total Dry Matter Yield (Tons/Acre)

PR 980 56.1 US 67-22-2 65.7 B 70-701 58.8

Mean 60.2

Each figure is the computed mean of four replicates and three regions.

TABLE 3. DRY MATTER YIELDS FOR THREE VARIETIES HARVESTED AT 12-AND 18-MONTHS INTERVALS; PLANT CROP

Dry Matter Yield (Tons/Acre), Age in Months ~ Variety 12 18 Tons Increase

PR 980 36.6 US 67-22-2 65.7 23.8 B 70-701 38.8 2.6

Mean 36.6 35 70.9

Includes detached trash 1X Increase 478 56.8

TABLE 4. TRASH YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED AT 6-AND 18-MONTHS; PLANT CROP

Variety Total Trash Yield (Tons/Acre)

PR 980 40 7.3 16.6 US 67-22-2 an 89 wt B 70-701 37 6.2 15.7

Mean 38 73 at

Trash Yield (Tons/Acre)

PR 980 23.3 US 67~22-2 26:9 B 70-701 21.2 23.8

Each figure is the computed mean of four replicates and three regions, and includes both attached and detached trash.

TABLE 5. MEAN JUICE QUALITY AND SUGAR YIELD VALUES FOR THREE ENERGY CANE VARIETIES HARVESTED AT 12-AND 18-MONTH INTERVALS: PLANT CROP

Juice Quality Parameter — Yield (Tons/Acre) — Variety 12 Months 18 Months

PR 980 bo Wt we ws Te 6 23 ea? ara as

US 67-22-2 121.1 8s 2 Le De Ba we a3

B 70-701 2 56079 6 07

The corrected text is:

This text seems to be a mix of tables, notes, and possibly some coding. It's difficult to correct it without full context or understanding the intended meaning, but I've tried to clean up the formatting:

TABLE 44: ENERGY YIELDS FROM FIRST AND SECOND GENERATION ENERGY CANES; PLANT CROPS
BTUs/Acre (x 10^8): Bagasse, Trash, Total
2a: 35, 286, 336
uy: 433, 45, na

TABLE 45: NET ENERGY BALANCES FOR PRODUCTION OF THREE SECOND GENERATION ENERGY CANES; PLANT CROP, 12 MONTHS
BTUs/Acre (x 10^8), Ratio
Variety: Output, Input, Balance (Output/Input)
7: 980 fos, 29.4, 374.7, 13.7
us 67-22-2: 470.3, 29.4, 440.9, 16.0
3 70-701: 493.8, 29.4, cond, 16.5
Mean: 452.5, 29.8, 23.1, 154

TABLE 46: ENERGY BALANCE AS A FUNCTION OF N SUPPLY; PLANT CROP
Energy Balance 1/ Lbs N/acre (Output/Expense)
200: 19.7
400: 15.4
600: 2s
1/ Mean of three varieties.

Values for ACO-Test Volumes for Energy Cane Acres
Yield/acre: Variety (tons/acre, tons/cut, etc.)

TABLE 48: PERFORMANCE EVALUATIONS FOR THE ROTARY SCYTHE OPERATING ON SORGHUM PLANTS

Mower, Scythe, Status, Crop Age, Cut Notes

Please note that I made assumptions about the content and formatting based on the available information. You may need to adjust this to fit your exact needs.

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

Plot No.	Mowing Height (in.)	Area (Acres)	Yield (Tons/Acre)
1	10	0.69	7.98
2	8-10	0.69	8.77
3	12	0.69	1.67
4	12	0.69	8.80

Note: This includes approximately 20% of the total dry matter in the form of unraked residues, which could not be windrowed with the available forage rake. Observations are based on subsequent production of new shoots.

[Unrecognizable text]

TABLE 52: DRY MATTER YIELD AND MOISTURE CONTENT VALUES FOR ENERGY CANE STUDY, HATILLO: SOME RANGES

Note: Certain details are not clear in the text provided and may need additional information or context.

TABLE 54: MOISTURE CONTENT CHANGES FOR NAPIER GRASS THAT WAS SOLAR-DRIED, BALED, AND STORED OUTDOORS

Note: Certain details are not clear in the text provided and may need additional information or context.

TABLE 55: MOISTURE CONTENT CHANGES IN VARIABLY-DRY NAPIER GRASS BALES STORED OUTDOORS

Storage Day	Bale Moisture Content (%)
4	60
Mean	36.5
Other Values	36.5, 32.2, 23.2, 22.0, 23.0, 21.8, 26.4, 15.8, 15.8, 26.0, 16.0, 15.4, 16.1, 15.5

Note: Harvested at 6 months of age.

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

Note: Certain details are not clear in the text provided and may need additional information or context.

Cane (1st Gen.) 2/36.0 95.9 208.5, 80.1 Cane (2nd Gen.) ¥ 50.2 124.9 126.6 99.9 Yield 39.098. ~107.7 as A/ Simulated PR Sugar Corporation, var. PR 980, unirrigated. 2/ Energy cane management, var. PR 9860, irrigated 3/ Energy cane management, var. US 67-22-2, irrigated. A/ Detached trash excluded.

M8 - TABLE 57, MILLABLE CANE YIELDS BY FIRST AND SECOND GENERATION ENERGY CANE; PLANT CROP, HATILLO Millable Cane (T/A), At Month — Treatment 6 12 18 Mean control 2/ 19.3638 TT 53.4 E. cane (1st Gen.) 2/ 24.0 82.6 98.3, 7.8 B. Cane (2nd Gen.) 2/ 34.7960 109.0, Mean 26.6 80.8 one 42/ Simulated PR Sugar Corporation, var. PR 980, unirrigated. 2/ Energy cane management, var. PR 980, irrigated. 13/ Energy cane management, var. US 67-22-2, irrigated.

14g - TABLE 58, DRY MATTER YIELDS FOR FIRST AND SECOND GENERATION ENERGY CANES PLANT CROP, HATILLO Tot. DM (Tons/A) Treatment, 6 12 Mean control 2/ 5.7 29.4 30.0 28 E.cane (1st Gen.) 2/ 5.9 32.8 37.0 25.2 B. Cane (2nd Gen.) 2/ 8.8 50.5 49.6 36.3 Mean 8 A/ Simulated PR Sugar Corporation, var. PR 980, unirrigated 2/ Energy cane management, var. PR 960, irrigated. 3/ Energy cane management, var. US 67-22-2, irrigated. 4/ Detached trash included.

TABLE 59. CANE QUALITY & SUGAR YIELDS BY FIRST AND SECOND GENERATION ENERGY CANE 12-MONTH HARVEST, PLANT CROP, HATILLO (Quality Parameter — Treatment Month Pol Trix Fiber Purity Yield. Control 276 97 TS bt 6.83.9 Cane (1st Gen.) 120 9.5 22 Cane (2nd Gen.) 22 10.3 18.3 AT 16.8 %.0 7.8

TABLE 60. TRASH YIELDS IN FIRST AND SECOND GENERATION ENERGY CANE AT HATILLO; PLANT CROP Treatment Cane (1st Gen.) 2/ 62 37 Cane (2nd Gen.) 2. Mean 38 Simulated PR Sugar Corporation. 2/ Variety PR 580. 3/ Variety US 67-23-2

TABLE 61. RELATIVE BIOMASS AND SUGAR YIELDS BY ENERGY CANE VARIETY US

The text seems to contain a lot of errors and misplaced numbers, and without context, it's challenging to correct it fully. However, here's a possible interpretation:

"67=22-2 AP, LAS 480, HATILLO. Series: 12,416 months, plant crop total of (E/n). Month Lajas Hattilo, tonnage difference 1, difference 2 notes 128.9. Mele lies 98, he ios tae as 22, 20.5. Cane/acre 2,589, 96.5 = 28,239. Santo lah 583, tone sugar/acre 2, 35, 78 = 0.7.

133 - TABLE 62. SUGARCANE CROSSES FOR BIOMASS; NOV.-DEC., 1979. Female Parent B77 x Neo 310, Nco 310 x PR 62-195 x PR 68-330 x R960 x PR 67-1070 x PR 64-1618 x Male Parent. Objectives: ST-NC-34 Fiber only, US 67-22-2 Fiber & Fermentable 8.

Table 63. Tons cane per acre and tons dry matter per acre for six progeny of the cross US 67-22-2 x B 70-701. Progeny total 93.7, 9.7, 2.7306.

155 - Table 64. Growth features of the top six progeny from the cross US 67-22-2 x B 70-701. Stem characteristics: height, diameter. Progeny (a) (cm) No./Acre.

165 - Table 65. Qualitative values for the top six progeny of the cross US 67-22-2 x B 70-701. Parameter — Progeny Pol Brix E Fiber Purity Sucrose.

137 - Table 66."

Please provide more context or specific information for a more accurate correction.

"Sugarcane Crosses for Biomass and Sugar: 1978 Breeding Season"
Cross: Second Number
Ros Selections: Seton 79-4
PR 67-245 x S. sp. RP 2! 5 7-12
US 67-22-2 x PR 68-3061 2/
AG 79-5 PR 68-330 x US 67-22-2 2/
73-6 PR 67-1070 x US 67-22-22/
YG 79-3 F 160 x US 67-22-2 2F
3 79-17 68-3061 x US 67-22-2 10
79-16 US 67-22-2 x F 160 2 A/

These are being evaluated in 20" x 20° field-plot tests for biomass. Two progeny had been crossed with conventional breeding canes during the 1961 cane breeding season.

Table 67: Cane Crosses for Biomass: 1979 Breeding Season
Cross: Bo-1 PR 980 x S. sp. RP
Cross: PR GAteiB x S. sp. Sop
Cross: PR-66-255 x S. sp. Rs.
Cross: 80-27 PR 1019S x PR II-DSI-137 BH Ss Aps 2/

These crosses are being evaluated in 20" x 20" field-plot tests for biomass and sugar.

Table 68: Cane Losses for Biomass - Performed During 1980 Breeding Season
Cross: Neo Bio x US 67-22-28 10
Cross: CO 310 x S 70-701
Cross: PR 69-3061 x 1-29 PR 70-260

Cross: PR IED B30 Fy (PR 66-955 x S. cob.) & FLOR 67-1070
Cross: RP a137 (PR 68-355 5. 208) x Fy (PR 67-1070 « S. ap. me) x (PR 68-395 KS Fob.)

Table 69: Sugarcane Crosses for Biomass: 1981 Breeding Season
Cross: 82-2 PR 62-195 x PR 9-4-1 3C, S. sp.
Cross: 82-23 TAC 51/205 x PR 79-4-3 3C, S. sp.
Cross: 82-30 76-424 x Fy (PR 68-355 x Bc, S. rob. / 57 NC 54)
Cross: 82-33 PR 67-1070 x F (PR 68-355 x BC, Ss. 357. NC 54)

Crosses are to be evaluated for biomass and sugar.