CEER-B-170 PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE THIRD QUARTERLY REPORT 1978-1979 - THE UNITED STATES DEPARTMENT OF ENERGY CENTER FOR ENERGY AND

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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE Second Annual Report 1978-1979 To The United States Department of Energy, Oak Ridge Operations Office, and the Division of Solar Technology Fuels From Biomass Systems Branch Washington, D.C. By The University of Puerto Rico Center for Energy and Environment Research Through The Office of the President University of Puerto Rico CONTRACT NO. ET-78-8-05-$912 (AES-UPR Project C~481) PERIOD COVERED: June 1, 1978—May 31, 1979 ENDORSEMENT: By Project Leader Alex G. Alexander

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SECOND ANNUAL REPORT 1978-1979

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

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ABSTRACT

Research continued on tropical grasses from Saccharum and related genera as sources of intensively-produced, solar-dried biomass. Categories of candidate grasses include short-, intermediate-, and long-rotation species. These categories are based on the time interval required for maximum dry matter production, and on future management requirements of energy crops for intensive co-production with food crop commodities. Year 1 studies at the greenhouse and field-plot levels were continued and broadened during Year 2. This included candidate screening, importation and quarantine of new clones, breeding, controlled nitrogen and water regimes, chemical growth control, tissue expansion and maturation control, seeding rates, harvest frequency, and variable row spacing. Second-year studies were extended to the project's field-scale and mechanized-harvest phases, Those include initial economic analyses for the short-rotation category of candidate species. © contract no. ER 8-05-5912 (AES-UPE project C-481).

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

INTRODUCTION: The biomass production studies reported herein were initiated on June 1, 1978, as a contribution to the Biomass Energy Program of the UPR Center for Energy and Environment Research (CEER). This research deals with sugarcane, tropical grasses related to sugarcane, and other tropical grasses with large growth potentials on a year-round basis. Its basic promise is that such plant materials can be produced as a renewable, domestic source of fuels and chemical feedstocks that will substitute for imported fossil energy. The studies reported herein constitute Year 2 of a five-year work plan and the first year results under DOE contract no. ET-78-S-05-5912.

Project Objectives: Primary objectives include: (a) Determining the agronomic and economic feasibility of mechanized, year-round production of solar-dried biomass, through the intensive management of sugarcane and napier grass tropical forages, and (b) examination of alternate tropical grasses as potential sources for intensive biomass production. A secondary objective concerns the selection and breeding of new sugarcane progeny with superior biomass productivity as their principal attribute. © Contract No. ET-78-S-05-5912 (AES-UPR Project No. C-481).

Emphasis is directed towards a highly-intensive and mechanized production of tropical grasses as solar-dried forages. This is a deviation from conventional cane and cattle feed production in that total dry matter rather than sugar and food components is the principal valuable commodity. Management of Production inputs - particularly water, nitrogen, and candidate species, together with harvest frequency, will vary significantly from established procedures. On the other hand, advances in mechanized production and harvest operations within the sugar and cattle forage industries will be utilized to the maximum extent possible for the production of solar-dried biomass. Optimized production operations require identification of a few select clones and the conditions required for their management in an efficient manner.

Economically-realistic operation. This is being accomplished in the continued development of three project phases, including greenhouse, field-plot, and field-scale investigations (Table 1). A fourth phase, commercial-industrial operations, follows logically but lies beyond the scope of the present project. The second year's work herein reported deals with a continuation of the greenhouse and field-plot phases begun earlier (1), and includes initial field scale studies together with the first mechanization experiments.

The tropical grasses have never before been evaluated under conditions such that biomass energy would be the principal salable product. As a consequence, it is necessary to screen a broad range of candidate cultivars if the optimal yield capacity of these genera is to be realized. Under certain circumstances, existing sugar-and fiber-producing varieties may excel also in total biomass yield, but it is generally recognized that the growth attribute has not been fully intensified in the hybridization progress that led to the present-day varieties of commerce (2,3,4).

Screening studies have therefore included older hybrid varieties no longer produced commercially, “noble” or pure intraspecific clones, superior selections from wild populations, and more primitive forms bearing the germplasm from which modern genotypes have been assembled. A screening technique was adopted for this purpose in which deviant, physiological, and agronomic attributes are evaluated in a stepwise program involving greenhouse, field-plot, and field-scale trials.

In certain respects, this is a tropical application of the herbaceous species screening concept originally formulated by the DOE Fuels From Biomass Program (5,6). A breeding program designed to intensify the biomass-yielding attribute of Saccharum and related species lies beyond the scope of this project. Thorough breeding.

Studies would require and justify a separate project. This would include the screening of candidate parental types, a physiological phase to synchronize flowering periods at the intergeneric level, and basic genetic research to break some serious constraints operating to prevent the exchange of germplasm among Saccharum and allied genera (7,8). At a very modest level, some limited breeding is included in the present project. This work is confined to a few obviously desirable parent clones that have suitable flowering characteristics and which can be incorporated without inconvenience into an ongoing breeding program for sugarcane (9). Certain progeny originating with the AUS-UPR sugarcane breeding program are also being considered as long-rotation biomass candidates. Under these circumstances, some prospect is created for the emergence of superior new progeny at very little expense. Categories in detail on tropical grass candidates for biomass are on page H-43.

3 This report covers the period June 1, 1978, through May 31, 1979. Some of the longer-term experiments were not initiated until after July 1, 1978, and first-ratoon data are presented from Year 1 plantings. In these instances, final harvests were not complete at the close of Year 2. For example, the first-ratoon yields of the first major field-plot study on sugarcane, a 36-month experiment dealing with harvest frequency, varieties, and row spacing, were completed only through the tenth month by the end of May, 1979. The compiled data thus include five of six 2-month harvests, two of three 4-month harvests, and one of two 6-month harvests. Similarly, statistical analyses are confined to "within harvest" variables, since the "between harvest" analyses would have little meaning if based on an incomplete set of data. The finalized data for Year 2 will appear in the first quarterly report of the project's third year. Certain of the results recorded in this report were presented in fragmentary form in earlier quarterly statements. In a few cases, these

Findings will be reiterated here as they were originally given. However, to the maximum extent possible, prior findings will be represented in the clearer perspective of two years' experience. The project's statistical data for Year 2 will be presented both in this report and the quarterly report to follow.

TECHNICAL REPORT

A. GREENHOUSE STUDIES

The project's greenhouse phase is concerned with the screening of candidate tropical grasses and the response of superior cultivars to growth impact and management variables. Much information of this nature is obtained more rapidly and cheaply than is possible under field conditions. Greenhouse data are not definitive in the sense that direct field responses and cultural recommendations can be stated, but perhaps two-thirds or more 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 20,000 to 300,000 plants per acre, the greenhouse offers a level of precision for control of the individual plant that is not remotely possible in the field. This method is currently used in Puerto Rico for its economy of project resources; under temperate-climate conditions, it offers an economy of time where field work is seasonally limited to four or five favorable months per year.

1. Greenhouse Methods

All plants are propagated either by sand culture in glazed, 4-gallon pots, or in 1:1 or 2:1 mixtures of soil and cachaza contained in 10-liter control of water and galvanized drums (10). Sand culture offers precise control of water and nutrient variables. Soil-cachaza mixtures provide convenient media for determining relative growth rates, growth curves from germination to the young-adult stage, responses to chemical growth regulators, and tolerance to frequent recutting of candidates having superior growth potentials. Most candidates to date have been established with stem cuttings of uniform size, age, and vigor. A few candidates such as sweet sorghum varieties and the sorghum.

Sudan grass hybrids are established with true seed. Insects are controlled with weekly applications of Malathion. All plants receive controlled water and nutrient supplies that are not rate-limiting for growth.

Mott of the second-year experiments employed the interspecific sugarcane hybrid PR 980, a reference clone having recognized excellence as a high tonnage producer. However, in this capacity, PR 980 has not been very satisfactory (1). The major dry matter accumulation begins after 6 months and the project requires some cultivars that will do this as early as 2 to 3 months after planting.

Also, several Saccharum imports and AES cane breeding progeny have been identified already as tonnage producers superior to PR 980. When possible, future reference clones will be selected from the specific category of candidates under scrutiny, i.e., Sordan 70-A for short-rotation candidates, Napier grass (var. Merker) for intermediate rotations, and a suitable spontaneous hybrid for the long-rotation category.

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

The principal biomass parameters measured during the second year included total green weight, dry weight (oven dried to about 6% moisture), dry matter content (% DM), and water content (% moisture). Leaf samples, including the entire blades of leaf ranks +1 and +2, are harvested for foliar mineral analyses. In some experiments, leaf samples are harvested for blade-area and saccharum officinarum (9/16) x S. spontaneum (5/16) x S. sinense. The uppermost leaf bearing a fully-emerged overlap is designated "+1". In sugarcane, this is the young leaves are designated.

"+2, +3, 1st fully developed leaf. Progressively older tissue, while progressively younger leaves are still 0, 2, =2, etc.

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

Screening

The first clearly outstanding candidate to emerge during the project's first year is a sweet sorghum x Sudan grass hybrid produced by the Northrup-King Company (11). Marketed under the trade name "Sordan 70A," this hybrid has shown considerable growth potential as a cattle forage on Puerto Rico's arid south coast (12). For biomass production, it is basically a short-rotation candidate, that is, it makes very rapid growth over a short time-course, and completes both tissue-expansion and maturation phase within about 9 or 10 weeks after seeding (1). It is rather severely attacked by insects, is highly consumptive of water, and is susceptible to downy mildew disease.

A greenhouse experiment comparing Sordan 70A with three intermediate rotation candidates (napier grass and two napier hybrids) and sugarcane was initiated during Year 1 and completed during the first quarter of Year 2. Harvested at 6-week intervals over a time-course of 30 weeks, Sordan 70A was the superior biomass producer at 6 weeks and approached the productivity of Napier grass over the entire 30-week period (Table 3). Sugarcane (PR 980) was not an effective biomass producer when harvested this frequently.

This correctly belongs in long-rotation studies allowing 6 to 12 months for both tissue expansion and maturation to be..."

Completed. The Napier grass hybrid PI 30086 was superior to common Napier grass at 18 weeks (1) and this relationship persisted through week 30 (Table 3). Although we have less information about this hybrid in Puerto Rico than we have for common Napier grass (var. Merker), we have increased seed of PI 30086 during Year 2 as a replacement for Merker in forthcoming biomass field experiments. Dry matter percentages for the same five clones remained persistently low until the final six weeks of the study (Table 4). At this time each clone appreciably increased its dry matter content. Since the harvested material itself was only six weeks old, as was true of all prior material, the higher values suggest that the aged crowns produce shoots with a better fiber-yielding capability than do younger crowns. Putting this another way, the age of the shoots was not the only factor governing the shoot's maturation. This in itself would not be remarkable since maturation rates can be altered by numerous management and treatment variables; however, none of these were introduced here and the only accountable variable is the age of the crowns.

Two other NK hybrids were evaluated during the first quarter using Sudan 704 as the reference variety. These were Trudan 5, a true hybrid grass, and Millex 23, a growth-resistant Pearl Millet hybrid (11). Over a time-course of 14 weeks, Trudan 5 and Sudan 704 produced virtually identical green weight, dry weight, and DM values (Table 5). Millex 23 was inferior to Trudan 5 and Sudan 704 (Figure 1). The similarity between Trudan 5 and Sudan 704 is encouraging in the sense that one variety or the other could be disqualified as a biomass production candidate. This situation could arise owing to disease or insect susceptibility, drought intolerance, salinity or pH factors, etc. The principal strong point of Millex 23, its drought tolerance, was not a factor in this experiment where water supplies were adequate for all varieties.

-9- 3. Candidate Grass Superior to Sudan

704 While Sordan 70A is regarded as an extremely promising candidate for various production, a series of screening experiments have been initiated with the objective of identifying superior or more versatile candidates. The reasons for this are as follows: (a) There is a strong likelihood that the same breeding programs for commercial forage grasses that produced Sordan 70A could also yield superior biomass-yielding varieties; (b) candidates are needed with greater tolerance to severe heat and drought conditions; (c) greater disease resistance is needed (Sordan 70A has shown downy mildew susceptibility in Puerto Rico); (d) there is a need for somewhat longer-during grass to supplement Napier grass and Napier hybrids in the intermediate-rotation category; and (e) there is also a need for shorter-maturing grasses to accommodate extremely short-rotation situations. One screening experiment initiated during the second quarter included seven forage grasses from the same breeding program (Northrup King Company) that produced Sordan 70A. In this instance, Sordan 70A was retained as the standard or reference variety. Dry matter yield values were recorded from weeks 3 through 7 (Table 6). In essence, this covers the period of rapid tissue expansion for Sordan 70h. On an individual plant basis, Sordan 70A appeared to outyield each of the other grasses by week 7; however, the difference was statistically significant only in the instance of Millex 23. At the time this experiment was terminated, it was felt that the total productivity of varieties such as Sordan 77 and NK 300, when measured in terms of total dry matter/acre year, could conceivably equal or exceed that of Sordan 70A. This potential was borne out in subsequent experiments employing variable moisture regimes.

10 - 4. Candidate Screening with Multitovarid Moisture Regimes

Variable water regime studies were initiated during the second quarter. Treatments consisted of simulated humid, normal, and semi-arid growth regimes with a series of Northrup-King.

Forage grasses. In an additional experiment, it was initiated during the third quarter which included a simulated severe drought (arid) condition together with normal and semi-arid regimes. Johnson grass was also examined for the first time as a candidate minimum-tillage species. Seven Northrup-King grasses (Sordan 70A, Sordan 77, Trudan 5, Trudan 7, Millex 23, NK 300, and NK 326) plus Johnson grass, were seeded in a 1:2 soil/cachaza mixture and given adequate water supplies for two weeks to assure uniform germination. Variable moisture regimes were then established by varying the frequency of watering. Being under glass, with complete reliance upon irrigation, the moisture requirements of such plants are considerably intensified and variable degrees of moisture stress are easily simulated. The first harvest was performed one week after moisture variables were established (at 3 weeks of age), and harvests continued at weekly intervals until the plants were 12 weeks of age. Although this was an "observation" experiment without replications, several important trends emerged from the yield data: (a) Sordan 77 was superior to Sordan 70A at all moisture levels but progressively more so under moisture stress (Table 7); (b) the varieties NK 300, NK 326, and Johnson grass out yielded Sordan 70A under moisture stress but not when water was adequate; and (c) highest yields under the semi-arid and arid regimes were only 61% and 46%, respectively, of maximum yields with normal water supply. In an actual field cropping situation, minimum tillage plants would receive irrigation at the time of planting to assure germination even under the most arid conditions.

Mean values for main effects (for the different moisture regimes as a whole), indicate that little more than 50 to 60% of normal productivity can be expected from the present candidate species when subjected to moisture stress (Table 8). Plotted graphically (Figure 2), dry matter yields are not seen to plateau per se under moisture stress, and in fact, growth continues at a reduced rate.

The experiment continued until its conclusion. However, without adequate moisture, the plants were simply unable to sustain beyond week 4 the linear flush of growth which characterized normal water regimes through week 9. Of further interest was the inability of moisture-stress regimes to induce earlier maturation as main effects (Table 9). In other words, lack of moisture did not encourage the young plants to begin their physiological maturation earlier, as would have been evident in data for dry matter content. In sugarcane, for example, withholding moisture is the most effective means available to hasten maturation (24, chap. 11). However, the sugar planter deals with relatively old plants in which some level of maturation has already begun. In the present experiment, the essentially immature plants deprived of moisture simply continued their tissue-expansion processes at reduced rates. As a varietal effect, Trudan 7 continued to display a tendency toward early maturation in direct comparisons with Sordan 70A (Figure 3). Sordan 77 showed a similar tendency (Table 8). This property was noted previously in both species (9). As unreplicated data, these trends are not yet statistically verified, but they have important implications nonetheless. They suggest that a fairly large pool of short-rotation candidates exists having a productive capability at least equal to Sordan 70A under favorable growing conditions, and superior to Sordan 70A under adverse conditions. Putting it another way, a species offering the same quantity of biomass as Sordan 20A with less water is one that can be grown more cheaply, and under the kind of water constraints likely to prevail in Puerto Rico's future. The emergence of Johnson grass as a viable biomass candidate, from the role of an arid-loving "weed", is especially encouraging in this respect. One "ratoon" crop was harvested four weeks after the experiment's principal harvest was complete. Yield trends were very similar to those of the plant crop.

Although total DM was lower due to the immaturity of the ratoon plants, combined DM yield data for the two crops and three moisture regimes were compiled to evaluate varietal performance as main effects (Table 10). From these data, the varieties Sordan 77 and NK 326 are superior to Sordan 70 by an order of magnitude of 20 to 25%. The very favorable performance of Sordan 77 is consistent with Northrup King Company claims of its greater productivity and drought tolerance (13), and with our own earlier observations (9) in direct comparison with Sordan 70A. Together with downy mildew and insect resistance, these properties speak strongly for the replacement of Sordan 70A with Sordan 77 as the project's principal short-rotation species. However, a definite superiority of Sordan 77 must first be verified in replicated trials. Similarly, the superiority of NK 300 and NK 326 for arid environments must also be verified. The toughness of Johnson grass and the ease of its establishment and maintenance also favor its further study as short-rotation species for arid and semi-arid conditions.

Candidate Screening; Multiple-Rotation Tests: The first "multiple rotation" experiment of the project was begun during the third quarter. This involves the simultaneous propagation of discrete species having variable growth habits, and the harvest of part of each species population at different intervals coinciding with short and intermediate rotation cropping periods. This procedure enables multiple-species and multiple-category screening to proceed continually under conditions such that not all of the seed or cuttings needed for a year's work can be made available at one time. Candidate grasses for the on-going experiment include five Saccharum types regarded as potential replacements, or supplements, for napier grass (Gonewetum species), the outstanding intermediate-rotation candidate studied to date. Grasses in this category would maximize dry matter at 4 to 6 months after seeding (Table 1). The five Saccharus

The candidates include the S. spontaneum clones SES 231 and Tainan, the domestic S. spontaneus hybrids US 67-22-2 and US 72-70, and a wild S. caneum hybrid collected in the Rio Piedras of S. spontaneum. Additional test varieties for this experiment included PR 980, a confirmed long-rotation sugarcane hybrid, and the hybrid Napier grass PR 30086. The latter is classified as an intermediate-rotation plant (1,15) with a biomass potential moderately superior to common Napier grass (var. Merker). Also being tested is common Johnson grass (Sorghum halepense). Originally brought into Puerto Rico as a cattle forage, Johnson grass has “escaped” to the wild and is regarded as a weed by land owners along the semi-arid south coast. However, its unattended growth in the Lajas region is sufficiently impressive to warrant testing as both a short and intermediate-rotation species. It is also a potential “low till" candidate in view of its excellent survival properties under semi-arid conditions. All test species were propagated in the greenhouse using a 1:2 soil/cachaza mixture as the growth medium. Water supplies were adequate to sustain maximum growth for all candidates. There were three replications of each treatment arranged in a randomized block design.

A single candidate species, Johnson grass, gave a clearly outstanding performance for the first two-month growth period (Figure 4). It is the only candidate that appears suitable for further consideration as a short-rotation species. Napier grass hybrid PI 30086 also produced superior growth (Table 11), but Pennisetum species are already known to maximize their dry matter yields over a longer time course, that is, between 4 and 6 months after planting (1,15,16). All of the six S.

spontaneum candidates gave growth performances that were roughly equal and unimpressive. Dry matter content ranged from 14.1 percent for Napier grass to 20.0 percent for SES 231 (Table 11). This indicates that none of the species, including Johnson grass, had completed their maturation phase.

6. Growth Regulator Experiments

The plant growth inhibitor Polaris (Monsanto Agricultural Products Co.) produces increased growth in sugarcane when applied in low concentrations as an aqueous foliar spray (18,1). Initial attempts to induce the same effect in Sorden 70 were made during the first quarter of Year 2. Polaris was administered to 3 weeks-old plants propagated in a soil-cachara mixture, and whole plants were harvested for growth evaluations from weeks 2 to 8. Polaris concentrations ranged.

From $0 to 600 ppm. Dry weight yields were increased moderately (about 35%) by the fourth week after treatment with 200 ppm Polaris, but the effect did not persist to the sixth week (Table 16).

16 - Dry matter was maximized in all Polaris-treated plants two weeks earlier than in control plants (Figure 5). This latter response, even when total yields are not increased, could itself be highly desirable in short-rotation crops where timing of the harvest is a critical factor. The Polaris effects on Sordan 70A require further study with special reference to the timing of application. Efforts were made to repress growth in Sordan 70A using Polaris concentrations of 2000 and 4000 ppm. These levels will terminate all tissue expansion activity in sugarcane and drastically increase the rates of sucrose accumulation (18). Only slight repression was noted in Sordan 70A, even by 4000 ppm Polaris (Table 17). By the sixth week after treatment, the high Polaris plants were moderately exceeding control plants in dry matter production. Although this was only a small observation experiment, at this point the sensitivity of Sordan 70A to Polaris appears totally different from that of Saccharum species.

Nutrition - A nitrogen nutrition experiment established late in Year 1 was completed during the first quarter of Year 2. Variable nitrate-N levels were provided to Sordan 70A to establish the plant's N-response curve. The objective was to determine the slope of the dry matter response to progressively higher levels of N. Accordingly, N supplies were increased in a geometric progression from 1.0 to 61.0 milliequivalents per liter of NO3. The 1.0 meq/l treatment would be deficient for virtually all plants. By way of reference, an N supply of 61.0 meq/l is much more than sugarcane can utilize efficiently (14).

Growth data recorded at 4, 8, and 12 weeks after seeding are illustrated in Figure 6. Over this time course, maximum dry weights were produced by the 3, 9, and 27 meq/l treatments, respectively.

This may reflect the plant's increasingly well-developed root system with advancing age. There were no growth increases as NO3 was doubled to 54 meq/1, and significant growth repression occurred as NO3 was raised to 81 meq/1 (Table 18). It should be noted that, during the plant's rapid growth phase (from 0 to 8 weeks), there were no significant growth responses to NO3 levels higher than 9 ueq/1. Higher N levels may be needed to maximize Sordan fiber accumulating phase which occurs approximately between weeks 6 and 10 under field conditions (1). Optimal dry matter percentages were a function of N supply in young material (4 and 8 weeks) but there were no significant differences for dry matter content in mature plants (Table 16). Nutritional information obtained by the sand culture technique is not directly applicable to field conditions; however, important relationships of nutrient supply to growth potential are revealed in this way. For example, the shape of the N-response curve is a characteristic feature of the candidate variety or species whether propagated in soil in an open field or by nutrient culture under glass. The response curve for Sordan 70A appears quite favorable in that a distinct growth plateau is reached beyond which additional N supplies are wasteful (Figure 6). Moreover, NO3 concentrations higher than 9 weq/1 significantly reduced the number of plants/plot (Table 19), while 27 meq/1 very severely restricted the number of regrowth stems following the final harvest (Table 20). By contrast, NO3 levels in the order of 54 or 61 meq/1 produce very profuse tillering in sugarcane (19).

Foliar mineral analyses for 12-week old plants suggest an inability of Sordan 70A to incorporate N from solutions containing more than 27 meq/1 of this element (Table 21). The absorption data actually corresponded quite closely with the N-response curve for dry matter production (Figure 7). Both P and K incorporation was significantly increased at NO3 concentrations of 27 meq/1 and

Higher. (b) Napier Grass: Nitrogen-response curve studies were extended to the intermediate rotation category of tropical grasses during the second and third quarters of Year 2. The hybrid Napier grass PI 30086 was used as the representative cultivar. Plants were propagated with the same sand culture technique and nutrient levels employed earlier for Sordan 70A. Samples consisting of six whole plants per replicate were harvested when the plants were 8, 12, 16, and 22 weeks of age. Yield data for total dry matter indicate that never more than a fraction of the 81 meq/l of nitrate were needed to sustain maximum growth (Table 22). There were no appreciable yield responses to NO3 levels above 3 meq/l at 8 weeks (Figure 8), possibly reflecting a root zone too poorly developed to absorb much of the higher N level. However, a distinct growth pattern had begun to develop by week 12 showing a repressive effect of high NO3, and this trend was through week 22. By the close of the study at 22 weeks, there was no growth benefit whatever from supplying Napier grass with more than 3 meq/l of NO3 (Table 22, Figure 8). (c) N Requirements; Biomass vs Forage: One of the clearest examples to date of the need to distinguish between tropical grasses when propagated for conventional cattle forage on one hand, and the same species produced for biomass on the other, is presented in Figure 6 where N-response curves for Napier grass are graphically illustrated. As noted above, there was no need to supply these plants with more than 3 meq/l of NO3 to maximize total biomass in the time-frame when they were botanically most effective in producing biomass, i.e., between 5 and 6 months after planting. Nor was more than 3 meq/l of NO3 needed to maximize maturity at this period (Figure 9). Conversely, 27 times this amount of NO3 (81 meq/l) was hardly sufficient to maximize biomass when the plants were only 4 weeks of age. Ironically, our present understanding of the growth management requirements of Napier grass come from forage.

Studies where 8-week old material is almost excessively old and where harvests are normally performed at 4 to 6-week intervals (20,21,22). In producing Napier grass for cattle feed, emphasis is understandably directed towards large numbers of succulent stems having high water content, low fiber content, and a high content of soluble protein (20). These conditions are encouraged by high nitrogen fertilization. In one Puerto Rican study with common Napier grass (var. Merker), high nitrogen treatments in the order of 2000 lbs of elemental nitrogen per acre per year did not fully maximize the plant yields as cattle forage (22). This level is perhaps three times the quantity that a Puerto Rican farmer could afford to purchase at 1979 fertilizer costs. Moreover, the ecological impacts of using such high fertilizer levels are unknown and could very possibly be detrimental if the practice were pursued for any appreciable length of time. A vastly more favorable picture is emerging for the nitrogen requirements of Napier grass grown as an energy crop. First, the harvest rate from frequent recutting (at 6-week intervals) will be lowered appreciably when the same species is harvested for energy (at 16 to 24-week intervals). Second, the more mature energy plants should have a correspondingly better root development.

And hence, a more efficient utilization of applied nitrogen. Third, in a purely quantitative sense, the elemental nitrogen needed to produce fiber (mainly cellulose, hemicellulose, and lignin) is less than that needed to produce soluble protein. Taken together with the potential improvements in soil ecology (resulting from fewer heavy machinery operations and lower nitrogen applications to agricultural lands), these factors suggest that energy planting will be a far simpler and less costly operation even when dealing with a species whose management needs have supposedly been known for years.

8. Variable Moisture Regimes

The first variable-moisture study of the project was performed during the first and second quarters of Year 2.

Using the same Northrup-King varieties discussed on pages 9 to 12, it was a non-replicated observation experiment in which humid, normal, and semi-arid conditions were simulated by varying the frequency of plant watering. All plants were propagated in the greenhouse in a 1:2 mixture of soil and cachaza, and Sordan 70A again served as the reference variety. In this instance, the experiment's duration was extended to 11 weeks, thereby encompassing both the tissue-expansion and maturation phases of Sordan 70A (1). Summary data for all varieties revealed the following trends: (a) The “humid" regime in which the propagation medium was kept constantly moist was repressive for total Di production (Table 23), while the “normal” regime was superior to both humid and semi-arid conditions; (b), mean values for dry matter content indicate that, as a group, the candidate grasses experienced a rapid maturation phase from week 6 to 10 (Figure 10); (c), individual varieties, in direct comparisons with Sordan 70A and propagated with normal water regimes, revealed a much superior maturation curve for Trudan 7 (both earlier and more extensive DM accumulation), and an inferior maturation curve for Millex 23 (Figure 11); (d), under semi-arid regimes, the varieties Trudan 7, Sordan 77, NK 300, and NK 326 gave growth performances which equaled or exceeded those of Sordan 70A (Table 24, Figure 12).

Importation and Quarantine: A number of Saccharum clones and clones from both related and unrelated Tropical Grasses genera were available in Puerto Rico for screening as biomass candidates when this 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. 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 include 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 25) is available. The Beltsville shipment consists entirely of S. robusta clones, a species which has been noticeably lacking in Puerto Rico. The majority of the Canal Point group are spontaneous clones. This group also includes germplasm from the genus Ripidium, Miscanthus, and Erianthus, along with the Saccharum species S. fusca, S. narenga, and robusta. These candidates were planted in soil-cachasa mixtures and all but one have shown satisfactory germination. Growth has been adequate though unremarkable for most clones. Several clones produced tassels (flowers) late in November and December 1978. Saccharum species very rarely flower under greenhouse conditions, but the late flowering trait could be a useful factor. It could ensure 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-summer time of planting. None of the imported species are thought to be suited for short-rotation cropping. They are regarded as candidates for long-rotation and minimum tillage biomass crops, although certain 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 is to find superior producers of dry biomass (fiber) for intensive propagation as solar-dried forages. It's also important to find minimum-tillage candidates that will survive and produce acceptable yields under arid conditions and various types of marginal lands.

5. FIELD PLOT STUDIES

A. Saccharum Species Candidates: Gurabo Substation

An observation field-plot study.

With the candidate S. spontaneum and S. sinense clones, a study has been underway at the AES-UPR Gurabo Substation since October 1977. The principal objective was to define the total biomass-producing capabilities of these candidates. A second objective was to determine their qualitative value when sufficiently-aged plants became available. Interestingly, 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.

3. Total Biomass Production: The final harvest, completing one year of growth evaluations, was taken during October of 1978 (Table 26). Cut repeatedly at 2-month intervals during the final eight months of Year 1, the plants were subjected to a reharvest syndrome comparable to that of short-rotation cropping. Under this harvest regime, the S. spontaneum clones SES 317 and SES 327 died out, as did the one Erianthus ravennae clone tested to date, NC 132. Yield values (Table 26), together with tillering and maturation characteristics (Table 27), indicate that three outstanding candidates emerged in two categories.

The first group is dominated by the S. spontaneum clone SES 231, a wiry, thin-stemmed grass having no sugar potential, but persistently high fiber production per acre year. It tillers abundantly and has a fairly high dry matter content for 2-month old material (Table 27, Figure 19). Similar traits were evident to a lesser degree in the S. sinense clones Chunnee and Tainan.

The second category includes thick-stemmed S. spontaneum clones having a sugar-yielding capability in addition to high fiber production. The outstanding clone is US 67-22-2, followed closely by US 72-70 (Table 26). Their dry matter yields slightly exceed that of SES 231 while exceeding the commercial hybrid reference clone (PR 980) by roughly 50 percent. Neither US 67-222 nor US 72-70 tillered as profusely as SES-231, but

Nonetheless, they produced more than double the number of stems recorded for PR 980. Each of the three outstanding grasses is regarded as a potential mini candidate for field plot trials on the Island's semi-arid south coast. At this point in time, SES 231 is viewed as an intermediate-rotation candidate to be harvested as a solar-dried forage at intervals of 4 to 6 months. There is some possibility also that it can serve as a dryland short-rotation crop to be harvested at 2 to 3 month intervals. The thick-stemmed grasses, US 67-22-2 and US 72-70, should probably stand a year between harvests to obtain both sugar and fiber. In any case, these varieties would require milling as a dewatering step in their processing operations for fuels. They cannot be accommodated by any existing equipment for production of solar-dried forages. The S. spontaneus and S. sinense crowns presently established at the Gurabo Substation are being retained for one additional year. This will provide the project with data on the long-term durability of such species without accruing the added time and expense of a new experiment. During the second year, these clones will also be managed as mini tillage crops receiving low water, fertilizer, and pesticide inputs. Harvest intervals are being extended from two months to six months.

(b) Qualitative Characteristics: The first qualitative data for this group of species became available during the third quarter. Very little was expected by way of sugar-producing potential and a majority of the candidates in fact showed very poor juice quality (Table 28). However, surprisingly favorable values for polarization, brix, fiber, purity, and rendement were recorded with US 67-22-2. The qualitative performance of this S. spontaneum clone clearly exceeded that of the reference variety, PR 980. The latter is an interspecific hybrid which for many years has been a superior sugar producer in Puerto Rico. Hence, there is a distinct possibility that US 67-22-2 can assume a dual role of biomass.

and sugar production in Puerto Rico's future. 'As expected, the thin-stemmed clone SES-231 contained virtually no sugar but high fiber (Table 28). Very similar values were obtained for the unknown S. spontaneum hybrid which has attracted the interest of this project. The qualitative data for this plant strongly suggest that its parents were both original S. spontaneum clones (23).

Water was administered by overhead sprinklers at planting and by flooding as needed thereafter. Whole plots were harvested for green-weight determinations at 10, 20, and 30 weeks following seeding. Sub-samples consisting of ten whole plants per plot were harvested and dried in a forced-air oven for dry matter determinations. Identical sub-samples were also harvested for foliar mineral analyses. The entire blades of leaf ranks +1 and +2 were oven-dried, ground to pass a 100-mesh screen, and submitted to the AES Central Analytical Laboratory for total N, P, and K analyses.

Although statistical analyses are still pending, neither increased N levels nor increased seeding rates appreciably raised the dry matter yields of Sordan 70A (Table 29). Similar results were obtained for total green matter (Table 30). While unexpected, these responses do have the effect of minimizing input costs for future planting of Sordan 70A.

(a) Responses to Variable N Supply: Mean values for increasing N supply indicate that the highest yields of the study were obtained from 600 lbs of N per acre (224 kg/ha), but that this constituted an increase of only four percent over the yields from 300 lbs N/acre (Table 29). Similarly, mean values for increased seeding rates reveal that the highest dry matter yields were produced by 100 lbs of seed per acre (112 kg/ha). This was an increase of only 10 percent over yields obtained from 60 lbs/acre. Yield gains of such low magnitude cannot justify the higher fertilizer and seed costs that would be incurred.

Foliar N analyses were consistent with the view that Sordan 70A made little or no response to

N-fertilization levels higher than 300 lbs/acre (Table 31), it should be noted that the dry matter and foliar N data are at least consistent with earlier data obtained by sand culture during Year 1 (2). At that time, the N-response curve revealed an abrupt plateau for dry matter which could not be altered by large increases in nitrate-N supply. It is now evident that the N-fertilization range established for this experiment was too high. The optimal level probably lies within the range of 390 to 300 lbs N/acre. This point can be verified rather easily with a small field plot experiment far less elaborate than the one presently described.

Maturation Responses to Variable N and Seeding Rates: Data from the first harvest (at 10 weeks) indicate that neither the N nor seeding-rate variables appreciably affected the plants' state of maturation. Mean values presented in Table 32 reflect only small decreases in dry matter content as a result of increased N supply and plant density, although fairly pronounced changes could have been expected, for example, on the basis of N effects upon sugarcane maturation processes (24,25). Tissue samples harvested weekly during the plants' growth and saturation phases similarly reveal little effect on saturation by the two controlled variables (Table 33).

Plotted graphically (Figure 13), the maturation curves for low-N and high-N plants are seen to differ persistently from week 4 onward, with high N causing a moderate delay in maturation, However, this delay amounts only to a week or less in the saturation time-course. It is interesting to note that all plants experienced a minor increase in dry matter at about week 3 (Figure 13). This may have been caused by a temporary soil moisture stress.

The plant number was increased by only 24 percent in response to a 100 percent increase in seed. Somewhat larger gains in harvestable plants resulted when seeding rates were increased within the lowest two N regimes (300 and 600 lbs/acre). These gains were negated in the higher N regimes (Table 34). Some evidence of downy mildew was detected at about the fifth week of the study. By week 10, the disease had spread in varying degrees to all plots. The infection was not sufficiently severe to reduce yields among any of the treatments; however, the apparent severity of this disease was visually ranked on a numerical scale to determine whether it was directly related to the land and seeding-rate variables. Some evidence of lodging was also visible in certain plots by week 10, and this was similarly rated on a numerical scale while the plots were being harvested. The numerical rankings indicate that downy mildew became moderately more severe with increasing levels of N fertilization (Table 35). Lodging was apparently unrelated to the variable N levels. In a similar vein, neither downy mildew nor lodging were related to variations in seeding rate (Table 36).

3. Sugarcane and Napier Grass Trials; Lajas Substation

A major study was conducted during Year 1 evaluating high-tonnage varieties (sugarcane and napier grass), row spacing (150 cm and 50 cm for sugarcane; 50 cm and 25 cm for napier grass), and harvest frequency (2-, 4, 6 and 12-month harvest intervals). Complete data for first-year results were presented in the first quarterly report of Year 2 (15). The study was continued during the project's second year with the following objectives: (a) to evaluate ratoon-crop responses, as opposed to "plant crop" responses; (b) to provide increased fertilization for plants receiving an apparently inadequate N supply during Year 1; and (c) to evaluate longer-term effects of narrow row centers and frequent recutting on plant crown productivity.

Irrigation and Crown Maturity: During Year 1, sugarcane received nitrogen at the rate of 300 lbs per acre, applied in three increments (2/5 at planting, 1/3 at 4 months, and 1/3 at 8 months). Napier grass received 600 lbs of nitrogen per acre, applied in three increments at the same time intervals. For Year 2, these levels were increased to 600 and 1200 lbs per acre for sugarcane and napier grass, respectively, by increasing the number of incremental applications from three to six (i.e., to six applications at two-month intervals). Growth data for the plant crop revealed major growth surges in the two months following the application of each fertilizer increment, followed by a growth decline for the subsequent two months preceding the next fertilizer increment (Figure 14). This response was more pronounced for napier grass than for sugarcane. One potential effect of applying fertilizer at two-month intervals rather than four months could be a persistent growth surge throughout the crop’s second year. Added to this, the increased maturity of the plant crowns (particularly for sugarcane) might logically sustain throughout Year 2, greater yields. Biomass yields for the first two 2-month harvests and the first 4-month harvest of Year 2 were summarized and discussed in the previous quarterly report (9). Yields for the third, fourth, and fifth 2-month harvests (Tables 37, 38 and 39), and the second 4-month harvest (Table 40) are herein reported.

Yield increments for the third and fourth 2-month harvests were progressively lower (Tables 37 and 38) than those reported earlier in the ratoon crop (9). This is possibly a reflection of Puerto Rico's "winter" season (mid December through mid-March). For varieties PR 980 and PR 64-1791, this also reflects a varietal inability to sustain crop vigor under the rather severe conditions of repeated harvest at close intervals. The fourth recutting, for example, produced on the whole little more than 1/3 of the dry matter obtained from July through November. At this writing (June,

1979) Many of these plots are losing their sugarcane crowns entirely; space formerly occupied by cane is being overgrown by Johnson grass. The sugarcane variety Nco 310 still retains considerable vigor. Napier grass yields also declined in the December-March period but proportionately less so than for sugarcane. In no instance was a consistent trend observed in response to narrow row centers. The fifth 2-month harvest revealed an increase of productivity (Table 39). This growth interval, covering the period March 15 to May 15, represents Puerto Rico's spring and early summer. The renewed productivity is hence interpreted as a seasonal response. Somewhat more favorable yields were obtained from the second 4-month harvest (Table 40). Nonetheless, dry matter production for sugarcane was only 40-50 percent of the levels obtained earlier under "summer" conditions (9). Napier grass yields also were about 40 percent lower for the second 4-month harvest. Again, no appreciable differences could be shown for the narrow-row treatments (Table 40). Hence, seasonal effects on plant yield are more evident in the first ratoon crop than in the plant crop, since in this case yield decline cannot be attributed to lack of nitrogen.

(c) Total Yields and 6-Month Harvests: By the end of the fourth quarter, combined yield data were available for four 2-month harvests, two 4-month harvests, and one 6-month harvest. Although the data are incomplete, several trends are quite clearly evident for sugarcane and Napier grass as main effects (Table 41): (a) Sugarcane yields increase as harvest frequency is decreased; (b) Napier grass yields are far superior to those of sugarcane at frequent harvests (at 2- and 4-month intervals); and (c) both sugarcane and Napier grass experienced major yield declines from months 4 to 8 (November-February). These trends are identical to those reported previously for the plant crop (9). Consistent differences have now emerged in the performances of individual sugarcane varieties (Table 42).

Variety NCo 310 was apparently superior to PR 980 and PR 64-1791 at each harvest interval. This trend was most pronounced at the 2-month interval where NCo 310 exceeded PR 980 and PR 64-1791 by 144% and 86%, respectively. However, there was no consistency of performance on a varietal basis at the same stage of data accumulation for the plant crop. At the tenth month into Year 2, ratoon-crop yields as main effects differ in several respects from the plant-crop yields (Tables 43 and 44). As already indicated above, sugarcane ratoon yields were clearly inferior at the 2-month harvests. The 6-month harvest totals are about the same for Year 1 and Year 2, while 6-month data indicate a ratoon-crop superiority of about 33% (Table 43).

Napier grass yields are very comparable for the plant and ratoon crops. Among individual clones (Table 44), sugarcane variety PR 980 was most severely affected by frequent recutting while NCo 310 was least affected. Ratoon crop yield increases at 6 months were most pronounced in variety NCo 310, amounting to 50% more dry matter than that produced by the plant crop.

(a) Trash Year

Since around 1960, when mechanical harvest machines had largely replaced hand labor, Puerto Rico's sugar industry has been disposing of sugarcane trash by burning the mature cane stands as a pre-harvest operation. By this means, less fiber was delivered to the sugar factory and the machine operator's task was eased considerably. Pre-harvest burning has highly variable effectiveness, however, and it was still necessary to clean incoming cane by "wet" or "dry" cleaning equipment installed at the site of delivery.

Moreover, this practice is both wasteful of energy (roughly 12 to 16% of the total biomass energy/crop) and is a source of air pollution. By law, Puerto Rico's cane industry will be required to cease burning trash in the open field by January 1, 1981. Hence, sugarcane trash is seen as a valid biomass source which must be credited to the total energy yield capability of future production.

Sugarcane-Energy Plantations in Puerto Rico (27). Project cane harvests have included the collection and weighing of trash at the 12-month harvest (15). Both cane and Napier grass trash was collected at this time. Trash is also being collected and weighed for the ratoon crop, this time beginning with the 6-month harvest (Table 45). Yields of this material from both cane and Napier grass amounted to less than two tons/acre. This figure should increase several-fold between months 6 and 12 (15). Total dry matter yields, i.e., standard harvest material plus trash, are presented in Table 46. Taken together main effects, sugarcane yields at six months into the ratoon crop are 33% higher than at the same period for the plant crop, and Napier grass yields are 6% higher.

(C) Juice Quality Responses (Year 1 Data): Juice quality data from the sugarcane and Napier grass trials of Year 1 became available during the first quarter of Year 2. Hand refractometer values (a rough estimate of soluble solids in raw juice) is presented for cane samples aged 6 months and older in Tables 47-49. Moderate increases in juice quality were recorded between months 6 and 12, although none of the values are especially high. An "average" or high sucrose variety ready for harvest should give hand refractometer readings in the order of 22 to 23. Nonetheless, several trends were evident, including a superiority of the variety NCo 310 (Table 48), and of the narrow row center (Table 49). The latter trend may signify considerable importance if it holds also for recoverable fermentable solids. It suggests that the increased sugarcane densities needed for total biomass production may not result in lower cane quality. The long-term outlook for Puerto Rico's sugarcane industry holds that high-test molasses for ethanol production, together with cane fiber as a boiler fuel and feedstock for cellulose-based industries, will be the principal objective for both field and factory managers (28). This is a break from the traditional emphasis on

Refined sucrose: for domestic and foreign sales, which the industry has been involved in for more than a century. The change in emphasis reflects the high cost of producing sucrose in Puerto Rico today (about 28 cents/pound in 1978), but it also underscores the need to develop sugarcane as an "energy cane" (29, 20, 31, 35) while supporting the local rum industry with both qualitative and quantitative increases in fermentation feedstocks (28, 32). In an energy cane context, the parameter Brix becomes the most meaningful measure of energy cane quality. Brix values, together with polarization, purity, rendment, and fiber data from the 6 and 12-month harvests of Year 1, are presented in Table 50. Brix values are slightly lower (at 12 months) than one would ordinarily expect from conventional cane management for sucrose (a value of 14 to 16 would be normal for PR cane). This probably reflects the higher input of water and fertilizer received by this cane in our attempt to maximize total biomass. There were no consistent effects of narrow row centers on Brix data, and only slight differences on a varietal basis. Hence, assuming an essentially constant recovery of fermentable solids (85-80% would be normal for PR cane), the highest production of total fermentable solids should seemingly be a function of the highest tonnage of millable cane that can be obtained through intensive cane management. The importance of maximizing the tonnage of millable cane for increased yields of fermentable solids cannot be overemphasized (28). An example of this is presented in Table 51, using the average yield of Puerto Rico's cane industry in 1978 (30 green tons/acre), plus the approximate mean value for first-year millable cane from the present project (80 green tons/acre). Also listed is a projected tonnage for first and second-ratoon cane from the same project (100 green tons/acre). Immediately evident is the large increase of fermentable solids that will accrue even with low Brix (13.12) and a conservative extraction estimate (85%). The low

The Brix value is normal for sugarcane that is continually forced towards high biomass tonnage without regard for sucrose. The relatively low extraction estimate reflects the expected sugar losses arising from higher fiber and cane residue delivered to the factory (33,34). However, these "losses" are quite negligible when viewed in the context of the two to three-fold increases in tonnage of energy cane over conventional sugarcane. In this scenario, it is high-test molasses and fiber rather than sucrose that constitute the prime management objectives.

For Cane and Napier Grass: While the first-ratoon crop data are incomplete at this writing (June, 1979), several trends are evident for the first six months of Year 2 (Table 52). For purely botanical reasons, the cane plant will normally produce more dry matter for at least two ratoon crops following the plant crop (i.e., following the first year's productivity from the original seeded cane). However, as indicated by the summary data in Table 52, the first-ratoon response for sugarcane is heavily reliant on the frequency of harvest.

Ratoon plants harvested at 2-month intervals were no more productive than their first-year predecessors. Ratoon plants harvested at 4- and 6-month intervals produced about 65% and 43% more dry matter than the first-year cane, respectively. This trend towards a lesser difference between plant and first-ratoon cane yields should continue throughout the second year, with first-ratoon superiority in the order of 20% being about normal for PR cane. Second-ratoon yields should equal or slightly exceed those of the first ratoon crop.

For Napier grass, ratoon yields were markedly higher for both the 2- and 4-month harvest intervals (Table 52). A curious feature of the 4- and 6-month cane is the much greater increase of dry matter than green matter in the ratoon plants (Table 52). This effect, although noted previously (1), is extremely difficult to explain on a physiological basis. In essence, two sets of plants of the same species, having... [Text cut off]

The same calendar age and agronomic care show widely differing physiological ages, that is, in terms of tissue expansion and saturation. The only variable factor here is the age of the crown; hence, the maturity of above-ground shoots of equal age can apparently vary as a function of the age or degree of development of the crown and root system. The is 4, Sordan 704 and Napier Grass. A second field-plot study was established during January of 1978 for direct evaluations of Sordan 70A and Napier grass (Common Marker) as short-rotation candidates. Two Napier hybrids (PI 7350 and PI 30086) were also tested for the first time as possible replacements for Common Marker. PR 960 was retained as a reference clone. This experiment was conducted at the semi-arid Lajas Substation under soil and climatic conditions identical to those described earlier (1). Common Marker, the Napier hybrids, and PR 980 were planted at 50 cm row centers, i.e., approximately the commercial spacing for Napier grass but about 1/3 the commercial distance for PR 980. Sordan 70A was seeded at 25 cm row centers, slightly farther apart than the standard seed drill setting of 22.5 cm for this crop. Harvest intervals were at two, four, and six months. Overhead irrigation amounting to about two acre inches was applied at planting and at four weeks, and flood irrigation was administered at 10 weeks. Fertilizer was given in three increments; 1/3 at planting, 1/3 at two months, and 1/3 at four months. Harvests for this experiment were only partially complete at the close of Year 1. Yields are presently reported on finalized data from three 2-month harvests, one 4-month harvest, one 6-month plus 2-month harvest, and one 8-month harvest.

(Table 53). Key findings from this study include the following:

© Sordan 70A (an NK hybrid) is an excellent short-rotation candidate.

© Napier grass is a superior intermediate rotation candidate.

© Napier hybrid No. 30086 outperforms common Napier grass.

© Six-month maximum yields are approximately 10 and 15 dry tons/acre for Sordan and Napier grass, respectively. These results essentially confirm the preliminary findings reported earlier (1).

Crucial implications for biomass research, and for collaborative energy and food planting strategies, are discussed in detail in that report.

(a) Final Tonnages; Monthly Harvest: The final harvest for this experiment took place during the first quarter of Year 2. The six-month data confirmed the impressive growth potential of Sordan 70A when harvested every two months. This hybrid matched or exceeded the yield of the three Napier grasses and greatly surpassed that of PR 980 (Table 53).

When given four months for development, Napier grass emerged as the top producer, while the sugarcane control still lagged behind. Sugarcane improved its yields significantly at six months, but remained inferior to Napier grass.

Of the three Napier grass varieties tested, the Plant Introduction hybrid 30086 significantly outperformed the standard variety, Common Merker (Table 53).

(b) Trash Yields: Trash data was recorded for the five varieties at six months (Table 54). Relatively little material was expected, yet approximately one ton/acre was collected for sugarcane and the Napier grasses. This amounts to roughly 8 to 10 percent of the total dry matter yield over a time period of six months. Sordan 70A produced virtually no trash.

The highest yield for

The total dry matter (trash plus intact plants) was 15.3 tons/acre, achieved by Napier hybrid PI 30086. This was significantly higher than the Common Merker yield of 12.7 tons/acre.

(c) Response to Variable Growth Establishment Periods: An important but challenging

The question underlying the use of tropical grasses for frequently-recut biomass is the time required for stems and root systems to be fully established, that is, to develop to the point where they can best withstand the "shock" of repeated harvests at 6-to 10-week intervals. For example, should harvests planned for 2-month intervals be initiated two months after seeding, or should four months or a year elapse before such harvests are begun? The project's limited resources have not allowed this point to be studied as a controlled variable. Some limited information was obtained from the present experiment owing to the two and 6-month harvest intervals tested in a 6-month study. The plants from the two-month harvest were recut at six months, thereby providing a "4 months plus 2 months" harvest in which 2-month old plants were cut from crowns having four previous months to become established. This contrasts with prior 2-month harvests, all of which were performed either two months after seeding or two months after a prior harvest. Mean values for the five test varieties indicate that tonnages of 2-month old tops were increased by about 50 percent if crowns were allowed either two or four months development time before the first 2-month growth performance is measured (Table 55). Putting this another way, the two months of measured growth was significantly less productive when reckoned from the day of seeding rather than from established crowns. This in itself is not surprising since the germination process is a time-consuming factor. However, there was no appreciable difference between the yields from 2-month old crowns and 4-month old crowns. This suggests that the pre-establishment of crowns is important only up to a very limited point in time, possibly just enough time to compensate for the germination process. The same question remains as to whether or not common Napier grass is actually more productive than hybrid forms, or whether there is a difference in the amount of water needed for their maximum yields to be realized (36).

The growth period was lost in the initial germination process. This is substantiated by the fact that Sordan 70A, the only direct-seeded variety and the only variety noted for its rapid germination, was also the only candidate producing superior growth when measured from the day of seeding rather than from an established crown (Table 55). With Sordan 70A, it would be clearly to the planter's advantage to perform his first 2-month harvest at two months from the time of seeding—and this in fact is a principal characteristic of an authentic short-rotation species. For the three Napier grasses, it could very well be better to perform the first harvest at four months after seeding. With sugarcane, the question of crown establishment becomes a moot point since the plant is obviously neither a short nor intermediate-rotation candidate. For long-rotation candidates such as sugarcane, the process of crown establishment would be accommodated within the long time lapses between planting and the first harvest, and between all subsequent harvests.

5. Minimum Tillage Studies at Lajas Substation

A majority of the tropical grasses discussed above are needed for intensive production of biomass, but there is also a need for minimum tillage candidates, that is, for grasses that will produce at least moderate yields with the bare minimum of production inputs. This requirement is underscored by two factors: (a) Puerto Rico's water resources, even if fully developed, would supply only about half the water needed for highly intensive production throughout the Island (37), and (b) economic considerations will not always permit a maximum expenditure of production resources even where such resources are otherwise available. The principal requirements of minimum tillage candidates in Puerto Rico are discussed in a prior report (1).

The first experiment involving minimum tillage conditions was conducted during the spring and summer of 1971. Five clones were planted in 1/50 acre plots on a Fraternidad Clay soil.

Characteristics of the AES-UPR Lajas Substation (38) included several clones. These clones consisted of three with predominantly S. spontaneum germplasm (US 67-22-2, US 72-72, and US 72-93), a wild Saccharum clone believed to be an S. spontaneum hybrid, and the interspecific hybrid PR 980, which served as the reference clone. A single fertilizer application containing 100 lbs. of N/acre was given at planting, along with approximately two acre-inches of water. Two additional irrigations of approximately two acre-inches each were administered during the course of the experiment.

Germination was very poor for the S. spontaneum hybrid, but all other clones experienced excellent germination and vigorous early growth. A single harvest was taken at six months. The leading biomass producer was US 67-22-2, while the S. spontaneum hybrid lagged behind due to its very sparse stand (Table 56). Both grain and dry matter yields for US 67-22-2 were significantly greater than those of the reference clone PR 980. Trash yields were exceptionally high for 6-month old plants (Table 57), but this was probably a result of the generally low water supply, which totalled only six acre-inches above natural rainfall.

Under these conditions, sugarcane tends to shed its oldest leaves as a water-conserving measure. Low water supplies may also have been a factor, although no visible deficiency symptoms were observed. At first glance, the yield data for total dry matter do not appear impressive (Table 57), until one recalls that this was only a 6-month experiment with rather meager production inputs. Yields for PR 980 (9.0 tons) were consistent with those at six months from a more intensive propagation regime (Table 58, 8.6 tons for PR 980). Moreover, this was significantly exceeded by US 67-22-2 (20.9 tons). This, in fact, compares very favorably with the island's sugar industry average, which is placed in the order of about 9 dry tons/year.

Field-Scale Studies Purpose: A major objective of this project is to establish methodology for the mechanized harvest and post-harvest.

Handling of tropical grasses propagated as biomass energy sources. This objective covers both a broad range of species with varying maturation and stand-density characteristics, and a series of diverse production inputs that heavily influence subsequent harvest operations. Solar drying, which involves the use of incident sunlight to remove plant moisture in the field, is to be developed to the maximum extent possible. The annual dry season at Lajas, with a duration of about eight months, was a decisive factor in locating this project's field phases at the AES-UPR Lajas Substation.

2. Species Categories

From an agricultural engineering standpoint, the mechanized harvest tasks to be accomplished are closely tailored to the short-, intermediate-, and long-rotation species categories already established by the project (9). Up to this point, these categories had been defined first by species botanical characteristics, and second by the need to integrate such plants into food-crop rotations in which the timeframe available to the biomass crop can vary from two to 18 months. In essence, the harvesting tasks can be grouped into three classes based on the density, or standing mass, of plant materials confronting the harvest machine, and the percentage of fiber contained by those materials at the time of harvest (39).

The first category deals with standing biomass in the order of 15 to 25 green tons per acre. Sordan 704, a short-rotation crop, is characteristic of species having yields of this magnitude. The project's approach to such materials is to harvest these solar-dried forages. The machinery tasks will vary with the state of the crop's maturity, i.e., with plants having from 10 to 12% fiber at six weeks to 30 to 35% fiber at 12 weeks.

A second category deals with standing biomass in the order of 25 to 50 green tons per acre. The representative species here is Napier grass, an intermediate-rotation crop whose dry matter content is maximized between four and six months after planting (9). Again, the crop's state of maturity influences the tasks of the machinery.

The rotary scythe does not cut or mow grasses like a conventional sickle-bar mower, but rather breaks off and "conditions" the grass with a series of steel plates rotating at high speed with extremely powerful force (Figure 15). The conditioned material is deposited in windrows of adjustable width directly behind the mower. The rotary scythe is a thoroughly rugged machine (40). 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. No difficulty of any kind was encountered in the first trial with Johnson grass. This material amounted to roughly 10 to 12 green tons per acre. The rotary scythe was moved to a second field where Johnson grass had grown wild for several years. The implement performed quite adequately, with the exception of "heavy" areas where accumulating dead Johnson grass had formed mats approximately two to three feet thick. In such areas, the mats sometimes tended to push ahead of the implement rather than pass under it in contact with the rotating blades. It should be noted that the rotary scythe is designed to function most effectively on individual plant stems. The stems would preferably be upright but the rotary scythe is also designed to harvest lodged material. All of the materials that were harvested (conditioned) with the rotary scythe were effectively solar-dried within three to four days. The drying process was assisted by turning the windrows twice with a side-delivery forage rake. The round baler performed quite effectively on Johnson grass with initial bales weighing in the order of 1000 to 1200 pounds.

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. The seeding rate was 60 pounds per acre, drilled in 9-inch row centers in two directions on the field. The planting of...

The planting in these fields was delayed by approximately two months due to atypically heavy rainfall in December-January, 1978-79. Harvests for the respective blocks of Sordan 70k were performed at 6, 10, and 14 weeks after seeding. Performance ratings for the rotary scythe are presented in Table 59. The 6-week old material presented no problems of any kind for this machine. The plants were completely upright and succulent. Initial concerns 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 when mowing. As a rule, the rotary scythe will rarely encounter plant materials more than about three feet high. Hence, the leading edge of the implement often causes the plants to fall forward without problems. The rotary scythe may struggle more with certain types of tropical grasses which are much flatter and thicker.

The rotary scythe was used without exception (Figure 16). There was no tendency to form balls or stop in front of the mower, even when operating at "high" speed (in the fourth and fifth forward gears of the Model 8700 Ford Tractor). A much worse set of harvest conditions was experienced for the 10- and 14-week old crops, but the rotary scythe nonetheless gave a very satisfactory performance (Table 59). 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 70k was flattened to a height of 8 to 12 inches and was severely matted, that is, the stems had cross-crossed and interlaced in all directions. The plants harvested at 14 weeks had remained in this condition for up to five weeks. During this interval, the matted Sordan 70k 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 baited 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. Good weather followed the mid-week harvest, allowing for baling within three days. Baling operations for the solar-dried Johnson grass and Sordan 70A were performed without encountering major problems (Figures 17 and 18). Minor problems incident to hydraulic connections between the Baler (a New Holland product) and the project's Ford tractor were easily corrected. Because no one on the project staff was directly familiar with the baler's operation, it was necessary to practice its handling on solar-dried weeds and Johnson grass. For example, the correct amount of twine needed for a 1500 pound bale, about 150 feet, was determined by trial and error. Such factors as the baler's best operating speed, the correct size and compaction of the bale, and the amount of twine needed to secure the bale for subsequent loading and transport operations are largely a matter of judgement by the machinery operator confronted with a specific set of conditions.

ECONOMIC ANALYSES

The project's initial economic analyses were performed at the close of Year 2. Production cost estimates for Sordan 70A, including solar drying, baling, and delivery to a centralized combustion site, were prepared on the basis of field-plot and field-scale data obtained since Sordan 70A was identified as an...

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APPENDIX
Appendix Tables 1-60
Appendix Figures 1-19

CATEGORIES OF CANDIDATE TROPICAL GRASSES
Production Water Demand. 2
Crowning Category (Test one)
Short Duration “B”
Intermediate Duration “M”
Long Duration “O”
Minimum Tillage (Intermediate to low)
Accepting Frequency at Least one Category
Factor is 2/ ripened required physiologically to maximize dry matter.

TABLE 2. BIOMASS PRODUCTIVITY PARAMETERS BEING EVALUATED DURING THE PROJECT
GREENHOUSE PHASE 1/
Performance (Relative to Reference Clone Performance 'R'980)
Required For Field Plot Phase
Total Biomass Superior Growth Curve
Superior Regrowth Rate
Superior Water Response: Equal or Superior
Superior Nutrient Tolerance
Superior Insect Tolerance Equal
Disease Resistance Equal
Wintering Density Superior
2 plants propagated by hand culture or in

Table 5. Clone Performance of Rootstock Varieties
Growth Rate (g/plant)
At week — year
Mass 2.5
Store tox 5.33
B3 vine x 2.3
ASA 5. 5.6
Water Retention & Weight
Total Water Content (%)
At week — water 2.3
Temperature Tolerance

Heat 2.3
Test Pest Resistance
B32 bio me
Seed Pod Weight
2.5
B3 2.7
Developed by the Northrup-King Company, Minneapolis, Minn.
2.1 Each year in the same color bearing only the letters differ significantly (0.05) from the average annual

The text appears to be a mix of random characters, possibly from a document that has been incorrectly scanned or transcribed. It's hard to make sense of it without knowing the original context, but here's an attempt to clean it up a bit:

Ao letter does not significantly alter the static. On the hangar (x/Plane), we have 300 am 62m 76a be “x 26 ose 20a KI 6b TS 4a. The year value in the same column. Dearing values, letters differ significantly. Can values nearing one or more letters in common do not differ significantly.

Glass with simulated characteristics in a semi-arid environment. AX A810 AOTSTIME REXDHES. Toca Om Cea. 1) Soret Soréan 704 (Cont) 00 a 17 aS Troden 7. Same case 2. Approximately 30 square feet.

Aumapandes worsens pEUe>y108I60. AL Gavovatea Suseve. WOLO DOW Ae SOTSIA ELEM AG. FINE BN a Go ODM Y HAO.

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Table 10, Total water yield of eight candidate tropical grasses. Green yield for the regions. MDIsTIRE Recs canesane Grasa or'anted nies 8’ an Pot onteot fecdan 70 (Conts01) 2.00 100 soréan 77 asa ns Trolan 5 pa 1os rates 7 nat xo wsutex 23, aa n x 300 19.06 m2 mx 326 1.78 ns Y approximately 0 square feet.

Table 11, Dry matter production by eight candidate tropical grasses harvested two months after planting. Dry matter cultivar Genus & Species g/Planted area g/Plant zm 7 980 charun Hyori 650 40 16.2 vs enaz2 cont. Hybeis 2,055 ae ana bs 72-70 S spent. tybetd no 2 18.4 ses 201 S: spontaneum 1,090 aa 20.0 ‘Teinan spent. Wybrid 1,370 28 16.4 wad Ss spent. lybrid 1a 28 ws Pr S008 Fenniseton porpurewm 3,032 a0 Ma JJehason Grass Sorghum hatepense 4,061 a 9.7 24 propagated Sn 4 1:2 soil-cachaza mixture with adequate water supply. 21 approximately 30 square feet.

Table 12, Dry matter content of eight candidate tropical grasses harvested after 2, 4 and 8 months of planting. 1. BAe ont = cultivar Genus & Species z ‘ ‘ re 980 Saccharus Hybrid 2 356 ws 6722-2 cont. Wybrid 25.5 5 72270 $a ssont. Wyprsd 2.2 Cncomptace sus 231 5.

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"NORTHERN GRASSES PROPAGATED WITH VARIABLE WATER SUPPLY OVER A TIME COURSE OF ELEVEN WEEKS on May 23. Dry Matter (Plant), At Indicated Week — highly stimulated foliar colors. A replicated observation experiment.

Recognized by agronomic properties / Test for mean ‘Top yield season Seen in sunny days.

On SUMMER 25, TROPICAL GRASSES CARRIED INTO PUERTO RICO FOR EVALUATION AS BIOGAS Sources for tests for an extensive conversion.

TABLE 27, TELLERING ON DRY MATTER CHARACTERISTICS OF CANDIDATE S. SPONTANEUM TO S. SINENSE Crops IN SMALL FIELD PLOTS. Species variety of tillers.

TABLE 29, DRY MATTER YIELDS BY SORGHUM PROPAGATED WITH VARIABLE FERTILIZATION AND SHARING RATES OVER A SEASON COURSE OF TEN HOURS supply tons/acre, At Seeding rate (lbs/A) — lbs/a) 6 to rear 100 B40.

TABLE 31, FOLIAR NUTRIENT CONTENT OF SORGHUM PLANTS PROPAGATED WITH VARIABLE N FERTILIZATION AND SEEDING RATES, At Seeding rate (lbs/Acre) — supply ABM Seeding Rate (lbs/acre).

Tea Gatherer. 100120 100 any near EB? 2.80 200 2a aces 278 300 290 2892.86 2.88 100 279 2a 2.06 ei Meas 2, 20022288 eee 4 tea ranks “1 and "2, harvested 10 weeks after seeding.

Table 32. Dry Matter Content of Sorghum propagated with variable fertilization and seeding rates over a time-course of ten weeks.

Seeding Rate (kg/ha)	Dry Matter Content (%)
100	28.6
200	25.0
300	26.8

Table 94. Effects of variable fertilization and seeding rates on the number of harvestable stems for

sorghum, 10 weeks after planting.

Seeding Rate (kg/ha)	Harvestable Stems
100	161.8
200	148.8
300	102.6

Table 25. Effects of variable nitrogen supply on the incidence of mildew and lodging in sorghum.

Nitrogen Supply (kg/ha)	Mildew	Lodging
100	3.06	2.35
200	3.5	2.46
300	3.06	2.83
400	5.08	2.83

Mildew and lodging incidence was ranked by visual inspection on a numerical scale of 1 to 10 (1 = no symptoms, 10 = severe symptoms). Each tabulated number is the arithmetic mean of 2 ranked plots. Data were recorded 10 weeks after seeding.

Table 96. Effects of variable plant density on the incidence of mildew and lodging in sorghum.

Seeding Rate (kg/ha)	Mildew	Lodging
50	2.38	2.38
100	2.38	2.38

Mildew and lodging incidence was ranked by visual inspection on a numerical scale of 1 to 10 (1 = no symptoms, 10 = severe symptoms). Each tabulated number is the arithmetic mean of 2 ranked plots. Data were recorded 10 weeks after seeding.

Table 97. Biomass production by the first-ratoon crop of three sugarcane varieties and one Napier grass variety.

Propagated with variable row centers: Third 2-month harvest green matter (tons/acre), at row center - cultivar IO CN 50 EE £ CN change PX 980 18s 139 -4.0 EO 310 EMS CO's PR SIE1791 EAR 07 CS OE Napier Cress 12.67 Le Dry Matter (tons/acre) 980 0.33 0.28 CO" 310 OIS TOE PE EIEI791 OUS O1AS Napier Grass 1891.86 Dry Matter Content (%) 980 Vane 28 EO 310 2010 OE A0 PE GEET 791 I ISL -18 Napier Cress 3.0 KS -33

Table 1. Silage production by the first ratoon crop of three sugarcane varieties and one Napier grass variety propagated with variable row centers; Fourth 2-month harvest green matter (tons/acre), at row center - cultivar 150 EE 50 CA Change PR 980 0.60 2.75 25.0 EE 310 TES ZON

25 PE EEE7A1 OSS, O36 NI SEX SEU Napier Grass 30 Dry Matter (Tons/Acre) PR 980 0 0.20 TO EO 310 OAT OUT ° PE EAEINEN ONE ONS 18.7 Napier Grass 0.02 0.87 60 Dry Matter Content (%) PR 980 19.0 25.7 35.2 EO 310 3531 20.6 A PEAS I ‘ 3 2 2 O28 IS Napier Grass 13.6 16.9 S

Table 2. Biomass Production by three sugarcane varieties and one Napier grass variety first ratoon crop, farm dry matter (tons/acre) at row center - cultivar 150 EE 50 CW Change PR 980 0.38 0.54 TO" 310 OG 7 PR 6B-T79 OA O54 EE EM Napier Grass 2240 F Change 38.4 WER ERE =P. PE 980 2.08 2.99 NEO 310 SA SE PE EI-I791 2H Napier Grass Y. 2 Green Matter (Tons/Acre) — 45.1 1) 2023 =A AOE EEE Dry Matter Content (%) PR 980 W.2 IO 30 ISI PE ETEI791 2012 Napier Grass 51K

Table 3. Biomass Production by the first ratoon crop of three sugarcane varieties and one Napier grass variety propagated with variable row centers; Second 6-months harvest, year 2 Green Matter (Tons/Acre), at row center - cultivar OC SE Change PR 980 NE? OY EO 310 SAR 37 16 PE EIEI1 EAE BD 52 WEA EE Napier Grass AKE A2 Dry Matter (Tons/Acre) WE 1.6 20 OE I313 SO S.3E Dry Matter Content (%) PX 980 WS 20 83 EO 310 BAY CA ME EE791 AE 30) A Napier Grass 1 A8

SR SANPEN ANS (2 REE . NE NEN ® MT WE 9 A 8 A O F EVENS OE WE FO SE BET EWAN 2 WERK WEER EE PR

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Column and sampling period bearing unlike letters differ significantly (P-2-08). Values in the same row and sampling period bearing unlike letters also vary significantly. Means having at least one letter in common are not significantly different.

Table 48: Random Refraction Index Values for Three Sugarcane Varieties at Four Soil Intervals

Values at Month:

1.0 - 19.0
0.0 - 18.5

Each figure is the computed mean of two row centers.

Table 49: Mean Refractometer Values for Sugarcane Propagated at Standard Row Centers

Row Spacing (cm): 10, 20

Mean: 130 (cm), 120

Each figure is the computed mean of three.

Table 50: Cane Quality Values for Three Sugarcane Varieties Propagated at Variable Row Centers and Harvested at 6 and 12-Month Intervals

Variety:

PR 980 - 32, 48, 28
Neo s10 - 512, 510
Peseta - 96, 33, 48

Table 51: Estimated Yields and Value of Extractable Solids and High-Test Molasses from Velvet-Propagated Sugarcane

Estimated values for:
Cane: 20, 2.6, 655
Molasses Value (Gross/acre): 100, 2, 2183, 1638

Assuming a mean Brix value of 13.12 and an average extraction of 85. Molasses value is computed at 95 cents/gallons.

Table 54: Total Dry Matter Yields of Five Candidate Tropical Grasses Harvested Six Months

After planting, the tons per acre for the cultivar Trash Intact Plants PR 980 (Reference) was 0.95 and 8.024 respectively. This includes leaf blades and leaf sheaths that have detached from the stem in the process. This material may contain slightly more organic matter.

Table 55. Dry Matter Yields of Five Candidate Tropical Grasses During an 8-Week Interval Following Variable Periods for Establishment of Growth.

The tons per acre following the indicated establishment time (months) for the cultivar PR 980 (Reference) was 0.41 and 0.766 respectively. Other variants were also tested including Conon Napier, Napier hybrid 7350, Napier hybrid 30086 and Sordan 708. The data was based on mean values from replicated 1/50 acre plots.

Table 56. Dry Matter Yields for Five Saccharum Candidates for Many Tillage Production.

The tons per acre for clone PR 980 (Reference) varied. The data was based on replicated 1/50 acre plots. Some of the Saccharum hybrid experienced less than optimal germination.

Table 57. Trash and Total Dry Matter Yields for Five Nominate Tillage Candidates.

The projected dry tons per acre for clone PR 980 (Reference) varied. The data was obtained from replicated 1/50 acre plots. The spontaneum hybrid experienced less than 40% germination.

This section includes a reference to various data points and results from the experiment.