CEER-B-171

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

THIRD ANNUAL REPORT
1979-1980

TO

THE UNITED STATES DEPARTMENT OF ENERGY

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

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To

The United States Department of Energy
Oak Ridge Operations Office, and the Division of Solar Technology
Biomass Energy Systems Branch
Washington, D. C.

By

The University of Puerto Rico
Center for Energy and Environment Research
Río Piedras, Puerto Rico

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ENDORSEMENT:

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Project Leader

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

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INTRODUCTION

The biomass production studies herein reported were initiated June 1, 1977 as a contribution to the Biomass Energy Program of the UPR Center for Energy and Environment Research (CEER-UPR). This research deals with sugarcane, tropical grasses related to sugarcane, and other tropical grasses having large growth potentials on a year-round basis. Its basic premise is that such plant materials can be produced continuously as a renewable, domestic source of fuels and chemical feedstocks that will substitute for imported fossil energy. The present report covers the period June 1, 1979 to May 31, 1980.

1. Project Objectives

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

2. Scope of the Project

Emphasis is directed toward a highly-intensive and mechanized production of tropical grasses as solar-dried forages. This is a deviation from conventional cane and cattle feed production in that total dry matter rather than sugar and food components is the principal salable commodity. Management of production inputs—particularly water, nitrogen, and candidate species, together with harvest frequency—varies significantly from established procedures. On the other hand, advances in mechanized production and harvest operations within the sugar and cattle forage industries are being utilized with considerable success for production of solar-dried biomass.

Optimized production operations require the identification of a few select clones and the conditions required for their management in an economically-realistic operation. This is being accomplished in 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 work herein reported deals with a continuation of the greenhouse, field-plot, and field-scale phases begun earlier (1, 2) [1/].

The project's screening operations are designed to identify high-yielding grasses that can be harvested on a year-round basis. They have indicated three broad categories based on the time required after seeding to maximize total dry matter (Table 2). Among sugarcane cultivars the superior growth rate *per se*, a botanical feature, has not been recognized historically as a desirable attribute unless combined with an acceptable level of sugar production (3, 4, 5, 6, 14, 15). Similarly, the tropical forage grasses have required acceptable digestibility and nutritive characteristics rather than high yields of dry matter (7, 8). Accordingly, our screening program often deals with long-established cultivars, but in a manner that would have astonished their original developers. In some respects this is a tropical application of the herbaceous species screening program formulated by the DOE Biomass Systems Program (9, 10).

A breeding program designed to intensify the biomass-yielding attribute of *Saccharum* and related species lies beyond the scope of this project. Thorough

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1/ Numbers in parentheses refer to relevant published literature. Complete citations are listed on pages 33 and 34.

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 (11, 12, 13, chap. 1). 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 (1, 2). Certain progeny originating with the AES-UPR sugarcane breeding program are also being considered as long-rotation [1/] biomass candidates (16). Under these circumstances some prospect is created for the emergence of superior new progeny at very little expense.

3. Statement on the First Quarter of Year 3

A separate report on the first quarter of year 3 was not considered justified and the project leader received authorization to combine the first two reports for this year's work. Owing to funding delays the period June 1 through August 31 was essentially on "hold". Emergency funding amounting to about 15 percent of regular levels enabled some limited progress to be made at the greenhouse level where candidate screening and nutrition experiments can be performed at relatively low cost.

The project's principal collaborators were retained during the first quarter but without labor support. The most important experiment was kept active during this period. This included the varietal, row-spacing, and harvest-frequency studies with first-ratoon sugarcane and napier grass. Field-scale

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[1/] Categories of tropical-grass candidates for biomass production are discussed in detail elsewhere (1).

plantings of Sordan 70A, for mechanized harvest studies, were discontinued and new plantings previously scheduled for August were postponed until January, 1980. Owing to exceptionally good weather during October of 1979 (ordinarily the wettest part of the PR rainy season) it was possible to plant six acres of napier grass for subsequent study of mechanized harvest equipment and procedures.

TECHNICAL REPORT

A. GREENHOUSE STUDIES

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

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

1. Candidate Screening

The first clearly outstanding tropical grass candidate to emerge from the project's screening tests was a sweet sorghum x sudan grass hybrid. Developed by the Northrup-King Company and marketed under the trade name "Sordan 70A", this is an extremely rapid-growing grass which completes its growth and maturation processes within 10 to 12 weeks after seeding (1, 2). Subsequent screening tests revealed other candidate clones moderately superior to Sordan 70A, particularly under conditions of moisture stress (2). All of these grasses are clearly short-rotation species.

A number of additional clones became available to the project whose correct categories for field-plot testing were less clearly defined. These range from potential short-rotation species (Johnson grass, SES-231) to potential long-rotation species (US 67-22-2, US 72-70). Seven of these grasses were propagated in the greenhouse during the spring and summer of 1979, using the interspecific commercial cane hybrid PR 980 as the reference clone (Table 3). This type of experiment is conveniently termed "multiple rotation", and it enables multiple-species and category screening to proceed simultaneously. The species and methods used in this experiment are described in more detail elsewhere (2).

One-third of the plants was harvested each at 2,4 and 6 months after seeding. These time intervals correspond to short-rotation (2 months) and to both early and late intermediate rotation (4 and 6 months, respectively). Long-rotation experiments (12 to 18 months) cannot be maintained adequately with potted plants. In terms of DM yield/planted area (Table 3) and maturity (Table 4), Johnson grass clearly emerged as the leading short-rotation candidate. The napier grass hybrid PI 30086 was the leading intermediate-rotation candidate.

As illustrated graphically in Figure 1, all clones except Johnson grass made enormous yield increases when harvest was delayed from the second to the fourth month after seeding. Only in the case of Johnson grass would greater yields derive from simply repeating the 2-month harvest over and over again. Alternatively, all species showed relative yield decline as harvest was delayed from the fourth to sixth month after seeding. This latter trend is misleading in the case of valid long-rotation candidates such as PR 980 and US 67-22-2; in field plots these clones would have begun their heaviest dry matter accumulation around 6 or 7 months after planting. On an individual plant basis napier grass was the superior producer at each of the three test ages (Table 5).

2. Maturation Profiles Of Three NK Hybrids

The Northrup-King hybrids Sordan 77 and NK 326 gave very favorable growth performances in previous direct comparisons with Sordan 70A (2, 17). In subsequent greenhouse trials the maturation curves for both candidate grasses were determined using Sordan 70A as the reference variety. Dry matter yields for NK 326 clearly exceeded those of Sordan 70A from the 8th to 13th weeks after seeding (Figure 2, Table 6). Although there were no large differences in the rate of dry matter accumulation, Sordan 77 contained significantly more dry matter than the other candidates from about the 9th week onward (Table 6). Sufficient data are now available to justify field-scale comparisons of the three tropical grasses.

3. Screening of Dekalb Company Hybrids

Screening trials were begun during the third quarter on a series of tropical grass hybrids developed by the Dekalb Company. Like the NK hybrids, these grasses incorporate both sorghum and Sudan grass germplasm and are basically intended for summer production as cattle forages. Preliminary (unreplicated) yield data for six Dekalb grasses are presented in Table 7. The NK hybrids Sordan 77 and Trudan 5 were also included in this trial. At six weeks of age the variety Dekalb FS-25 a+ compared favorably with Sordan 77 and Trudan 5. At 10 weeks, all of the Dekalb grasses were at least equal to Sordan 77 and Trudan 5 in dry matter yield while Dekalb FS-25 a+ and Dekalb SX-17 + indicated moderately higher yields. The latter two hybrids were also superior on a per plant basis (Table 7).

4. Variable Moisture Regimes

The same NK and Dekalb candidates noted above were subjected to variable moisture regimes in an unreplicated trial initiated during the third quarter. Given a series of tropical grasses having comparable yield potential under ideal growing conditions, the ability to maintain a high yield performance under conditions of moisture stress is a decisive factor in the final screening process. Moisture regimes ranging from excessive water supply ("humid") to inadequate water supply ("semi-arid") were simulated by varying the frequency of irrigation. All plants were propagated under glass using a 2:1 soil-cachaza mixture as the growth medium. Plant samples were harvested at three intervals over a time-course of 11 weeks.

All of the Dekalb grasses equalled or exceeded Sordan 77 (the project's principal short-rotation hybrid) in dry matter yield (Table 8). Under humid conditions the varieties Dekalb ST-6 and SX-16a exceeded the Sordan 77 yields by at least 30 percent. However, none of the candidates maintained a satisfactory growth performance when water supply was cut back in a simulated semi-arid regime. The need for additional testing of these grasses as "low-till" candidates is clearly indicated.

Mean values for dry matter content, an indication of plant maturity, did not vary consistently among moisture regimes (Table 9). A pronounced increase of dry matter was recorded with increasing plant age (Table 9). The latter response was quite distinct among all moisture regimes.

5. Mineral Nutrition

A nitrate-N nutrition experiment established late in Year 2 was completed during the first quarter of Year 3. Variable nitrate levels were administered to Johnson grass to establish the plant's N-response curve. As in earlier nutrition experiments with Sordan 70A and napier grass (1, 2), the objective was to establish the slope of the dry matter response to progressively higher levels of N. Accordingly, nitrate-N supplies were increased in a geometric progression to Johnson grass propagated in sand culture. Nitrate levels ranged from 1.0 to 81.0 milequivalents per liter, in nutrient solutions given three times each week over a time-course of 10 weeks.

Dry matter yield and content data (Tables 10 and 11, respectively) suggest that the maximum growth response was obtained at around 9 meq/l of NO_3; however, both visible and real growth improvement was obtained from the 27 meq/l treatment as well. This was particularly evident as plant age (and hence root development) was advanced to 10 weeks. Johnson grass is the only candidate at this point in time to show major growth responses to 54 meq/l, and an absence of growth repression by 81 meq/l of NO_3 (Figure 3). Ironically, as a minimum tillage candidate Johnson grass is less likely to receive fertilization than species from other cropping categories.

With reference to nutrient uptake, Johnson grass did not respond to N levels higher than 27 meq/l of NO_3 (Table 12). A surprisingly high foliar K content was recorded, ie, in the range of 2.4 to 2.8 percent on a dry weight basis. These levels are more typical of sugarcane which accumulates relatively large amounts of potassium. Post-harvest regrowth data indicate that high NO_3 levels (above 27 meq/1) are repressive against both the number and weight of new shoots (Table 13).

B. FIELD PLOT STUDIES

1. Saccharum Species Candidates; Gurabo Substation

An observation field-plot study with candidate *S. spontaneum* and *S. sinense* clones 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.

The candidate clones listed in Table 14 were harvested at 2-and 4-month intervals for one year, and subsequently harvested after six more months had elapsed /data summarized elsewhere (2)/. At that point the experiment was converted to an observation "low till" study in which the plants were allowed to subsist on rainfall and native soil fertility. Harvests are planned for 6-month intervals for the duration of the project.

The first 6-month yields under minimum tillage conditions are presented in Table 14. The *S. spontaneum* clone SES 231 continued to be the superior dry matter producer, followed closely by SES 317 and Chunnee. Each of these clones attained an advanced state of maturity during their 6-month growth period, ie, each exceeded 35% dry matter. SES-231 is a very impressive candidate at this time; however, it did require nearly a year to establish a vigorous crown. Its present growth is vigorous, dark green in color, and generally unmarred by nutrient deficiency symptoms or pest injury. SES 231 is presently regarded as a late short-rotation or early intermediate-rotation candidate. Its thin, wiry, and persistently upright stems should lend themselves well to mechanized harvest and solar-drying operations. Field-scale plantings of SES 231 will be made for mechanized harvest trials during the project's fourth year. At present the clones PR 980, Saretha, and Natal Uba are rapidly dying out (Table 14).

2. Minimum Tillage Experiment; Lajas Substation

There is a need for tropical grasses that will produce at least moderate yields with the barest minimum of production inputs. The characteristics and principal requirements of minimum tillage candidates for Puerto Rico are discussed at length in prior reports (1, 18).

A long-term minimum tillage study on *Saccharum* species was initiated at the AES-UPR Lajas Substation during mid-February of 1977. There are four *S. spontaneum* clones and an interspecific commercial hybrid (PR 980) serving as the control. Receiving no production inputs since the original planting, harvests have been taken at 6-month intervals. The fourth such harvest was performed during the third quarter. Although dry matter yields are relatively low, it is evident that all of the *S. spontaneum* clones are sustaining themselves far more effectively than the commercial hybrid PR 980 (Table 15).

The superior clone at this stage of the experiment is US 72-72. Its green and dry matter yields were 3.92 and 1.36 tons/acre, respectively. By way of reference, the PR cane industry is producing approximately 9 green tons/acre and 3.5 dry tons/acre, as an Island-wide average, over a comparable time-course. Both production costs and energy inputs for US 72-72 are nil. Production costs for the PR industry cane are approximately $64.00/OD ton; the energy output/input ratio for this cane is approximately 3.5/1.

3. Seed Expansion From "Energy Cane" Plantings

From the seed sources available in 1977, three sugarcane varieties were selected for the project's initial studies on cane biomass. Each variety has a history of high yields for both sugar and bagasse over a range of PR soil and rainfall conditions. Moreover, seed was available in adequate quantities for project needs. Nonetheless, there was no question but that these canes represented something less than the maximum biomass yielding potential of Saccharum in Puerto Rico. Seed expansion for more promising biomass energy canes was begun late in 1979. The S. spontaneum clones US 67-22-2 and B 70-701 have shown especially favorable promise as biomass producers and are included in the seed expansion phase. This material is being propagated at the AES-UPR Gurabo Substation. Field-plot experiments using both varieties will be established at the AES-UPR Lajas Substation during August of 1980. Additional plantings of US 67-22-2 and B 70-701 will be made on privately-owned lands near Hatillo (on the humid north-coastal plain) during August of 1980. It is believed that these varieties can produce about 40 OD tons/acre as primavera cane (10 to 12 months old at harvest) and close to 50 OD tons/acre as gran cultura cane (16 to 18 months old at harvest). By way of reference, the highest yields attained to date with conventional varieties averaged about 25.5 and 33.6 OD tons/acre, respectively, for the "plant" and "first-ratoon" crops.

4. Sugarcane And Napier Grass Trials

A large field plot study on row spacing, varieties, and harvest frequency for sugarcane and napier grass has been underway at the AES-UPR Lajas Substation since 1977. The intent of this experiment is to maximize total biomass yield for the two species over a three-year cropping cycle, ie, for a "plant" crop plus two "ratoon" crops [1/]. It is believed that three crops, ie, the plant crop plus two ratoon crops, probably represent the best time-frame package for energy cane production in Puerto Rico.

Yield trends for the first six months sustain the results of years 1 and 2. These trends include: (a) A superiority of napier grass over sugarcane when harvested frequently (at 2-, 4-, and 6-month intervals); (b) a failure of narrow row spacing to increase yields over standard row spacing; and (c) relatively small varietal differences for sugarcane given suitable time for development (6 months), while 2/3 of the cane varieties continue to weaken in response to 2-month harvest intervals.

Growth data from the first five 2-month harvests (Tables 16 to 20; Tables 21 and 22) reconfirm the fact that sugarcane will not respond favorably to frequent cutting (1, 2). During this interval the maximum dry matter yield for sugarcane was 0.64 tons/acre (Table 16, var. NCo 310) while napier grass exceeded this amount by a factor of about 3. Contrary to the plant crop results, but consistent with data from the first ratoon crop, narrow row spacing for sugarcane failed to increase yields. There was in fact a tendency for close spacing to reduce yield in two of the three varieties tested. Napier grass (var. Merker) was not consistently affected by narrow row spacing.

Two of the sugarcane varieties (PR 980 and PR 64-1791) indicated a continuing decline of vigor in response to frequent recutting. Variety NCo 310 was more tolerant of this harvest interval (Tables 16-22). A seasonal effect on sugarcane vigor was also evident (Tables 21 and 22). Hence, biomass yields for the third

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1/ Commercial sugarcane in Puerto Rico is managed on a 5-year cycle while napier grass plantings are generally indeterminate, sometimes remaining a generation or longer.

2-month interval (November 15 to January 15) were only 1/3 of the yields obtained from the first 2-month interval (July 15 to September 15). Napier grass was much more tolerant to the cooler "winter" temperatures. While mean sugarcane yield declined by 66% (from 0.30 to 0.10 OD tons/acre/2 months), napier grass yield declined by 26% (from 1.96 to 1.45 OD tons/acre/2 months).

Yields from the 4-month harvests were in some respects similar to the 2-month harvests. Sugarcane variety NCo 310 remained dominant over PR 980 and PR 64-1791, and close spacing had a generally detrimental effect on growth (Tables 23 and 24; Tables 21 and 22). However, the importance of delaying harvest frequency as a means of increasing dry matter yield was very pointedly demonstrated. For sugarcane the monthly dry matter yield averaged 0.06 ton/acre when harvested at 2-month intervals and 0.75 ton/acre when harvested at the 4-month interval. For napier grass, the average monthly yield rose from 0.40 to 1.92 tons/acre as harvest frequency was delayed from 2 to 4 months. Hence, by merely doubling the time interval allowed for tissue expansion and maturation, 12-fold and 4-fold yield increases were obtained for sugarcane and napier grass, respectively. Moreover, equipment usage was reduced by 50 percent, with all that this implies relative to reduced fuel expenditure, soil compaction, and salaries and wages.

A seasonal growth response, amounting in effect to a "winter" growth decline, was also evident for the 4-month harvest intervals. Mean DM yield for sugarcane was only 1.4 tons/acre during the period November 15 to March 15, whereas it had been 3.0 tons/acre between July 15 and November 15. This was a decline of 53%. Napier grass was again more tolerant of the seasonal change, with DM yield declining by only 31% (Table 22).

The first 6-month harvest revealed that NCo 310 was still the superior sugarcane variety midway through the second-ratoon crop (Table 25; Tables 21 and 22). A moderate but persistent depressing effect on dry matter yield was being exerted by the close-spacing treatment. At this time napier grass continued to exceed the average sugarcane yield but the difference was less pronounced than at 2-and 4-month harvest intervals. The average cane DM yield for a single harvest at 6 months was 10.5 times greater than the combined yield of three, 2-month harvests (Table 22).

Mean values for dry matter content (Table 26) indicate that napier grass had essentially reached peak maturity by the fourth month after cutting. Sugarcane progressively increased DM content from the 2-to 6-month harvest intervals.

At six months into the second-ratoon crop sugarcane yields were in the order of 20 to 30 percent lower than the first-ratoon crop, and very slightly lower than the plant crop. This suggests that the 3-year cropping cycle planned for energy cane is a correct interpretation of biomass yield potential. Puerto Rico's sugarcane industry employs a 5-year cropping cycle which is based on sugar production rather than total biomass. Sugar yields can actually increase in plants whose growth rates are declining (13, 14, 15) 1/. With biomass replacing sucrose as the primary commodity a more frequent replanting may be justified.

The apparent yield decline at 6 months might also reflect an unseasonal drouth affecting the Lajas Valley from late September to mid-November. Ordinarily this is a warm and humid period highly conducive to cane growth.

1/ Sugarcane "ripening" (sucrose accumulation) is directly dependent upon growth repression induced either by chemicals or by natural means.

Irrigation was increased during the unexpected dry spell but this may not have compensated completely for the reduced rainfall.

C. FIELD-SCALE STUDIES

1. Minimum Irrigation of NK Hybrids; Lajas Substation

The Northrup King hybrids Sordan 70A, Sordan 77, and NK 326 were examined with minimum irrigation in small field-scale plots ranging from 1.8 to 3.6 acres in area. Both Sordan 77 and NK 326 have shown considerable tolerance to simulated arid conditions in comparisons with Sordan 70A (2, 19). Both Sordan 70A and Sordan 77 respond to high water supply.

Each variety was planted at the rate of 60 pounds of seed/acre. The seedbed received 100 pounds/acre of elemental N, 50 pounds of P_2O_5, and 50 pounds of K_2O, broadcast and disced in just prior to planting. Two acre inches of water were administered by overhead sprinklers immediately after seeding. The experiment was planted on December 20, at the onset of Puerto Rico's dry season, when irrigation is needed to assure rapid germination and seedling establishment. No further irrigations were administered. During the subsequent 10 weeks an additional 2.75 inches were received as rainfall. The approximately 4.75 acre inches total received between planting and harvest amounts to about 40 percent of the water requirement for maximum yield of Sordan 70A and Sordan 77.

At 10 weeks the three varieties were mowed with a rotary scythe-conditioner, solar dried to 15 percent moisture, raked, and compacted with a bulk baler producing 1000-to 1200-pound round bales. All equipment items performed as designed without problems. Positive results from this experiment include the following: (a) Sordan 77 was verified as a superior short-rotation candidate (Table 27); (b) an appreciable yield potential was demonstrated for Sordan 77

(2.23 dry tons/acre); and (c), the yield potential was demonstrated under conditions generally unfavorable for growth, ie, with a short growth interval (10 weeks), during the least favorable season (late December to early March), and with a low water input.

Cost and energy-balance analyses for this experiment have not been completed. It is possible that the savings in water expenditures (about 7 acre inches) will not compensate for the reduced yield (in the order of 1.8 dry tons/acre). A decisive factor here is the relatively high fertilizer expenditure with an inadequate moisture supply for optimal nutrient utilization. Mineral N, at 100 pounds/acre/10 weeks, is by far the most costly and energy consumptive input of the study. It is possible that superior cost and energy figures would have emerged if water had been given at normal rates and fertilizer rather than water had been lowered to 40 percent of normal. Experiments are planned in which the effectiveness of low water x low fertilizer and normal water x low fertilizer regimes will be examined.

2. Mechanization Trials; Napier Grass Planting

Napier grass planting is traditionally a hand-labor operation in Puerto Rico. The seedbed and row furrows are sometimes prepared mechanically, but the seed stems themselves are carried manually into the field and dropped into the furrows. They are then cut into two-eye or three-eye segments by laborers walking along the furrows with machetes. The seed pieces are covered with soil as a final manual operation. This process is very costly. An added cost to the grower is the loss of viability of napier grass seed stems which often stand in open piles in the sun for several days while the hand operations are underway. However, since napier grass is usually planted on small lowland acreages or uplands too steep for machinery, no attempt was made to develop a planter for this purpose.

During the third quarter approximately eight acres of napier grass were planted for future mechanized-harvest trials. A two-row sugarcane planter was rented from the PR Sugar Corporation in an effort to reduce planting costs and to speed up seeding operations. Two napier grass varieties were planted having different age and stem condition at the time of cutting for seed. The napier grass stem is considerably thinner and lighter than sugarcane and has a greater adherance of dead leaves. There is also a greater tendency for the napier grass stem to bear lateral shoots and roots, and to be excessively curved, especially if the selected seed stems are overaged and have lodged prior to cutting. None of these factors prevented the sugarcane planter from performing quite effectively with napier grass. A few stems were discarded owing to excessive curvature but this is necessary for sugarcane also. The stems were laid straighter and the seeded furrows were covered with soil more evenly than is possible by hand labor. This implement automatically cuts the stems into billets as part of the seed placement process. Some damage to seed "eyes" occurs.

On the whole, both the planting operation with this implement and the subsequent seed germination were quite satisfactory. The only problems with germination could be traced to overage seed, or, very rarely, to "skipped" areas in the row where there had been some delay in feeding stems into the planter. By reference to our previous napier grass planting (6 acres seeded by hand) planting cost was reduced by 82 percent and planting time by about 65 percent.

3. Rotary Scythe And Round Baler Trials

Two harvest implements are of special interest to this project. These are the rotary-scythe conditioner and the round baler. They are viewed as potential answers to the harvest and post-harvest management of tropical grasses having standing tonnages at harvest far in exess of conventional forage grasses, but somewahat lower tonnages than sugarcane. Initial trials performed on mature Johnson grass and 6-to 14-weeks old Sordan 70A were described in a previous report (2). These tests posed no problems of any kind, even in heavily lodged and matted Sordan 70A. Solar drying, raking, and baling operations also were performed without incident. More recent trials with Sordan 70A, Sordan 77, and NK 326 were also successful (p. 16). However, the actual tonnages in these tests did not exceed about 14 standing tons/acre.

(a) Napier Grass; Three Months: Napier grass was submitted to mechanized harvest and forage-making operations for the first time during the third quarter. Approximately four acres of 3-months old napier grass (var. Merker) were mowed with the M-C rotary scythe conditioner. This material was solar-dried and baled with the New Holland Model 851 round baler. At 3 months of age, the total biomass confronting harvest machinery was only slightly greater than that of equally-aged Sordan and there were fewer stems/acre. The primary difference lay in the much thicker and more succulent stems of napier grass. These offer a somewhat different and possibly more difficult task for the stem-shattering or "conditioning" properties of the rotary scythe. The solar drying tasks are definitely more difficult owing to the greater thickness of napier grass stems [1/]. 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-

1/ It has been suggested that the best way to remove water from napier grass stems might be to grind them in a sugarcane mill and then solar dry the napier grass "bagasse" (20).

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

(b) Napier Grass; Six Months: The ultimate test of the rotary scythe-conditioner is encountered with 6-months old napier grass. Such material is in an advanced state of maturity with dry matter content approaching 3 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 28). 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:

(1) An excessive height of napier grass, in the order of 9 to 12 feet, as opposed to a maximum of 2 to 4 feet for conventional forage crops. Since the "cut" grasses must first fall forward and then be drawn backward beneath the implement to be conditioned, the taller napier grass could not have been harvested had it fallen backward on to the upper surface of the rotary scythe. In the actual tests there was no tendency for any material to drop backward on the implement's surface. The leading edge of the rotary scythe strikes the napier grass stems 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.

(2) An 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/acre for a typical forage crop. It was thought that the additional mass confronting the implement might cause its blades to become clogged with bunched material; alternatively, such material could effect a continual breaking of shear pins. The latter are incorporated into the implement's design and are intended to shear off when overloaded to prevent more serious damage. During the present tests there was no clogging or breaking of shear pins.

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

(3) 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 easing the windrowing and baling operations. Stems of 6-months old napier grass were quite effectively conditioned by the rotary scythe. Solar drying proceeded normally. Approximately one additional day was needed to attain 15% moisture (four days for napier grass as opposed to three days for Sordan). Increased drying time was mainly a function of the greater stem thickness and total mass of material per acre for napier grass.

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

or cube bales) or organization into round bales. In the present trials these requirements were met very effectively.

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

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

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

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

It is believed that the problems of tine breakage and unraked material can be eliminated by use of a different type of implement, one commonly described as a "wheel" rake. This rake is not driven by a power take-off but rather operates through contact of its tines with the ground surface. The times are mounted on a series of independent wheels which offer greater flexibility for penetration of a heavily-stubbled surface. Plans have been made to test a Farmhand model wheel rake with solar-dried napier grass and sugarcane trash during the project's fourth year.

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

4. Direct Firing Of Napier Grass

The first direct combustion tests for the solar-dried tropical grasses of this project were performed by PR Sugar Corporation engineers during late January of 1980. At the onset of a new campaign, sugar mill engineers need to ignite their furnaces to raise steam and process heat before the first harvested cane arrives at the mill. For this purpose almost any combustible material is used—old lumber, discarded railroad ties, wood scraps and refuse of varying description. Mill workers at Central Guánica, located about 10 miles from the project's Lajas Valley site, learned of the biomass bales accumulating there and received authorization to use some of these for start-up fuel. Some 50 bales of solar-dried napier grass were obtained for this purpose. Although no formal data were gathered, the engineers were highly pleased with the combustion performance and handling properties of this material. No fuel oil was needed to assist ignition as is the case with bagasse [1/]. This was the first instance when the project's experimental tropical grasses were actually used as fuel.

D. BREEDING

In Puerto Rico sugarcane breeding is performed from mid-November to mid-December. Crosses completed during November of 1979 are summarized in Table 29. Each of the five tabulated crosses was performed by Mr. T. L. Chu in conjunction with the AES-UPR sugarcane breeding program. All were performed with biomass rather than sucrose as the primary objective. One cross, B 70-701 x 57-NG-54, has a high probability of producing offspring with a predominantly high-fiber attribute (16). The remaining crosses could produce seedlings with both high fiber and high fermentable solids attributes (Table 29).

1/ Central Guánica ordinarily adds 4 gallons of residual fuel oil to each ton of bagasse (about 51% moisture) to promote combustion.

Three subsequent crosses were made in December using an early-flowering S. spontaneum hybrid as the male parent. This is an extremely vigorous clone found in the wild near Río Piedras. Its early tasseling habit has been overcome to a limited degree by cutting back wild stands during the late spring. This forces the ratoon plants to pass their normal floral induction period in the juvenile state, and to enter the adult (reproductive) phase in a later time-frame more consistent with potential crossing partners.

Three commercial Puerto Rico sugarcanes served as the female parents, including PR 980, PR 67-1070, and PR 64-1618 (Table 30). Nearly 1000 seedlings were obtained from the crosses with PR 980 and PR 67-1070. Only about 20 seedlings were produced by the cross with PR 64-1618. At this writing none of the progeny appear to resemble the male parent. Sufficient material is available to begin evaluating the transmission of a high-fiber attribute to hybrid progeny (16).

E. ECONOMIC STUDIES

1. Cost Estimates For Energy Cane Production

Preliminary cost analyses for energy cane production were performed on the basis of first-ratoon yields. A breakdown of production input charges is presented in Table 31. These figures pertain to a family-owned, 200 acre operation yielding 33 oven-dry tons of biomass per acre year. The most expensive equipment items, a whole-cane harvester and low-bed truck, would be hired from the P.R. Sugar Corporation together with the equipment operators. In an energy-cane industry such items would probably be family owned, in which case the operation and maintenance costs would be appreciably lower. Both water and fertilizer charges are entered moderately higher than project data actually indicate, mainly owing to potentially large consumption differences as varietal and ecological life zone factors. Total costs, including delivery to the milling site, amount to $25.46 per oven-dry ton, or about $1.70 per million BTUs. By way of reference Puerto Rico is presently paying about $4.30 per million BTUs in the form of petroleum boiler fuels.

In an energy cane scenario about 68 percent of this dry matter would be burned as boiler fuel. The remainder would be extracted as fermentable solids during the cane dewatering process and later sold as constituents of high-test molasses. Neither raw sugar nor refined sugar sales are anticipated. Cane milling costs in Puerto Rico today are presently about $5.00 per ton. The fermentable solids from one acre of energy cane (ie, with yields of 33 OD tons/acre), would be valued at $1,500 to 2,000 dollars if marketed today 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 (21) but has declined to an 88% dependency on imported molasses in 1979 (22). Because of this, local interest in the energy cane herein described is directed mainly toward its molasses yield potential rather than its role as a renewable domestic boiler fuel.

2. Cost Comparisons; Energy Cane vs Conventional Sugarcane

Production cost estimates for conventional PR sugarcane were computed during the third quarter for direct comparison with energy cane estimates (Table 32). Sugarcane cost estimates are based on data obtained from Central Aguirre for the 1979 milling season. They probably constitute a "best case" for production operations in the PR sugar industry as a whole. As indicated in Table 32, production costs for energy cane are higher than sugarcane in five areas: Seedbed preparation, seed, fertilizer, harvest operations, and delivery of harvested cane. Energy cane seed and fertilizer expenditures were double those of conventional sugarcane. Harvest operations and cane delivery expenses were 67 percent higher, and seedbed preparation costs were 50 percent higher. It should be noted also that the sugarcane cost estimates pertain to a private planter (or "Colono") for whom the major machinery items are rented rather than self-owned.

The overall cost for producing a ton of energy cane was 44 percent higher than conventional sugarcane. However, the decisive difference between the two management scenarios lay in the total dry matter yield per acre year (Table 32). Energy cane yield exceeded sugarcane by a factor of about 3.7. Hence, the increased cost of "pushing" sugarcane, ie, to maximize total biomass rather than sucrose, was more than compensated by even larger increases in dry matter yield. As a result of its relatively low productivity the PR sugar industry cane cost in the order of $65.00/OD ton, or about $4.31/million BTUs.

F. ENERGY BALANCES

The final energy balance figures for energy cane will be based on mean production yields from a 3-year cropping cycle. Preliminary analyses were performed during the third quarter using the first-ratoon crop means for varieties PR 980, NCo 310, and PR 64-1791. These varieties averaged 33 OD tons/acre year for the first-ratoon crop. Energy input estimates for this material are summarized in Table 33 [1/].

Total energy inputs for energy cane production are in the order of 28 x 10^6 BTU/acre year. Energy output amounts to 279 x 10^6 BTU/acre year (Table 34).

1/ Estimates prepared by Dr. Lewis Smith, Consulting Economist, CEER-UPR Biomass Energy Program.

The latter figure is computed on the assumption that most of the fermentable solids fraction of the total dry matter yield will be extracted at the sugar mill. The extracted fermentable solids amount to about 640 lbs/OD ton of energy cane. This figure is based on a recorded mean Brix value of 13.1° for energy cane juice and an assumed 80% extraction at the mill. In this instance only 1360 pounds of dry matter/OD ton, or 22.4 tons/acre, will be used as boiler fuel. On a steam recovery basis, assuming 85% efficiency for a utility boiler, an energy output/input ratio of 9.95/1 is obtained (Table 34).

Some authors have simply divided the total calorific value of their annual OD product by the total production energy input (23). By this method energy cane would have an energy output/input ratio of about 17.7/1.

It is instructive to note that nearly half of the total energy expenditure was for mineral N alone (Table 33). Hence, while the favorable energy balance obtained to date is mainly a reflection of high DM yield, future improvement of this balance can be gained both by increasing yields and by reducing the input of mineral N. One means of lowering N input is to apply the element as a soluble component of the irrigation water, particularly water applied via trickle irrigation (20). The increased efficiency of lower N supplies should compensate for the relatively inefficient plant usage of dry fertilizer administered in larger amounts to the soil surface. Another potential means of lowering mineral N expenditures is through increased usage of N-fixing legumes in conjunction with biomass energy crops. A large number of underutilized tropical legumes have been identified for possible use in this context (24, 25).

G. SUMMARY OF THIRD-YEAR STATUS

At the close of its third year the project has progressed to the approximate point envisaged for year 3 in the original 5-year work plan. There have been a series of developments more favorable than expected, and one unforeseen development that has required some limited modification of the project's work plan.

Biomass researchers working with tropical grasses in a tropical climate have many factors working in their favor. Nonetheless, exceptionally favorable trends emerged for us in three distinct areas. First, the botanical attributes of candidate tropical grasses conformed more favorably than expected with domestic energy resource requirements. It was possible to develop short-to long-rotation categories of grasses that would supply large quantities of biomass, on a year-round basis, in a solar-dried state that minimized dewatering and transportation costs. Second, the project's agricultural engineering phases were enormously eased by prior developments in forage-making machinery. A very appreciable work-load remains in our field evaluations of the rotary scythe, the bulk baler, and heavy-duty wheel rake; however, it is already evident that these machines can perform in the relatively massive biomass scenarios imposed by tropical grasses. If any one of them had failed to accommodate such materials a large engineering gap would have remained in tropical grass fuels technology. The third development favoring this project is a highly positive trend in production-cost and energy-balance data. The project's staff feels that considerably better data will emerge with improved yields and refined production operations during the final phase of the project.

One important concept has not developed as planned. The original plan to manage hybrid sugarcane as tropical forages had failed to perceive clearly the time-span needed for a long-rotation species to maximize tonnage. Hence, the repeated harvests at 2-and 4-month intervals were highly detrimental to dry matter yield. They simply underscored the need to allow sugarcane at least a year to complete its growth and maturation phases. Alternatively, it was found that short-and intermediate-rotation species, such as Sordan and napier grass, could fill the role originally planned for sugarcane. They have responded well to the repeated harvest, solar-drying, and bulk-baling operations for which sugarcane is completely unsuited. Moreover, these grasses can be stored for off-season use when sugarcane is not being harvested. By this means a continuous year-round fuels supply is provided in a convenient mix of bagasse and tropical grasses.

H. REVISED WORK PLAN FOR YEAR FOUR

The fourth-year work plan conforms basically with "evolutionary" changes projected at the onset of the project. Accordingly, the following changes of emphasis are planned for year 4: (a) A reduced level of candidate screening; (b) reduced greenhouse-phase studies in general; (c) increased emphasis on field-scale studies; (d) increased work on mechanized harvest and post-harvest technologies; and (e), expanded work on production-cost and energy-balance analyses.

Field-plot studies for the first three years have concentrated on hybrid sugarcanes and napier grass. Particular attention was given to varieties, row spacing, harvest frequency, and fertilization. In year 4 this emphasis will be redirected toward a "second generation" of sugarcane varieties specially selected for their high-biomass yielding attributes. Row spacing, together with frequent reharvesting, is being dropped as a controlled variable for sugarcane. Nitrogen variables plus 6-and 12-month harvest intervals will be retained. A " gran cultura" cropping interval (16 to 18 months between harvests) will be incorporated for the first time.

A second generation study on sugarcane for biomass (depicted as "energy cane" by the project staff) is being planted at the AES-UPR Lajas Substation during the first quarter of year 4. Napier grass studies are being shifted to the field-scale phase. Special emphasis will be directed toward the mechanized harvest, storage, and transport of 6-month old material. Post-harvest handling and storage operations for bulk bales (1000 to 1500 lb. round bales) will be studied in a roofed storage facility presently being constructed for this purpose. This phase includes the evaluation of storage behavior for grasses baled at varying stages of solar drying.

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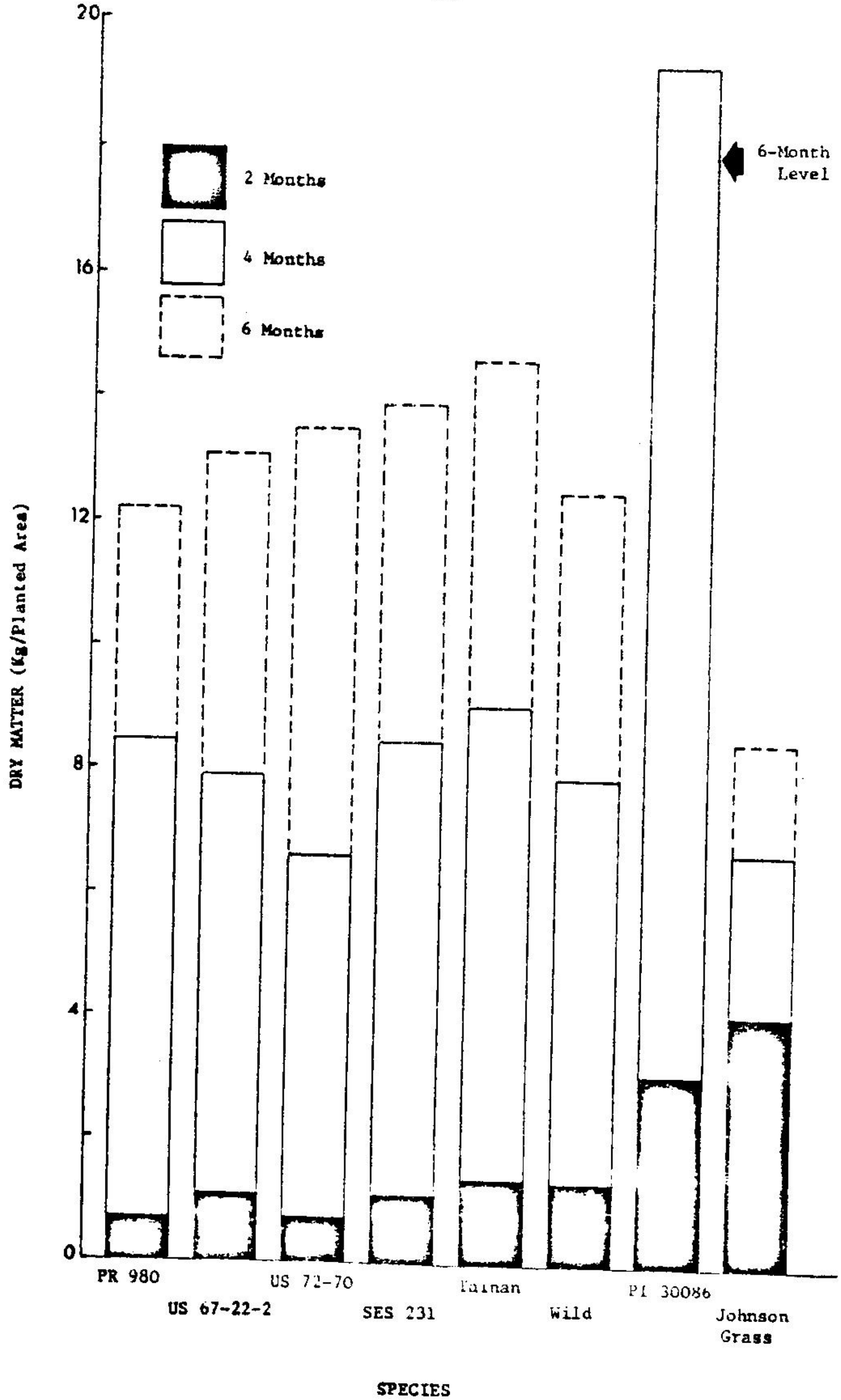

FIGURE 1. Dry matter yield as a function of plant age at harvest for eight candidate tropical grasses. Johnson grass attains maturity within two months (a short-rotation species) while napier grass hybrid PI 30086 is most productive during its second two months after seeding (an intermediate-rotation species).

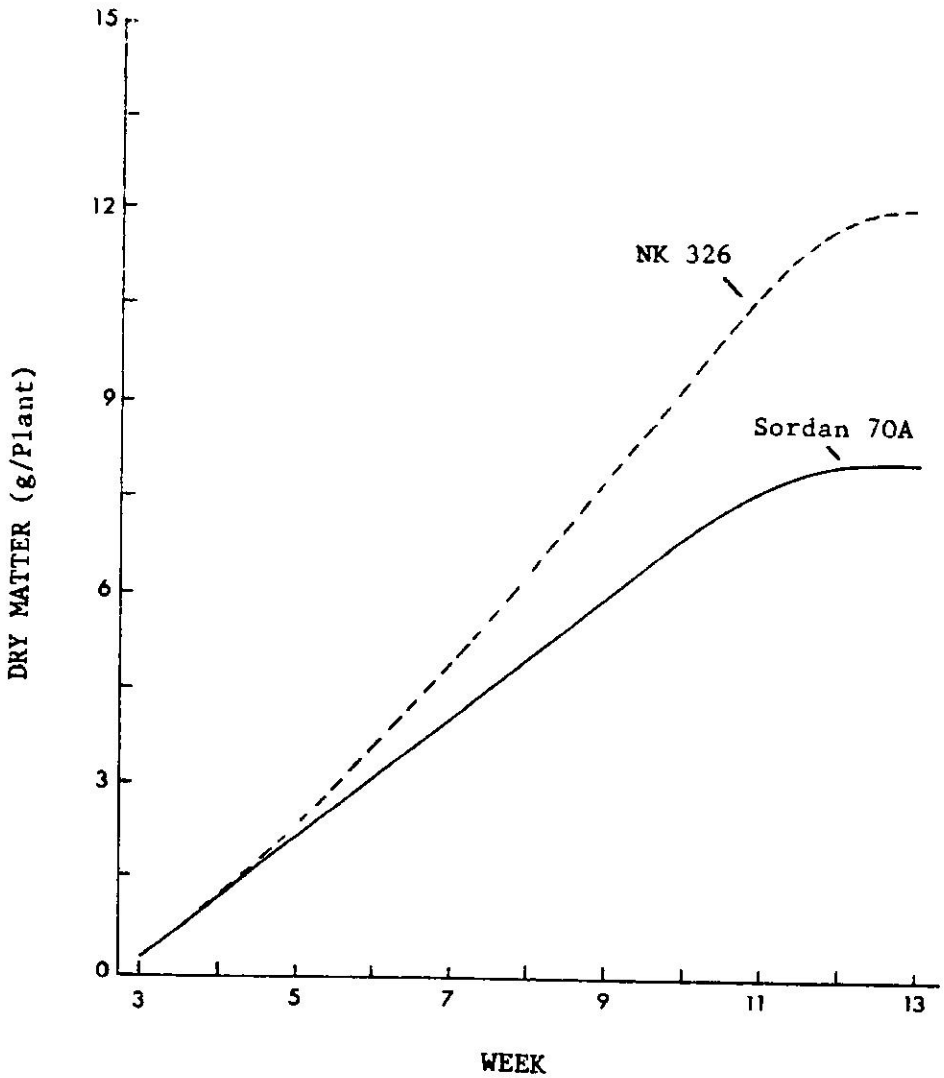

FIGURE 2. Dry matter production by Sordan 70A and NK 336 (both short-rotation species) propagated in a soil-cachaza mixture with adequate water supply.

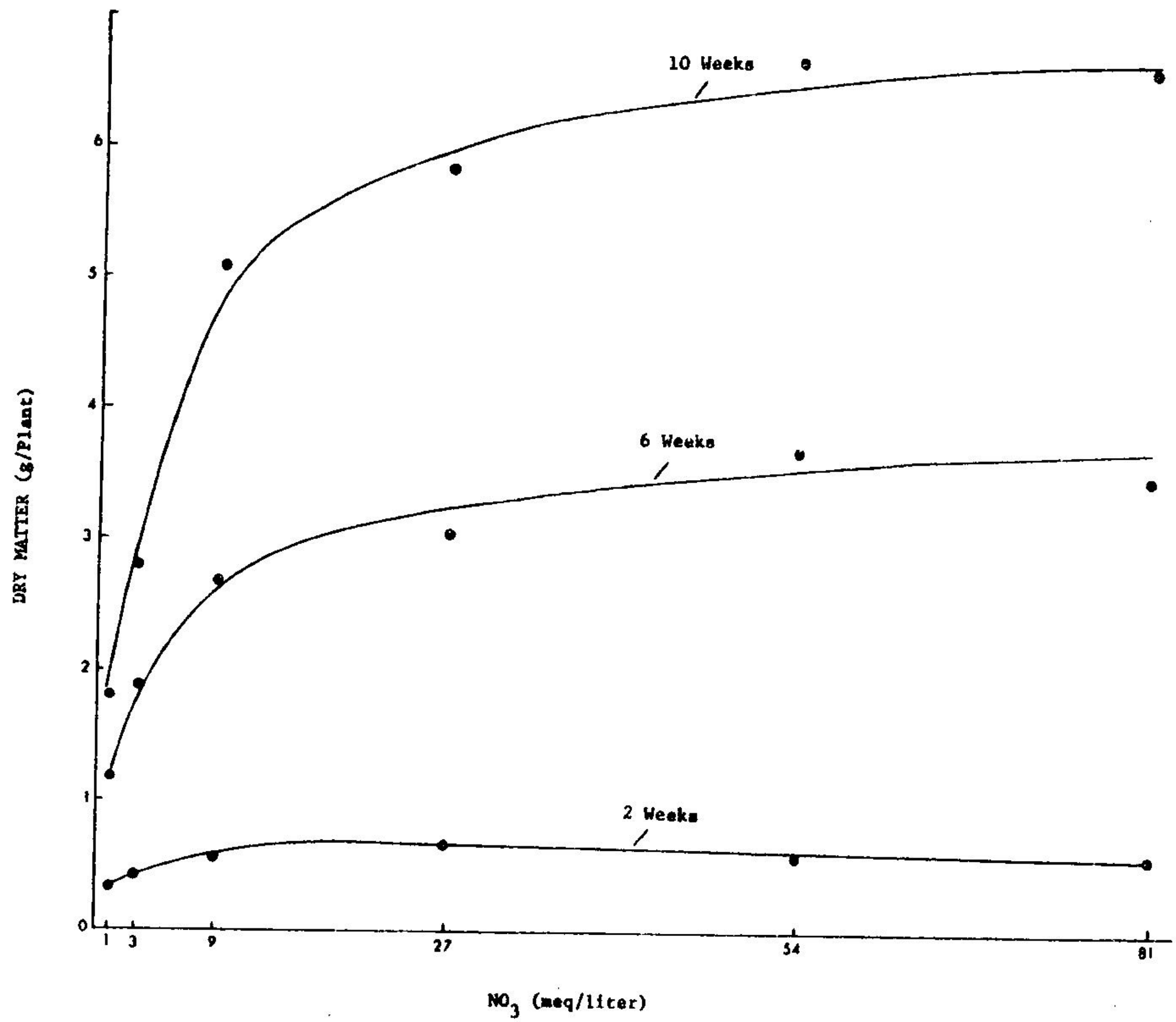

FIGURE 3. Dry matter production by Johnson grass supplied with variable nitrate in sand culture over a time-course of ten weeks.

TABLE 1. RESEARCH PHASES FOR BIOMASS PRODUCTION STUDIES WITH TROPICAL GRASSES

Research Phase	Class of Objectives
Greenhouse	Physiological-Botanical
Field Plot	Botanical-Agronomic
Field Scale	Agronomic-Economic
Commercial-Industrial	Economic

TABLE 2. CATEGORIES OF CANDIDATE TROPICAL GRASSES

Cropping Category	Growth Interval 1/ (Months)	DM Maximum 2/ (Months)
Short Rotation	4-6	2-3
Intermediate Rotation	8-18	4-6
Long Rotation	36-60	12-18
Minimum Tillage	Indeterminate	(?)

1/ Replanting frequency; at least two ratoon crops are anticipated.

2/ Time required physiologically to maximize dry matter.

TABLE 3. DRY MATTER PRODUCTION BY EIGHT CANDIDATE TROPICAL GRASSES HARVESTED 2, 4, AND 6 MONTHS AFTER PLANTING 1/

Cultivar	Genus & Species	DM (Kg/Planted Area) 2/ At Month –		
		2	4	6
PR 980	Saccharum Hybrid	0.65 d 3/	8.26 b	12.20 c
US 67-22-2	S. spont. Hybrid	1.06 cd	7.91 b	13.11 c
US 72-70	S. spont. Hybrid	0.71 d	6.61 b	13.49 c
SES 231	S. spontaneum	1.09 cd	8.43 b	13.93 c
Tainan	S. spont. Hybrid	1.37 c	9.05 b	14.58 b
Wild	S. spont. Hybrid	1.34 c	7.87 b	12.47 c
PI 30086	Pennisetum purpureum	3.03 b	19.31 a	17.91 a
Johnson Grass	Sorghum halepense	4.06 a	6.67 b	8.54 d
	Mean	1.66	9.26	13.28

1/ Propagated in a 1:1 soil-cachaza mixture with adequate water supply.

2/ Approximately 30 square feet.

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

TABLE 4. DRY MATTER CONTENT OF EIGHT CANDIDATE TROPICAL GRASSES HARVESTED AT 2, 4, AND 8 MONTHS AFTER PLANTING 1/

Cultivar	Genus & Species	DM (%) At Month — 2	4	6	Mean
PR 980	*Saccharum* Hybrid	16.2 bc 2/	25.6 b	23.5 e	21.8
US 67-22-2	*S. spont.* Hybrid	17.2 b	25.5 b	27.1 d	23.3
US 72-70	*S. spont.* Hybrid	18.4 b	27.2 b	28.5 d	24.7
SES 231	*S. spontaneum*	20.0 a	32.0 ab	34.6 bc	28.9
Tainan	*S. spont.* Hybrid	16.4 bc	34.7 a	32.8 c	28.0
Wild	*S. spont.* Hybrid	19.9 a	32.3 ab	35.6 b	29.3
PI 30086	*Pennisetum purpureum*	14.1 c	35.4 a	29.3 d	26.3
Johnson Grass	*Sorghum halepense*	19.7 a	38.2 a	42.2 a	33.4
	Mean	17.7	31.4	33.0	

1/ Propagated in a 1:1 soil-cachaza mixture with adequate water supply.

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

TABLE 5. DRY MATTER PRODUCTION, INDIVIDUAL PLANT BASIS, BY EIGHT TROPICAL GRASSES HARVESTED 2, 4, AND 6 MONTHS AFTER PLANTING 1/

Cultivar	Genus & Species	DM (g/Plant) At Month – 2	4	6
PR 980	*Saccharum* Hybrid	4.0 b 1/	42.4 b	60.8 bc
US 67-22-2	*S. spont.* Hybrid	3.4 b	26.5 c	56.4 cd
US 72-70	*S. spont.* Hybrid	2.9 b	20.4 cd	46.6 d
SES 231	*S. spontaneum*	2.1 b	14.0 cd	21.4 ef
Tainan	*S. spont.* Hybrid	2.9 b	18.1 cd	19.2 ef
Wild	*S. spont.* Hybrid	2.9 b	17.8 cd	25.7 e
PI 30086	*Pennisetum purpureum*	8.0 a	95.8 a	76.8 a
Johnson Grass	*Sorghum halepense*	4.2 b	6.8 d	5.9 f
	Mean	3.8	30.2	39.1

1/ Propagated in a 1:1 soil-cachaza mixture with adequate water supply.

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

TABLE 6. DRY MATTER YIELD AND CONTENT OF THREE CANDIDATE SHORT-ROTATION TROPICAL GRASSES [1/]

Cultivar	Dry Matter Yield (g/Plant), At Week – 3	4	5	6	7	8	9	10	11	12	13	Mean
Sordan 70A	0.3 a [2/]	1.2 b	2.1 a	3.1 b	4.2 b	4.6 b	6.2 b	6.1 b	7.9 b	8.4 b	7.4 b	4.7
Sordan 77	0.3 a	1.5 a	2.8 a	4.1 a	5.6 a	4.6 b	6.7 ab	7.9 a	9.2 ab	9.5 ab	8.7 b	5.8
NK 326	0.3 a	1.0 b	2.2 a	3.5 ab	5.1 ab	6.3 ab	8.3 ab	8.9 a	10.6 a	12.4 a	11.7 a	6.4
Mean	0.3	1.3	2.4	3.6	5.0	6.1	7.1	7.6	9.2	10.1	9.3	
	Dry Matter Content (%)											
Sordan 70A	7.9 a	9.4 a	10.8 ab	15.5 ab	17.4 b	23.7 ab	21.2 ab	22.0 b	24.6 b	27.4 a	26.6 b	18.8
Sordan 77	8.1 a	9.8 a	12.9 a	17.1 a	22.3 a	23.2 a	23.2 a	24.3 a	26.8 a	29.4 a	29.1 a	20.8
NK 326	8.0 a	8.4 b	9.3 b	14.5 b	16.4 b	19.1 b	19.1 b	19.2 c	20.8 c	28.0 a	24.6 c	17.0
Mean	8.0	9.2	11.0	15.7	18.7	23.3	21.2	21.8	24.1	28.3	27.1	

1/ Propagated in a 1:1 soil/cachaza mixture with adequate moisture supply. Each figure is the computed mean of three replicates.

2/ Mean values in the same column bearing unlike letters differ significantly ($P < .05$).

TABLE 7. DRY MATTER PRODUCTION BY EIGHT CANDIDATE TROPICAL GRASSES OVER A TIME-COURSE OF 10 WEEKS

Variety	DM Yield (Kg/Plot) 1/ At Week – 6	8	10	Mean
Sordan 77	0.31	0.55	0.71	0.52
Trudan 5	0.30	0.54	0.72	0.52
Dekalb FS-4	0.28	0.49	0.72	0.50
Dekalb FS-25 a +	0.36	0.56	0.80	0.57
Dekalb ST-6	0.33	0.55	0.74	0.54
Dekalb ST-6 +	0.33	0.53	0.72	0.53
Dekalb SX-16 a	0.32	0.53	0.71	0.52
Dekalb SX-17 +	0.29	0.54	0.80	0.54
Mean	0.32	0.54	0.74	

DM Content (%)

Sordan 77	18.4	24.4	33.4	25.4
Trudan 5	16.2	24.6	30.9	23.9
Dekalb FS-4	14.1	19.5	27.4	20.3
Dekalb FS-25 a +	16.5	21.6	28.3	22.1
Dekalb ST-6	17.1	25.2	32.2	24.8
Dekalb ST-6 +	17.0	21.8	30.2	23.0
Dekalb SX-16 a	16.3	21.1	27.8	21.7
Dekalb SX-17 +	14.4	20.7	28.9	21.3
Mean	16.3	22.4	29.9	

OD g/Plant

Sordan 77	3.1	5.6	7.4	5.4
Trudan 5	3.7	6.6	6.5	5.6
Dekalb FS-4	3.8	5.2	7.1	5.4
Dekalb FS-25 a +	3.8	6.2	8.6	6.2
Dekalb ST-6	4.0	5.8	7.0	5.6
Dekalb ST-6 +	3.3	5.8	7.2	5.4
Dekalb SX-16 a	4.6	6.4	7.9	6.3
Dekalb SX-17 +	3.4	6.4	8.2	6.0
Mean	3.7	6.0	7.5	

1/ Approximately 1/200 acre.

TABLE 8. DRY MATTER PRODUCTION BY EIGHT CANDIDATE TROPICAL GRASSES PROPAGATED WITH VARIABLE MOISTURE REGIMES OVER A TIME-COURSE OF 11 WEEKS

Moisture Regime	Variety	DM (Kg/Plot) 1/ At Week – 7	9	11	Mean
Humid	Sordan 77	.58	.74	.70	.67
	Trudan 5	.44	.57	.79	.60
	Dekalb FS-4	.41	.61	.77	.59
	Dekalb FS-25 a +	.41	.61	.74	.59
	Dekalb ST-6	.56	.79	.91	.75
	Dekalb ST-6 +	.58	.82	.81	.74
	Dekalb SX-16 a	.45	.65	.99	.70
	Dekalb SX-17 +	.50	.79	.85	.71
	Mean	.49	.70	.82	.67
Normal	Sordan 77	.36	.48	.57	.47
	Trudan 5	.34	.47	.56	.46
	Dekalb FS-4	.39	.54	.54	.49
	Dekalb FS-25 a +	.38	.56	.64	.53
	Dekalb ST-6	.40	.56	.67	.54
	Dekalb ST-6 +	.39	.47	.57	.48
	Dekalb SX-16 a	.33	.52	.69	.51
	Dekalb SX-17 +	.38	.51	.60	.50
	Mean	.37	.51	.61	.50
Semi-Arid	Sordan 77	.32	.42	.44	.39
	Trudan 5	.30	.40	.46	.39
	Dekalb FS-4	.31	.41	.48	.40
	Dekalb FS-25 a +	.34	.48	.48	.43
	Dekalb ST-6	.36	.47	.45	.43
	Dekalb ST-6 +	.28	.45	.48	.40
	Dekalb SX-16 a	.28	.45	.47	.40
	Dekalb SX-17 +	.32	.44	.49	.42
	Mean	.31	.44	.47	.41

1/ Approximately 1/200 acre.

TABLE 9. DRY MATTER CONTENT OF EIGHT CANDIDATE TROPICAL GRASSES PROPAGATED WITH VARIABLE MOISTURE REGIMES OVER A TIME-COURSE OF 11 WEEKS

Moisture Regime	Variety	DM (%) AT Week – 7	9	11	Mean
Humid	Sordan 77	16.5	25.4	27.6	23.2
	Trudan 5	14.9	22.1	26.7	21.2
	Dekalb FS-4	13.8	22.2	25.8	20.6
	Dekalb FS-25 a +	12.3	18.7	21.2	17.4
	Dekalb ST-6	15.4	25.1	29.1	23.2
	Dekalb ST-6 +	14.8	21.8	22.8	19.8
	Dekalb SX-16 a	13.4	20.2	24.3	19.3
	Dekalb SX-17 +	12.6	19.9	24.2	18.9
	Mean	14.2	21.9	25.2	20.5
Normal	Sordan 77	16.0	23.3	31.9	23.7
	Trudan 5	15.0	23.8	26.8	21.9
	Dekalb FS-4	12.9	21.1	22.3	18.8
	Dekalb FS-25 a +	13.0	19.7	23.2	18.6
	Dekalb ST-6	15.4	23.7	35.4	24.8
	Dekalb ST-6 +	13.2	19.8	29.6	20.9
	Dekalb SX-16 a	13.9	20.8	30.4	21.7
	Dekalb SX-17 +	13.0	20.6	25.1	19.6
	Mean	14.1	21.6	28.1	21.3
Semi-Arid	Sordan 77	19.3	24.5	29.1	24.3
	Trudan 5	17.7	24.6	31.3	24.5
	Dekalb FS-4	15.9	19.7	22.9	19.5
	Dekalb FS-25 a +	16.3	19.5	20.4	18.7
	Dekalb ST-6	20.2	25.3	23.9	23.1
	Dekalb ST-6 +	16.2	21.7	25.0	21.0
	Dekalb SX-16 a	17.1	20.5	25.1	20.9
	Dekalb SX-17 +	17.7	20.1	21.2	19.7
	Mean	17.6	22.0	24.9	21.5

TABLE 10. DRY MATTER PRODUCTION BY JOHNSON GRASS PROPAGATED WITH VARIABLE NITRATE SUPPLY IN SAND CULTURE

NO_3 Level (meq/1)	DM (g/Plant) At Week [1/]				Mean
	2	4	6	10	
1	.34 c [2/]	.61 c	1.21 c	1.82 c	0.99
3	.42 bc	1.14 c	1.90 bc	2.78 c	1.56
9	.55 a	1.84 b	2.68 ab	5.11 b	2.55
27	.64 a	1.92 b	3.10 a	5.68 ab	2.84
54	.57 ab	2.60 a	3.60 a	6.65 a	3.36
81	.57 ab	2.20 ab	3.38 a	5.57 a	2.93

[1/] Nutrient treatments were initiated when seedlings were two weeks of age. The initial harvest was taken two weeks thereafter, ie, when the plants were four weeks of age.

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

TALBE 11. DRY MATTER CONTENT (%) OF JOHNSON GRASS PROPAGATED WITH VARIABLE NITRATE SUPPLY IN SAND CULTURE

NO_3 Level (meq/1)	DM (%) At Week —				
	2	4	6	10	Mean
1	14.7 a [1/]	20.1 a	25.5 a	31.3 a	22.9
3	13.5 ab	18.4 a	25.2 a	31.3 a	22.1
9	11.0 c	15.5 b	23.8 a	29.4 a	19.9
27	12.0 bc	14.0 bc	19.3 b	25.7 b	17.8
54	9.6 c	13.1 c	20.7 b	25.1 b	17.1
81	9.8 c	13.3 bc	20.5 b	24.1 b	16.9
Mean	11.8	15.7	22.5	27.9	

[1/] Mean values in the same column bearing unlike letters differ significantly ($P < .05$). Values bearing at least one letter in common do not differ significantly.

TABLE 12. FOLIAR CONTNET OF N, P, AND K FOR JOHNSON GRASS PROPAGATED WITH VARIABLE NITRATE SUPPLY IN SAND CULTURE 1/

NO_3 (meq/1)	Foliar Content (% Dry Wt.) For —		
	N	P	K
1	1.07 2/	0.25	2.83
3	1.16	0.23	2.54
9	1.57	0.26	2.57
27	2.14	0.29	2.37
54	2.14	0.27	2.37
81	2.19	0.25	2.53
Mean	1.71	0.26	2.54

1/ Entire blades of leaf ranks 1 & 2, harvested at week 10 of variable NO_3 treatments.

2/ All Figures are the computed means of three replicates.

TABLE 13. POST-HARVEST REGROWTH BY JOHNSON GRASS PLANTS PROPAGATED WITH VARIABLE NITRATE SUPPLY IN SAND CULTURE 1/

NO_3 (meq/1)	Shoots/Plot	g/Plant for — Green Wt.	Dry Wt.	% DM
1	263	93.3	22.2	23.8
3	332	149.7	34.9	23.3
9	280	206.0	45.1	21.9
27	185	149.1	25.7	17.2
54	118	151.0	26.2	17.4
81	142	173.2	30.7	17.7

1/ Recut four weeks after termination of the variable NO_3 treatments. All figures are the computed means of three replicates.

TABLE 14. DRY MATTER PRODUCTION BY CANDIDATE *S. SPONTANEUM* AND *S. SINENSE* CLONES GIVEN MINIMUM TILLAGE FOR SIX MONTHS 1/

Species	Clone	Yield/Plot (Kg) For -- Green Matter	Yield/Plot (Kg) For -- Dry Matter	% DM
Saccharum Hybrid	PR 980	8.51	2.40	28.2
S. sinense	Saretha	1.54	0.37	24.1
	Chunnee	80.64	28.32	35.1
	Natal Uba	3.05	0.74	24.2
	Tainan	8.87	3.42	38.5
S. spontaneum	SES 231	94.08	34.3	36.5
	SES 317	79.30	33.9	42.8
	SES 327	18.82	6.62	35.3
	US 67-22-2	43.01	11.61	27.0
	US 67-34-24	32.48	9.62	29.6
	US 72-97	77.28	24.00	31.0
	US 72-70 2/	(Incomplete Data)		
	US 72-72 2/	39.20	12.39	31.6
	US 72-144 2/	44.85	14.85	33.1

1/ Plot size = 1/200 acre.

2/ *S. spontaneum* hybrids.

TABLE 15. BIOMASS PRODUCTION BY FIVE SACCHARUM CLONES UNDER MINIMUM-TILLAGE CONDITIONS; AUG. 11, 1979-FEB. 11, 1980 1/

Clone	6-Months Yield (Tons/Acre) For —		% DM
	Green Matter	Dry Matter	
PR 980	1.32	0.49	34.0
US 67-22-2	2.47	0.86	34.8
US 72-72	3.92	1.36	34.7
US 72-93	1.66	0.79	47.6
S. spont. Hybrid	3.18	0.96	30.1

1/ Fourth, 6-month harvest. Originally planted during February, 1977.

TABLE 16. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; FIRST 2-MONTH HARVEST

	Green Matter (Tons/A), At Row Center –		
Cultivar	150 cm	50 cm	% Change
PR 980	0.79 c 1/	0.84 c	6.3
NCo 310	4.52 b	3.92 b	-13.2
PR 64-1791	1.29 c	0.94 c	-27.1
	50 cm	25 cm	
Napier Grass	12.08 a	12.78 a	5.7
	Dry Matter (Tons/Acre)		
PR 980	0.11 c 1/	0.12 c	9.0
NCo 310	0.64 b	0.56 b	-12.5
PR 64-1791	0.20 c	0.14 c	-30.0
Napier Grass	1.87 a	2.04 a	9.0
	Dry Matter Content (%)		
PR 980	13.3 b	14.3 ab	7.5
NCo 310	14.2 ab	14.2 ab	0
PR 64-1791	15.5 a	14.8 ab	- 4.5
Napier Grass	15.5 a	16.0 a	3.2

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those bearing at least one letter in common do not differ significanly.

TABLE 17. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; SECOND 2-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center – 150 cm	50 cm	% Change
PR 980	0.51 d 1/	0.62 d	21.5
NCo 310	2.60 c	2.54 c	- 2.3
PR 64-1791	0.92 d	0.73 d	-20.6
	50 cm	25 cm	
Napier Grass	7.75 b	8.84 a	14.0
	Dry Matter (Tons/Acre)		
PR 980	0.07 c	0.09 c	28.5
NCo 310	0.39 b	0.34 b	-12.8
PR 64-1791	0.13 c	0.11 c	-15.3
Napier Grass	1.21 ab	1.42 a	17.3
	Dry Matter Content (%)		
PR 980	13.2 b	13.8 ab	4.5
NCo 310	15.0 ab	13.4 b	-10.6
PR 64-1791	14.0 ab	14.9 ab	6.4
Napier Grass	15.6 ab	16.1 a	3.2

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those bearing at least one letter in common do not differ significantly.

TABLE 18. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; THIRD 2-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center – 150 cm	50 cm	% Change
PR 980	0.28 b [1/]	0.40 b	42.8
NCo 310	1.47 b	1.45 b	- 1.3
PR 64-1791	0.38 b	0.27 b	-28.9
	50 cm	25 cm	
Napier Grass	11.74 a	11.29 a	- 3.8
	Dry Matter (Tons/A)		
PR 980	0.04 b	0.06 b	50.0
NCo 310	0.19 b	0.22 b	15.7
PR 64-1791	0.05 b	0.05 b	0
Napier Grass	1.48 a	1.41 a	- 4.7
	Dry Matter Content (%)		
PR 980	14.5 a	14.0 a	- 3.4
NCo 310	13.1 a	15.2 a	16.0
PR 64-1791	13.7 a	13.7 a	0
Napier Grass	12.6 a	12.5 a	- 0.7

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those having at least one letter in common do not differ significantly.

TABLE 19. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; FOURTH 2-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center – 150 cm	50 cm	% Change
PR 980	0.19 d [1/]	0.32 cd	68.4
NCo 310	1.65 b	1.42 b	-14.0
PR 64-1791	0.38 cd	0.21 d	-44.7
	50 cm	25 cm	
Napier Grass	11.60 a	10.21 a	-11.9
	Dry Matter (Tons/Acre)		
PR 980	0.02	0.07	250.0
NCo 310	0.21	0.19	- 9.4
PR 64-1791	0.08	0.02	-74.8
Napier Grass	1.29	1.25	- 3.1
	Dry Matter Content (%)		
PR 980	11.9 bc	13.5 ab	13.4
NCo 310	13.0 ab	13.8 ab	6.1
PR 64-1791	15.0 a	13.1 ab	-12.6
Napier Grass	11.2 c	10.4 c	- 7.1

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those bearing at least one letter in common do not differ significantly.

TABLE 20. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; FIFTH 2-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center – 150 cm	50 cm	% Change
PR 980	0.34 d [1/]	0.32 d	- 5.8
NCo 310	2.04 c	1.91 c	- 6.3
PR 64-1791	0.40 d	0.14 d	-65.0
	50 cm	25 cm	
Napier Grass	15.25 b	16.51 a	8.2
	Dry Matter (Tons/Acre)		
PR 980	0.06 c	0.07 c	16.7
NCo 310	0.40 b	0.32 b	-20.0
PR 64-1791	0.08 c	0.03 c	-62.5
Napier Grass	2.38 a	2.38 a	0
	Dry Matter (%)		
PR 980	19.1 a	20.4 a	6.8
NCo 310	19.7 a	21.0 a	2.0
PR 64-1791	18.2 a	20.4 a	12.0
Napier Grass	14.7 b	14.5 b	1.3

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those bearing at least one letter in common do not differ significantly.

TABLE 21. GREEN MATTER YIELDS FOR THE SECOND-RATOON CROP OF SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Species	Green Matter (Tons/Acre), At Indicated Month 1/						Total Yield
		2	4	6	8	10	12	
2 Months	Sugarcane 2/	2.1	1.3	0.7	0.7	0.9		5.7
	Napier Grass 3/	12.1	8.3	11.5	10.5	15.9	(Incomplete Data)	59.0
4 Months	Sugarcane		15.5		7.6			23.1
	Napier Grass		22.9		29.7		(Incomplete Data)	52.6
6 Months	Sugarcane			26.1				26.1
	Napier Grass			31.7			(Incomplete Data)	31.7
12 Months	Sugarcane							
	Napier Grass						(Incomplete Dara)	—

1/ Trash excluded.

2/ Mean values for three varieties and two row spacings.

3/ Mean values for one variety and two row spacings.

TABLE 22. DRY MATTER YIELDS FOR THE SECOND-RATOON CROP OF SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Species	Dry Matter (Tons/Acre), At Indicated Month 1/						Total Yield
		2	4	6	8	10	12	
2 Months	Sugarcane 2/	0.3	0.2	0.1	0.1	0.2		0.9
	Napier Grass 3/	2.0	1.3	1.4	1.3	2.4	(Incomplete Data)	8.4
4 Months	Sugarcane		3.0		1.4			4.4
	Napier Grass		7.7		5.3		(Incomplete Data)	13.0
6 Months	Sugarcane			6.3				6.3
	Napier Grass			8.5			(Incomplete Data)	8.5
12 Months	Sugarcane							
	Napier Grass						(Incomplete Data)	—

1/ Trash excluded.

2/ Mean values for three varieties and two row spacings.

3/ Mean values for one variety and two row spacings.

TABLE 23. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; FIRST 4-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center —		
	150 cm	50 cm	% Change
PR 980	14.0 bc 1/	11.9 bc	-15.0
NCo 310	21.7 a	20.9 a	- 3.6
PR 64-1791	15.3 bc	9.5 c	-37.9
	50 cm	25 cm	
Napier Grass	23.6 a	22.1 a	- 6.3
	Dry Matter (Tons/Acre)		
PR 980	2.59 cd	2.23 cd	-13.8
NCo 310	4.20 b	4.16 b	- 1.0
PR 64-1791	2.88 c	1.80 d	-37.5
Napier Grass	7.91 a	7.47 a	- 5.5
	Dry Matter Content (%)		
PR 980	18.9 b	18.8 b	- 0.5
NCo 310	19.5 b	19.9 b	2.0
PR 64-1791	18.9 b	18.9 b	0
Napier Grass	33.5 a	33.8 a	0.9

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those having at least one letter in common do not differ significantly.

TABLE 24. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; SECOND 4-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center — 150 cm	50 cm	% Change
PR 980	9.45 b 1/	6.37 c	-32.5
NCo 310	7.74 c	9.46 b	22.2
PR 64-1791	8.49 bc	4.34 d	-48.8
	50 cm	50 cm	
Napier Grass	29.78 a	29.68 a	0
	Dry Matter (Tons/Acre)		
PR 980	1.51 b	1.12 bc	-25.8
NCo 310	1.97 b	1.72 b	-12.6
PR 64-1791	1.40 b	0.70 c	-50.0
Napier Grass	5.27 a	5.25 a	- 0.3
	Dry Matter (%)		
PR 980	16.0 b	16.9 ab	5.6
NCo 310	17.0 ab	18.1 a	5.2
PR 64-1791	16.0 ab	15.7 b	-5.4
Napier Grass	17.8 a	17.7 a	0

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those having at least one letter in common do not differ significantly.

TABLE 25. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; FIRST 6-MONTHS HARVEST

	Green Matter (Tons/A), At Row Center –		
Cultivar	150 cm	50 cm	% Change
PR 980	24.8 cd [1/]	21.9 d	-11.6
NCo 310	35.8 a	33.6 ab	- 6.1
PR 64-1791	22.4 d	17.8 d	-20.5
	50 cm	25 cm	
Napier Grass	33.3 ab	30.0 bc	- 9.9

	Dry Matter (Tons/A)		
PR 980	6.1 b	4.9 b	-19.6
NCo 310	8.7 a	8.5 a	- 2.2
PR 64-1791	5.4 b	4.1 c	-24.0
Napier Grass	9.0 a	7.9 a	-12.2

	Dry Matter Content (%)		
PR 980	21.9 d	22.2 d	1.3
NCo 310	24.3 abc	25.3 abc	4.1
PR 64-1791	23.9 bc	22.8 cd	- 4.6
Napier Grass	27.1 a	26.2 ab	- 3.3

1/ Mean values bearing unlike letters differ significantly ($P < .05$); those having at least one letter in common do not differ significantly.

TABLE 26. DRY MATTER CONTENT FOR THE SECOND RATOON CROP OF SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Species	Dry Matter Content (%), At Indicated Month —						Mean
		2	4	6	8	10	12	
2 Months	Sugarcane	14.4	14.1	14.0	13.4	19.8		15.1
	Napier Grass	15.8	15.9	12.6	10.8	14.6	(Incomplete Data)	13.9
4 Months	Sugarcane		19.2		16.7			18.0
	Napier Grass		33.7		17.8		(Incomplete Data)	25.8
6 Months	Sugarcane			23.4				23.4
	Napier Grass			26.7			(Incomplete Data)	26.7
12 Months	Sugarcane							—
	Napier Grass						(Incomplete Data)	

TABLE 27. BIOMASS PRODUCTION BY THREE CANDIDATE TROPICAL GRASSES PROPAGATED WITH MINIMUM WATER SUPPLY OVER A TIME-COURSE OF 10 WEEKS 1/

Variety	Area Planted (Acre)	Biomass Yield (Tons/Acre)	
		Green Wt.	Dry Wt. 2/
Sordan 70A	3.6	11.13	1.67
Sordan 77	1.8	14.87	2.23
NK 326	1.8	9.26	1.39

1/ All plots received 2.0 acre inches of water by overhead irrigation at planting. No additional irrigations were administered. Rainfall for the 10-week growth period totaled 2.75 inches.

2/ Solar dried to approximately 15% moisture.

TABLE 28. PRELIMINARY PERFORMANCE EVALUATIONS FOR THE M-C ROTARY SCYTHE-CONDITIONER OPERATING IN STANDS OF TWO NAPIER GRASS VARIETIES AGED SIX MONTHS

	Estimated Crop Mass		Equipment Operation		Performance Ratings[1,2]						
Variety	Tons/acre	% DM	Tractor Gear (1900 rpm)	Mowing Height (in.)	Clean Cutting	Even Stubble	Conditioning	Plant Resistance	Crown Injury	Ratoon Regrowth	Total Rating
Merker	45-50	25-30	1	6-8	2.5	2.5	2.5	1.0	1.0	2.0	10.5
				2-3	1.0	1.5	1.0	1.0	2.0	1.0	7.5
			2	6-8	3.5	4.0	4.0	4.0	1.0	2.0	18.5
				2-3	2.5	2.5	3.0	3.0	2.0	1.0	14.0
PI 7350	40-45	30-32	1	6-8	1.5	1.5	1.5	1.0	1.0	2.5	9.0
				2-3	1.0	1.0	1.0	1.0	2.0	1.0	7.0
			2	6-8	3.5	4.0	4.0	4.0	1.0	2.5	19.0
				2-3	1.0	1.0	1.0	2.0	2.0	1.0	8.0

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

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

TABLE 29. NEW SUGARCANE CROSSES FOR BIOMASS; NOV., 1979

Female Parent		Male Parent	Objectives
B 70-701	x	57-NG-54	Fiber only
NCo 310	x	US 67-22-2 1/	Fiber & Fermentable Solids
NCo 310	x	B 70-701 1/	Fiber & Fermentable Solids
PR 62-195	x	57-NG-54	Fiber & Fermentable Solids
PR 68-330	x	47-NG-54	Fiber & Fermentable Solids

1/ Field cross.

TABLE 30. NEW SUGARCANE CROSSES FOR BIOMASS; DECEMBER, 1979

Cross No.	Female Parent		Male Parent	Estimated No. Of Seedlings
I	PR 980	x	*S. spont.* Hybrid	400 to 500
	PR 67-1070	x	*S. spont.* Hybrid	500
3	PR 64-1618	x	*S. spont.* Hybrid	20

TABLE 31. PRELIMINARY COST ANALYSIS FOR TOTAL DRY MATTER PRODUCTION BY FIRST-RATOON SUGARCANE MANAGED AS AN ENERGY CROP

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

Preliminary Cost Analysis

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

1/ Labor which is not included in other costs

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

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

TABLE 32. PRELIMINARY COST ANALYSIS FOR ENERGY CANE vs CONVENTIONAL SUGARCANE PRODUCTION IN PUERTO RICO (1979 DOLLARS).

Analysis For A Privately Owned 200 Acre Operation 1/

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

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

2/ Labor which is not included in other costs.

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

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

TABLE 33. MEAN ANNUAL ENERGY INPUTS FOR ENERGY CANE PRODUCTION IN PUERTO RICO

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

1/ Alexander, et al (2, 19).

2/ Adapted from Warren, et al (19).

TABLE 34. ENERGY INPUT AND RECOVERY FROM ENERGY CANE PRODUCTION 1/

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

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

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