MASTER

**PRODUCTION OF SUGARCANE AND TROPICAL
GRASSES AS A RENEWABLE
ENERGY SOURCE**

**FIRST QUARTERLY REPORT
1980-1981**

TO

THE UNITED STATES DEPARTMENT OF ENERGY

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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

First Quarterly Report; 1980—1981

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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CONTRACT NO.: DE-AS05-78ET20071 (AES-UPR Project C-481)

LOCATION: Río Piedras, Puerto Rico

PERIOD COVERED: June 1, 1980—August 31, 1980

ENDORSEMENT:

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

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ABSTRACT

Research continued on tropical grasses from Saccharum and related genera as sources of intensively-propagated fiber and fermentable solids. Final yield data for the second-ratoon crop of sugarcane and napier grass was compiled during the first quarter. The highest green matter yield for sugarcane was 92.0 tons/acre year (variety NCo 310). The highest dry matter yield, including trash, was 31.3 tons/acre year. For napier grass the highest green and dry matter yields were 88.9 and 22.4 tons/acre year, respectively. Sugarcane quality was generally low but sugar yields were favorable when computed on a per acre basis. Sucrose content averaged 7.20% for all varieties and row spacings. Fiber content averaged 16.4%. The second ratoon crop averaged 6.18 tons sugar/acre (TSA) at standard row spacing and 5.71 TSA at narrow row spacing.

Yield trends for sugarcane and napier grass over a 3-year period (plant crop plus two ratoon crops) were compiled during the first quarter. Four distinct trends are evident: (a) A general failure of narrow row spacing to increase yields; (b), major DM yield increases with delay of harvest interval; (c) a moderate superiority of the sugarcane variety NCo 310; and (d), a superiority of the first-ratoon crop over both the plant and second-ratoon crops. The second-ratoon yields were intermediate between those of the plant and first-ratoon crops. Over the three-year period, average DM yields for sugarcane and napier grass were 29.0 and 27.5 OD tons/acre year, respectively. Optimal harvest interval was 12 months for sugarcane and 6 months for napier grass. Optimal row spacing was 150 cm for sugarcane and 50 cm for napier grass.

Harvest machinery trials for mature napier grass continued during the first quarter. Two implements, an M-C rotary scythe-conditioner and a New Holland round baler, performed very adequately with 6-months old napier grass. With a standing green mass approaching 40 tons/acre, such material is a maximum test in the harvest and post-harvest management of tropical grasses as solar-dried forages. Diesel fuel consumption by a category III tractor operating the rotary scythe-conditioner in 6-months old napier grass ranged from 2.38 to 2.95 gallons/hour, or 1.92 to 2.69 gallons/acre. There was moderately greater fuel consumption at low mowing height (2.5 to 5.0 cm stubble) than at high mowing height (20.0 to 25.0 cm stubble). Horsepower usage ranged from 41.4 hp at low stubble to 35.7 hp at high stubble.

1/ Contract No. DE-AS05-78ET20071 (AES-UPR Project C-481)

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, 1980 to August 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 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). Categories of tropical-grass candidates for biomass production are discussed in detail elsewhere (3).

A breeding program designed to intensify the biomass-yielding attribute of Saccharum and related species lies beyond the scope of this project. Thorough breeding studies would require and justify a separate project. 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

^{1/} Numbers in parentheses refer to relevant published literature. Complete citations are listed on pages 23 and 24.

ongoing breeding program for sugarcane. Certain progeny originating with the AES-UPR sugarcane breeding program are also being considered as long-rotation biomass candidates (4). Under these circumstances some prospect is created for the emergence of superior new progeny at very little expense.

TECHNICAL REPORT

A. FIELD-PLOT STUDIES

1. 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 (3, 5).

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 fifth such harvest was performed during the first quarter. Dry matter yields are relatively low for all clones; however, it is evident that two of the S. spontaneum clones, US 67-22-2 and US 72-93, are sustaining themselves more effectively than the commercial hybrid PR 980 (Table 3).

The superior clone at this stage of the experiment is US 72-93. Its green and dry matter yields were 4.71 and 1.88 tons/acre, respectively. Energy inputs for US 72-93 under these circumstances are nil since neither irrigation nor machinery-use practices are involved. Cost inputs are confined to land rentals (\$50.00/acre year) and labor for harvest operations (approximately (\$45.00/acre

year). Assuming an annual yield of 3.76 OD tons/acre for US 72-93 (two 6-month harvests), its production cost at \$25.26/ton would be almost identical to that of "energy cane" at \$25.46/ton (2).

The yields herein reported are from the fifth 6-month harvest of a planting seeded early in February of 1977. They constitute the fourth consecutive harvest performed under minimum tillage conditions, that is, where no production inputs have been given other than harvest operations. All clones indicate that they can survive and produce some biomass under these conditions. The average dry matter yield for the group appears to have become fairly constant at slightly less than one OD ton/acre/6 months of growth (Table 4).

2. Sugarcane And Napier Grass; Third Year Results

(a) Final Growth Data of Year 3: Because this study was planted 1.5 months into Year 1, the final growth data for each year is obtained during the first quarter of the following year. Hence, the Third Annual Report covering activities for Year 3 was lacking data for the sixth 2-month harvest, the third 4-month harvest, the second 6-month harvest, and the 12-month harvest.

Final data for Year 3 (Tables 5-9) are consistent with yield trends reported previously for years 1 and 2 (2, 3). These trends include: (a) Lack of major yield differences between sugarcane varieties, with NCo 310 being moderately superior to PR 980 and PR 64-1791; (b) a general failure of narrow row spacing to increase yields; and (c), major yield increases by delaying the napier grass harvest interval from 2 to 4 or 6 months, and by delaying the sugarcane harvest until 12 months.

The 2-month harvest interval had virtually destroyed sugarcane varieties PR 980 and PR 64-1791 by the end of the third year of cropping (Table 5).

Napier grass was far more tolerant of frequent recutting than sugarcane. On the other hand, the 12-month interval which favored sugarcane was repressive for napier grass (Table 8).

Sugarcane trash yields were higher for variety PR 980 than NCo 310 and PR 64-1791 (Table 8). Napier grass generally produced less trash than sugarcane, but the percentage of its biomass comprised of trash was higher than for cane. Hence, 28.4 percent of the total napier grass DM consisted of trash, while sugarcane trash ranged from 14.1 to 28.8 percent of the total. Among the cane varieties NCo 310 produced the least trash (Table 8). Nonetheless, total dry matter yields (Oven-dry millable cane plus trash) indicate that NCo 310 was still the superior biomass producer for Year 3 (Table 9).

(b) Maximum Biomass Yields; Year 3: As noted above, the 12-month harvest was by far the most important for sugarcane while the 6-month harvest gave maximum yields for napier grass. The highest green matter yield (exclusive of trash) for Year 3 was 92.0 tons/acre year (Table 8, variety NCo 310); the highest dry matter yield was 31.3 tons/acre year, including trash (Table 9, variety NCo 310). As a point of reference the PR sugar industry currently produces 28 to 30 green tons and 9 to 10 dry tons per acre year as an Island-wide average. Trash is not credited to total cane yield by the PR Sugar Corporation.

The maximum napier grass yield at 12 months was 67.8 green tons and 19.9 dry tons/acre year (Tables 8 and 9). A much greater yield was obtained as the combined output of three, 4-month harvests (88.9 green tons, 22.4 dry tons) or two, 6-month harvest (88.7 green tons, 24.0 dry tons). This is indicated by summary data presented in Tables 10 and 11.

Napier grass continued to attain a higher level of maturity than sugarcane during Year 3 (Table 12). The maximum average DM content for sugarcane

was 26.7% at twelve months; napier grass achieved a comparable maturity (25.8%) within four months. By the twelfth month the napier grass DM content exceeded 32% (Table 12).

Although annual napier grass yields were roughly equal for combined 4-month and 6-month harvests, appreciably less cost would be incurred when only two harvests are performed (at 6-month intervals). There would be less damage to plant crowns, less soil compaction, and less destruction of irrigation borders by heavy machinery when one of the three harvests is eliminated. A decisive factor here is the work capacity of available harvest equipment. There is little point in attempting to harvest 6-months old biomass with harvest equipment designed to accommodate only 2-months old material. Machinery studies during Year 3 have shown quite decisively that 6-months old napier grass can be harvested with existing equipment (see pages 17 to 19).

(c) Sugarcane Quality: The sugarcane management practices for this project are designed to maximize growth rather than quality of the cane. Relatively poor juice quality was obtained for the plant crop and first-ratoon crop. The second ratoon plants showed moderately improved quality but nonetheless would be regarded as substandard in most cane sugar industries. Sucrose content averaged 7.2% for all varieties and row spacings (Table 13). Variety PR 64-1791, at standard row spacing, produced 8.4% sucrose. Fiber content averaged 16.4 percent, a value which is not exceptionally high.

While the quality of the cane herein described as "energy cane" was low, it is nonetheless equal to or better than that of Puerto Rico's commercial sugar industry. Commercial sugarcane in Puerto Rico today rarely produces more than 8% sucrose. This is a consequence of a whole series of field and factory problems which lie beyond the scope of our discussion. However, it must be

noted that cane grown for biomass cannot be faulted for low yields of sucrose or fermentable solids when these are computed on a per acre basis. For the Year 3 crop the three test varieties averaged 5.18 tons sugar/acre (TSA) at standard row spacing and 5.71 TSA for narrow row spacing (Table 14). By contrast the PR sugar industry produced less than 3.0 TSA in 1980 (6). The Government's long-term goal of 4.0 TSA (7) appears virtually unattainable under present conditions in the Island's sugar industry.

In the management of "energy cane", fermentable solids have been depicted as a major byproduct rather than the primary objective of sugarcane production (8, 9, 10). In Puerto Rico, especially when world prices for raw sugar are low, sucrose would be sold to the Island's rum industry as a component of high-test molasses. As recently as the autumn of 1979 sucrose values appeared constant at around 14 cents/pound, and high-test molasses was priced at approximately 95 cents/gallon.

At this writing (October, 1980) sucrose has risen to 35 cents/pound on the world market. The high-test molasses from energy cane would contain at least six pounds of sucrose/gallon. Hence, the value of high-test molasses could easily exceed \$2.00/gallon. Under these circumstances it would probably be profitable to recover part of the sucrose for local or foreign sales. One means of doing this would be to retain the "first strike" (containing perhaps 60% of the recoverable sucrose in cane juice) for raw sugar sales. The balance of the sucrose would remain in the molasses. This would be sold to the PR rum industry as a somewhat lower quality "high-test" molasses.

(d) Plant Densities: The number of stems produced by the cane and napier grass crowns was a function of species, harvest frequency, and row spacing (Table 15). Eventhough close spacing failed to increase yields for sugarcane and napier grass, the number of stems harvested from the second-ratoon crop

continued to reflect the increased seeding rates of three years earlier. The highest plant density attained by sugarcane was 183,896 stems per acre (variety NCo 310 at close spacing and the 6-month harvest interval). The highest tonnage of the second ratoon crop was achieved with about 93,000 stems/acre, from variety NCo 310 at standard row spacing (Table 15, 12-month harvest). Variety NCo 310 also produced the highest number of stems for 2-, 4-, and 6-month harvest intervals.

Napier grass produced more stems than sugarcane irrespective of harvest interval. The 4-month harvest period yielded the highest stem counts of the project to date, ie, 511,975 stems/acre for close-spaced napier grass (Table 15). However, like sugarcane, napier grass yield was not a function of stem numbers but of harvest interval. The maximum DM yield for napier grass (19.9 OD tons/acre year) was attained with 193,000 stems/acre, at standard row spacing and the 6-month harvest interval.

The lack of yield increases from plots having very appreciably larger numbers of stems suggests that there were too many plants occupying the available space for individual stems to attain maximum development. Under some circumstance the dispersal of a given biomass tonnage among a greater number of stems is seen as an important factor, particularly during harvest and solar-drying operations in which thin-stemmed plants are clearly favored over thick-stemmed plants.

B. FIELD-PLOT STUDIES; 3-YEAR TRENDS

With the completion of the second-ratoon harvests it is possible to begin evaluating some long-term trends in sugarcane and napier grass production as perennial sources of biomass. As a sugar crop, sugarcane can be grown for many years without replanting, but significant yield decline is usually evident

after the fourth or fifth crop. The PR sugar industry ordinarily harvests five crops (the plant crop plus four ratoon crops) before replanting. As a source of biomass, under conditions such that continuously high yields are of decisive importance, it was felt that only three crops (a plant crop plus two ratoons) might be justified.

The longevity of napier grass when managed as an energy crop remained an open question. Napier grass will prosper both as a cultivated crop and as a wild specimen. The author is aware of napier grass plantings in Puerto Rico that are over 30 years old. Very little is needed by such plants in the way of production inputs; alternatively, neither wild napier grass nor conventional plantings for pasture and forage purposes have been managed as energy crops in the past. In particular, the longevity of napier grass crowns under harvest regimes maximizing dry matter (recut at 4-to 6-month harvest intervals) rather than digestible green material (recut at 5 to 7 week intervals) is a critically important question. Equally important is the survival of napier grass crowns when exposed to the harvest, solar drying, baling, and transport operations that will characterize energy plantation cropping.

1. Sugarcane; 3-Year Trends

(a) Maximum Yields: Summary yield values for three years of sugarcane growth indicate the following trends: (a) The first ratoon crop (year 2) gave the superior yields of both green matter and dry matter (Tables 16 and 17); (b), the second ratoon crop was more productive than the plant crop but less productive than the first ratoon (12-month data); and (c), for all crops, yields increased progressively with lengthening time interval between harvests. The highest average cane yield for the 3-year study was 33.6 dry tons/acre year, including trash, produced by the first-ratoon crop (Table 17).

These results support the view that three crops will maximize the yield of a given sugarcane planting when managed for total biomass. The implication is that the land area should be replanted following harvest of the second ratoon crop. However, the 12-month plots are being retained for an additional year for confirmation of the apparent yield decline.

(b) Maturation Trends: Data for dry matter accumulation indicate that the second ratoon crop was the least mature of the three crops (Table 18). The first-ratoon crop was the most mature. For all crops there was a marked lack of maturity when cane was harvested at intervals of less than 12 months duration. The highest average value for dry matter content of sugarcane was 31.0 percent, recorded for the first-ratoon crop at the 12-month harvest interval (Table 18).

(c) Varietal Trends: Three-year growth performances for each variety are summarized in Table 19 (2-and 4-month harvest intervals) and Table 20 (6-and 12-month harvest intervals). Dry matter yield differences were not extensive among the three varieties; however, NCo 310 gradually emerged as the superior variety. Like the other varieties it was unable to produce very effectively at the 2-to 6-month harvest intervals. It was appreciably more successful in resisting a third-year yield decline which drastically affected PR 980 and PR 64-1791 at these intervals. For the 12-month harvest (the only harvest of practical importance), NCo 310 produced the highest yield of millable cane for each of the three crops. It was a relatively poor producer of trash, however (Table 21). The total DM yields, in which trash was included, revealed only small differences among the three varieties. NCo 310 was the superior producer

for the plant crop and second ratoon crop, while PR 980 slightly exceeded NCo 310 (by 0.5 tons/acre year) for the first-ratoon crop (Table 20).

Trash yields were clearly a varietal factor. Since only free trash was measured, ie, leaf and leaf-sheath tissues that had detached from the stem and fallen to the ground, ^{1/} these differences could reflect a genetic control of cane "cleanliness" long recognized by sugarcane breeders (11). Variety PR 980 produced appreciably more trash than NCo 310 and PR 64-1791 for each of the three crops (Table 21). Moreover, each crop's yield for PR 980 exceeded that of the previous crop. Narrow row spacing appeared to increase trash yields for varieties NCo 310 and PR 64-1791. This was especially true of the plant crop (Table 21), and to some degree might simply reflect the greater number of plants available to shed leaves at that time.

(d) Row Spacing Trends: Close spacing failed to increase yields of 12-month sugarcane for each of the three crop years (Table 22). Only for the 2-and 4-month harvests of the study's plant crop were any appreciable yield increases obtained from narrow row spacing. The very clear message from these results is that, under tropical conditions, sugarcane will fill in the available growing space through crown expansion from standard row centers spaced 150 cm apart. Narrowing row centers to 50 cm makes no sense at all unless the energy planter intends to harvest only a single crop within about 6 to 8 months after seeding. Such management for sugarcane in Puerto Rico would be a gross

^{1/} The leaf and leaf-sheath tissues which comprise trash, even though they may be long dead, do not always detach and accumulate on the ground. Trash adherence to the stem is probably a varietal characteristic. An example of such adherence to variety PR 980 is illustrated in Figure 1.

underutilization of the Island's year-round growing season. Such management would also ignore the plant's botanical need for at least two years to maximize its growth capability (12, 13).

2. Napier Grass; 3-Year Trends

(a) Maximum Yields: Three years of cropping show two distinct trends for DM production by napier grass: (a) Yields increase as harvest interval is delayed from two to six months, and decrease as the interval is extended to 12 months; and (b), the first-ratoon crop was the most productive while the plant and second-ratoon crops were about equal (Table 23). Unlike sugarcane, the general decline of DM evidenced by the third-year data was not expected.

Green matter yields were virtually equal for the 4-and 6-month harvest intervals (Table 24). Moreover, the second-ratoon yields were equal to those of the first-ratoon crop. In essence, the third year's napier grass appeared to be less mature at harvest than the previous year's crop (Table 25).

The highest average DM yield for the three crops was 27.5 OD tons/acre year, which derived from the combined yield of two, 6-month harvests (Table 23). This compares quite favorably with the highest 3-year average for sugarcane, ie, 29.0 OD tons/acre year (Table 17).

(b) Row Spacing Trends: Narrow row spacing had virtually no effect on DM yields by napier grass over a time-course of three years (Table 26). Very small yield increases were recorded at the 2-and 4-month harvests of the plant crop, but these subsequently disappeared and there were no consistent differences noted thereafter. Like sugarcane, there appeared to be sufficient plants at standard row spacing (50 cm) to take complete control of the area when sufficient time was allowed for them to do so. Narrow row spacing similarly had no effect on trash yields by napier grass (Table 21).

3. Plant Density; 3-Year Trends

(a) Sugarcane: As a main effect the number of sugarcane stems per acre was highest for the first ratoon crop and declined moderately thereafter (Table 27). However, for the critical 12-month interval the number of stems increased each year. The highest absolute number was approximately 115,000 stems/acre, produced by the 4-month harvest interval of the first-ratoon crop. The lowest number, slightly less than 8,000 stems/acre, was obtained from the 2-month harvest interval of the second ratoon crop.

(b) Napier Grass: Napier grass produced an enormous number of stems per acre, approximately three times more than sugarcane as a main effect (Table 27). Mean values indicate that stem density was highest for the second-ratoon crop. In terms of harvest interval, the greater number of stems was produced by the 4-month harvest and the fewest by the 12-month harvest. For both napier grass and sugarcane there was no apparent relationship between the treatments producing the highest number of stems and the highest tonnages of biomass.

4. Seasonal Influences On Cane And Napier Grass

The project's experiments are being performed at sea level at approximately 18° north latitude. This is a tropical setting widely recognized for its year-round growing season. Nonetheless there were definite seasonal variations in the growth rates of both sugarcane and napier grass.

The 2-month interval from January 15 to March 15 was the least productive for both sugarcane (Table 28) and napier grass (Table 29). This is attributed to the relatively cool nights in Puerto Rico during this period. Because this interval also falls within the Island's dry season, some claim can be made that the growth reduction was a result of reduced water supply. This could be a

contributing factor, for eventhough the experiments were irrigated it is impractical to simulate the region's natural rainy season by this means.

The 4-month harvest intervals correspond roughly with three seasons in Puerto Rico: Late humid summer (July 15 to November 15), semi-arid "winter" (November 15 to March 15), and early humid summer (March 15 to July 15).

For both sugarcane and napier grass the season least suitable for growth was the semi-arid winter (Table 30). This was clearly evident for the two ratoon crops of each species. In the case of sugarcane nearly half of the ratoon crops' total annual yield was produced in a 4-month period from July 15 to November 15. The importance of the warm, humid, late summer months to sugarcane growth has been recognized for many years by sugar planters seeking to maximize tonnage. Hence, the Island's "gran cultura" crop was always planted by early August, thereby enabling the cane to pass through two late summer growing seasons before being harvested at 16 to 18 months of age.

C. FIELD-SCALE STUDIES

1. Energy Cane Demonstration Study; Hatillo

Through the project's third year a majority of field-plot and field-scale experiments have been confined to the AES-UPR Lajas Substation on Puerto Rico's semi-arid southwest coast. This is a major agricultural region having important potential as a future zone for biomass energy cropping. There is an abundance of rain-free days suitable for solar drying operations. Irrigation is required for approximately 8 to 10 months annually.

The project's original work plan called for at least one major study with sugarcane somewhere on the Island's humid north coast. A site more closely integrated with private farms than is possible with Experiment Station lands

was also desired. A favorable opportunity arose for establishing such a study during the spring of 1980. Mr. José B. De Castro, an elderly landowner having a strong personal interest in biomass energy cropping, offered CEER-UPR the use of 30 acres near the northwest coastal town of Hatillo. The offer was accepted and an energy cane demonstration study was established there during July and August of 1980.

The land itself is situated on a deep alluvial plain bordered by the Camuy River. The predominate soil series is a freeable Coloso clay loam, much less plastic than the Fraternidad clay series at Lajas. The soil appears to be at least four to six feet deep and is well drained; in fact, this farm is an "all weather" site insofar as most agricultural production operations are concerned. The De Castro farm had not been cultivated for seven years and was occupied by a mixture of volunteer sugarcane and wild grasses.

During the first quarter approximately 25 acres were mowed with a rotary scythe, plowed, rotavated, land-planned, limed, and planted into three field-scale treatments: (a) An energy cane planting, of approximately 17 acres, in which intensive production operations will be demonstrated; (b), a control plot of about 2.5 acres managed as conventional sugarcane; and (c), a second control plot, about 6 acres, simulating the unmanaged wild sugarcane that had been occupying the site until the summer of 1980.

Production inputs for the three treatments are summarized in Table 31. A single cane variety, PR 980, is being used for all treatments. The energy cane treatment is double-seeded at standard (150 cm) row centers. Ungerminated spaces in the row were replanted, and the area was watered by overhead irrigation from the Camuy River. This cane received 200 lbs of elemental N/acre applied as a band beneath the seed in the furrow. An additional 400 lbs

of elemental N/acre will be administered in two or three increments dissolved in irrigation water. A single "gran cultura" harvest will be performed 18 months after planting. Total production input costs will be held under \$900.00/acre/18 months. Our primary objective is to demonstrate yields of at least 90 tons/acre of millable cane, plus about 15 tons/acre of trash, at costs commensurate with an attractive margin of profit for north-coast planters.

2. Mechanization Trials; Napier Grass

Mechanization studies continued during the first quarter with two implements 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 excess of conventional forage grasses, but somewhat lower tonnages than sugarcane. Initial trials on Johnson grass and Sordan were very successful (1). Considerably more demanding tests were begun on 6-months old napier grass late in Year 3. The results have already been described in detail (2). They seem to indicate that, with limited modification and correct training of the equipment operators, such implements can deal successfully with the high-density biomass offered by mature stands of napier grass (Figure 2).

(a) Yield Data; 6 Months: A 2.75 acre stand of 6-months old napier grass was evaluated for yield and crown injury with the M-C rotary scythe operated at two mowing heights. The latter were "low stubble" (1 to 2 inches) and "high stubble" (8 to 10 inches). Four subplots of 0.69 acres each were mowed on June 20 and were solar-dried and baled over a 4-day interval. Drying operations included two days exposure to the sun as the material lay behind the rotary scythe, followed by windrowing with a conventional forage rake, and turning the windrows over twice with the same rake. The solar-dried material

was baled on June 24, at which time the moisture content was approximately 15 percent.

Overall dry matter yields averaged 9.3 tons/acre, with high stubble and low stubble plots averaging 8.4 and 10.2 tons/acre, respectively (Table 32). Because of a large variation in low stubble yields these data are taken only as a very preliminary indication of mowing height effect. Moreover, a significant amount of conditioned biomass lay flattened between the stubble and could not be recovered with the available forage rake ^{1/}.

Upon visual inspection some of the stubble appeared broken and crushed by the tractor and rotary scythe. However, the same crowns generally produced an abundance of new shoots within a few days after mowing. It is believed that (a) either the latent buds (located at or slightly below the soil surface) were not injured by the machinery passing above, or (b), more than a sufficient number of buds survive these operations to reestablish a normal plant stand even when some of the buds are destroyed. It is also possible that some level of crown injury is stimulatory to shoot production.

(b) Fuel Consumption And Estimated Horsepower: Fuel consumption was measured for the napier grass harvests described above (Table 33). These measurements refer to the total diesel fuel consumed by a model 8700 Ford tractor (a category III, 120 hp unit), operating a M-C model 9-E rotary scythe (9 foot mowing swath), both idling and in actual movement on the measured test plot areas. They do not include movement of the tractor and implement to and

^{1/} This implement, like most standard forage rakes, operates as a single unit driven from the tractor's PTO system. When any portion of the rake is lifted by a plant crown, much of the entire rake is lifted and passes over a layer of biomass untouched by the implement's tines.

from the fields themselves. Estimates of the horsepower utilized by the tractor were calculated from the fuel consumption figures in accordance with published Nebraska Tractor Test Data for the model 8700 Ford tractor (Table 33).

Diesel fuel consumption was somewhat lower than expected, ranging from 2.38 to 2.95 gallons/hour, or 1.92 to 2.69 gallons/acre. A fuel consumption level in the order of magnitude of sugarcane harvesters had been anticipated (roughly 4 to 6 gallons of diesel fuel/hour). It should be noted that the standing green biomass confronting the rotary scythe (about 40 tons/acre) exceeded the sugarcane tonnages confronting cane harvesters in Puerto Rico today (approximately 28 tons/acre as an Island-wide average).

Low-stubble mowing utilized moderately more fuel than high-stubble mowing (Tables 33 and 34). This relates to the greater resistance offered by napier grass stems close to the soil surface, and to the greater tonnage of biomass to be conditioned with low-stubble harvesting. Alternatively, low stubble mowing does a much cleaner job. It minimizes the tendency of high mowing to leave long, ragged stubbles which in turn complicate raking and baling operations, in addition to leaving unharvested a significant fraction of the standing green napier grass.

Horsepower usage by the 8700 Ford tractor ranged from 35.7 hp at high-stubble mowing to 41.4 hp at low-stubble mowing (Table 33). Performance data provided by the Ford Company indicate that this tractor can supply about 95 gross hp at the power take off with an operating engine revolution range of 1500 to 1800 rpm (14). Hence, less than half of the tractor's work potential was being utilized in conditioning the 6-months old napier grass. On the other hand, it is estimated that the rotary scythe itself, although an extremely rugged implement, can utilize a maximum input of only about 60 hp without sustaining major damage (15). Exceptionally heavy stands of biomass, such as

mature sugarcane or 12-months old napier grass, could likely place the rotary scythe in the 60 hp range. There would be no purpose in attempting this since there are cane harvesters available to deal with such materials.

3. Napier Grass Processing

Formal utilization studies on tropical grasses lie beyond the scope of this project. However, project personnel have cooperated with others wishing to utilize or examine some of the harvested grasses that have no further use to the project. During 1979-1980, tropical grasses that had been solar-dried, baled, weighed, and then discarded, were donated locally for the following purposes: (a) As cattle feed by Lajas farmers, particularly Sordan 70A, but also mature napier grass (presumably mixed with more digestible forages); (b) as test additives to processed municipal refuse, by a firm developing alternative biomass products at Ponce, P. R.; (c) as a start-up boiler fuel by sugar mill engineers; and (d), as a source of cellulose for enzymic conversion to glucose in a local fermentation project.

Early in 1980, the New York-based firm Combustion Equipment Associates, Inc. became interested in solar-dried tropical grasses as potential feedstocks for a patented fuel product derived from agricultural residues. Termed AGRI-FUEL, the material is a fine powder that can be burned directly in existing oil-fueled furnaces. Such a product, if shown to be technically and economically feasible, would be of immense interest to Puerto Rico. During June of 1980 a SEA-LAND van was loaded with baled napier grass plus stored bagasse and shipped to CEA's processing plant at Bridgeport, Connecticut. CEA requested the materials for feedstock evaluation purposes and paid all transportation charges.

D. BREEDING STUDIES

1. Seedling Trials; Lajas Substation

The project's breeding phase aimed at producing new sugarcane progeny with superior biomass attributes was confined to the AES-UPR Gurabo Substation during the first three years. Recently, 92 seedlings showing some preliminary evidence of high tonnage capability were transferred to the Lajas Substation for second-phase evaluation. They were planted in unreplicated, 5' x 20' plots, with standard seedbed preparation, row spacing, fertilization, and weed control measures.

A total of six crosses are represented (Table 35). All were made by Mr. T. L. Chu during the autumn of 1979. All crosses were part of the AES-UPR Sugarcane Breeding Program (Figure 3), but in these instances there were parental types involved having important biomass attributes. Of special interest is the S. spontaneum hybrid US 67-22-2 which served as both female and male parent. Under Gurabo conditions this clone has shown very superior potential for the production of both sucrose and total biomass.

2. Seed Expansion For US 67-22-2

Early in 1980 the clone US 67-22-2 was planted in field plots at the AES-UPR Gurabo Substation for the purpose of producing seed for a "second generation" ^{1/} sugarcane biomass study. This study was planted at Lajas Substation late in July, 1980. The remaining seed of US 67-22-2 was shipped to Hatillo in August and planted on the De Castro farm for seed expansion

^{1/} The "first generation" studies planted in 1977 utilized the best varieties immediately available from the PR sugar industry. It is believed that US 67-22-2, unavailable in 1977, can out-produce by a significant margin such varieties as PR 980, NCo 310, and PR 64-1791 that have dominated this project to date.

purposes. Approximately 1.5 acres were planted in this variety. At intervals of 6 to 8 months the cane will be cut and planted in a larger seed expansion area. This in turn will be used for additional seed expansion. Within about two years there will be sufficient seed of US 67-22-2 to replace all older varieties in the Island's energy cane programs, including commercial-scale plantings of 50 acres or more.

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

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

TABLE 2. 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. BIOMASS PRODUCTION BY FIVE SACCHARUM CLONES UNDER MINIMUM-TILLAGE CONDITIONS; FEB. 11—AUG. 5, 1980 ^{1/}

Clone	6-Months Yield (Tons/Acre) For —		% DM
	Green Matter	Dry Matter	
PR 980	1.73	0.52	30.0
US 67-22-2	3.14	0.98	31.1
US 72-72	1.11	0.34	30.9
US 72-93	4.71	1.88	39.9
<u>S. spont.</u> Hybrid	0.86	0.26	30.0

^{1/} Fifth 6-month harvest. Originally planted during February, 1977.

TABLE 4. BIOMASS PRODUCTION BY FIVE SACCHARUM CLONES PROPAGATED WITH MINIMUM CULTURAL INPUTS AND HARVESTED AT INTERVALS OF SIX MONTHS

Growth Period	Clone	Tons/Acre (6 Months) ^{1/} —		% DM
		Green	Dry	
Feb. 5, 1978—Aug. 5, 1978	PR 980	16.5	6.4	38.8
	US 67-22-2	15.9	6.0	37.8
	US 72-72	14.7	5.5	37.4
	US 72-93	6.0	2.6	43.3
	<u>S. spont.</u> Hybrid ^{2/}	13.3	4.3	32.3
	Mean	13.3	4.9	37.9
Aug. 5, 1978—Feb. 5, 1979	PR 980	1.04	0.22	20.7
	US 67-22-2	1.70	0.37	21.8
	US 72-72	1.02	0.20	19.9
	US 72-93	0.60	0.11	18.9
	<u>S. spont.</u> Hybrid ^{2/}	2.54	0.64	25.0
	Mean	1.38	0.31	21.3
Feb. 5, 1979—Aug. 5, 1979	PR980	2.08	0.48	23.2
	US 67-22-2	4.24	1.08	25.4
	US 72-72	4.15	1.12	27.0
	US 72-93	2.46	0.74	30.2
	<u>S. spont.</u> Hybrid ^{2/}	3.96	1.37	34.5
	Mean	3.38	0.96	28.1
Aug. 11, 1979—Feb. 11, 1980	PR 980	1.32	0.49	34.0
	US 67-22-2	2.47	0.89	34.8
	US 72-72	3.92	1.36	34.7
	US 72-93	1.66	0.79	47.6
	<u>S. spont.</u> Hybrid ^{2/}	3.18	0.96	30.1
	Mean	2.51	0.89	36.2
Feb. 11, 1980—July 27, 1980	PR 980	1.73	0.52	30.0
	US 67-22-2	3.14	0.98	31.1
	US 72-72	1.11	0.34	30.9
	US 72-93	4.71	1.88	39.9
	<u>S. spont.</u> Hybrid ^{2/}	3.86	1.15	30.0
	Mean	2.97	0.97	32.4

^{1/} Originally planted during February, 1977.

^{2/} Approximately 40% germination was obtained at the time of planting.

TABLE 5. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; SIXTH 2-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center —		
	150 cm	50 cm	% Change
PR 980	0.06 b ^{1/}	0.15 b	150.0
NCo 310	0.61 b	0.71 b	16.3
PR 64-1791	0.19 b	0.04 b	-78.9
	50 cm	25 cm	
Napier Grass	8.65 a	7.67 a	-11.3

	Dry Matter (Tons/Acre)		
PR 980	0.01 c	0.03 c	300.0
NCo 310	0.11 c	0.13 c	18.1
PR 64-1791	0.04 c	0.01 c	-75.0
Napier Grass	1.17 a	0.98 b	-16.2

	Dry Matter (%)		
PR 980	21.2 b	20.2 b	- 4.7
NCo 310	19.5 b	19.4 b	- 0.5
PR 64-1791	18.4 ab	20.5 b	11.4
Napier Grass	13.5 b	12.8 b	- 5.1

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

TABLE 6. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; THIRD 4-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center —		
	150 cm	50 cm	% Change
PR 980	9.6 cd ^{1/}	7.3 cd	-23.9
NCo 310	18.0 b	13.2 bc	-26.6
PR 64-1791	12.1 bcd	5.2 d	-57.0
	50 cm	25 cm	
Napier Grass	34.9 a	37.7 a	8.0

Dry Matter (Tons/Acre)			
PR 980	1.7 b	1.4 bc	-17.6
NCo 310	3.3 b	2.4 bc	-27.2
PR 64-1791	2.2 bc	0.9 c	-59.0
Napier Grass	9.2 a	9.6 a	4.3

Dry Matter (%)			
PR 980	18.2 bc	19.7 b	8.2
NCo 310	18.4 bc	18.0 bc	-2.1
PR 64-1791	18.4 bc	16.6 c	-9.7
Napier Grass	26.0 a	25.8 a	-0.7

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

TABLE 7. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; SECOND 6-MONTH HARVEST

Cultivar	Green Matter (Tons/A), At Row Center —		
	150 cm	25 cm	% Change
PR 980	34.4 a ^{1/}	28.8 bc	-16.2
NCo 310	36.0 b	34.4 b	- 4.4
PR 64-1791	20.3 c	18.7 c	- 7.8
	50 cm	25 cm	
Napier Grass	55.7 a	58.3 a	4.6

Dry Matter (Tons/Acre)			
PR 980	5.6 b	5.2 bc	- 7.1
NCo 310	6.2 b	6.4 b	3.1
PR 64-1791	3.8 c	3.6 c	- 5.2
Napier Grass	15.6 a	15.3 a	- 1.9

Dry Matter (%)			
PR 980	15.9 c	18.1 bc	13.8
NCo 310	17.7 bc	18.8 b	5.0
PR 64-1791	19.3 b	19.8 b	2.5
Napier Grass	26.3 a	26.2 a	- 0.3

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

TABLE 8. BIOMASS PRODUCTION BY THE SECOND RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; 12-MONTH HARVEST

Cultivar	Green Matter (Tons/A), ^{1/} At Row Center --		
	150 cm	50 cm	% Change
PR 980	75.8 bc ^{2/}	71.5 c	- 5.6
NCo 310	92.0 a	90.2 a	- 1.9
PR 64-1791	84.0 b	84.3 b	0.3
	50 cm	25 cm	
Napier Grass	67.8 c	67.1 c	- 1.0

	Dry Matter (Tons/Acre) ^{1/}		
PR 980	19.0 cde	18.6 def	- 2.0
NCo 310	26.9 a	25.1 ab	- 6.6
PR 64-1791	20.3 cd	22.8 bc	12.3
Napier Grass	15.5 ef	15.0 f	- 3.2

	Trash (Tons/Acre)		
PR 980	7.7 a	7.5 a	- 2.5
NCo 310	4.4 b	4.6 b	4.5
PR 64-1791	5.1 b	5.0 b	- 1.9
Napier Grass	4.4 b	3.9 b	-11.3

	Dry Matter (%)		
PR 980	25.1 bcd	26.3 abc	4.7
NCo 310	29.1 a	27.7 ab	5.1
PR 64-1791	25.0 bcd	27.1 ab	8.4
Napier Grass	22.9 cd	22.3 d	-2.6

^{1/} Trash excluded.

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

TABLE 9. TOTAL DRY MATTER PRODUCTION BY THE SECOND RATOON CROP OF
THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY ^{1/}
PROPAGATED WITH VARIABLE ROW CENTERS; 12-MONTH HARVEST

Cultivar	DM (Tons/Acre) At Row Center —		
	150 cm	50 cm	% Change
PR 980	26.7	26.1	- 2.2
NCo 310	31.3	29.7	- 5.1
PR 64-1791	25.4	27.8	9.4
	50 cm	25 cm	- 5.0
Napier Grass	19.9	18.9	- 5.0

^{1/} Trash included.

TABLE 10. 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	11	
2 Months	Sugarcane ^{2/}	2.1	1.3	0.7	0.7	0.9	0.3	6.0
	Napier Grass ^{3/}	12.4	8.3	11.5	10.9	15.9	8.2	67.2
4 Months	Sugarcane		15.5		7.6		10.9	34.0
	Napier Grass		22.9		29.7		36.3	88.9
6 Months	Sugarcane			26.1			28.8	54.9
	Napier Grass			31.7			57.0	88.7
12 Months	Sugarcane						83.0	83.0
	Napier Grass						67.5	67.5

^{1/} Trash excluded.

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

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

TABLE 11. 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	0.1	1.0
	Napier Grass ^{3/}	2.0	1.3	1.4	1.3	2.4	1.1	9.5
4 Months	Sugarcane		3.0		1.4		2.0	6.4
	Napier Grass		7.7		5.3		9.4	22.4
6 Months	Sugarcane			6.3			5.1	11.4
	Napier Grass			8.5			15.5	24.0
12 Months	Sugarcane						22.1	22.1
	Napier Grass						15.3	15.3

^{1/} Trash excluded.

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

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

TABLE 12. 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 ^{1/}	14.4	14.1	14.0	13.4	19.8	19.9	15.9
	Napier Grass ^{2/}	15.8	15.9	12.6	10.8	14.6	13.2	13.8
4 Months	Sugarcane		19.2		16.7		18.2	18.0
	Napier Grass		33.7		17.8		25.9	25.8
6 Months	Sugarcane			23.4			18.3	20.9
	Napier Grass			26.7			26.2	26.5
12 Months	Sugarcane						26.7	26.7
	Napier Grass						32.6	32.6

^{1/} Each figure is the computed mean for three varieties and two row spacings.

^{2/} Each figure is the computed mean for one variety planted at two row spacings.

TABLE 13. JUICE QUALITY VALUES FOR THREE SUGARCANE VARIETIES
PROPAGATED WITH STANDARD AND NARROW ROW SPACING;
SECOND RATOON CROP

Variety	Brix Values, At Row Center --		
	150 cm	50 cm	% Change
PR 980	10.92	10.60	- 2.9
NCo 310	11.64	11.92	2.4
PR 64-1791	10.34	11.20	8.3

Polarization			
PR 980	8.81	9.35	6.1
NCo 310	8.90	8.75	- 2.0
PR 64-1791	9.73	8.83	9.2

Fiber			
PR 980	17.07	16.94	- 0.7
NCo 310	16.30	15.68	- 3.8
PR 64-1791	16.42	16.05	-2.2

Purity			
PR 980	79.94	87.45	9.3
NCo 310	76.15	72.62	- 4.6
PR 64-1791	93.28	78.06	-16.3

Rendement (% Sucrose)			
PR 980	6.89	7.77	12.7
NCo 310	6.75	6.42	- 4.8
PR 64-1791	8.45	6.86	-18.8

Tons Sucrose/Acre (TSA)			
PR 980	5.22	5.56	6.5
NCo 310	6.21	5.79	- 6.7
PR 64-1791	7.10	5.78	-18.5

TABLE 14. TONS SUCROSE PER ACRE (TSA) FOR THREE SUGARCANE VARIETIES PROPAGATED AT STANDARD AND NARROW ROW SPACING; SECOND RATOON CROP; 12-MONTH HARVEST

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

TABLE 15. PLANT DENSITIES FOR THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW SPACING AND HARVEST FREQUENCY; SECOND RATOON CROP (1979-1980).

Variety	Stems/Acre, At Indicated Harvest Interval And Row Spacing ^{1/} -					
	2-Month Interval			4-Month Interval		
	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	3,485	726	-79.1	36,409	64,469	77.0
NCo 310	25,483	12,306	-51.7	92,783	165,310	78.1
PR 64-1791	2,831	2,977	5.1	53,071	40,257	-24.1
	50 cm	25 cm		50 cm	25 cm	
Merker	124,691	318,061	155.0	175,002	511,975	192.3
	6-Month Interval			12-Month Interval		
	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	64,759	128,720	98.7	92,347	139,973	51.5
NCo 310	97,429	183,896	88.7	93,218	97,538	4.6
PR 64-1791	53,506	105,887	97.8	89,225	121,569	36.2
	50 cm	25 cm		50 cm	25 cm	
Merker	193,406	360,096	86.1	138,230	278,675	101.6

^{1/} Mean values from two replicates.

TABLE 16. GREEN MATTER YIELDS FOR THE PLANT CROP AND TWO RATOON CROPS OF SUGARCANE HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Crop ^{2/}	Green Matter (Tons/Acre) At Indicated Month ^{1/} -						Total Yield
		2	4	6	8	10	12	
2 Months	Plant	2.5	7.6	6.5	4.3	8.0	4.5	33.4
	First Ratoon	6.2	3.6	2.7	1.2	3.5	1.4	18.6
	Second Ratoon	2.1	1.3	0.7	0.7	0.9	0.3	6.0
	Mean	3.6	4.2	3.3	2.1	4.1	2.1	19.3
4 Months	Plant		24.5		20.0		18.2	62.7
	First Ratoon		33.9		7.7		22.3	63.9
	Second Ratoon		15.5		7.6		10.9	34.0
	Mean		24.6		11.8		17.1	53.5
6 Months	Plant			43.2			31.3	74.8
	First Ratoon			46.2			34.3	88.6
	Second Ratoon			26.1			28.8	83.0
	Mean			38.5			31.5	70.0
12 Months	Plant						74.8	74.8
	First Ratoon						88.6	88.6
	Second Ratoon						83.0	83.0
	Mean						82.1	82.1

^{1/} Trash excluded.^{2/} Mean values for three varieties and two row spacings.

TABLE 17. DRY MATTER YIELDS FOR THE PLANT CROP AND TWO RATOON CROPS OF SUGARCANE HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Crop ^{1/}	Dry Matter (Tons/Acre) At Indicated Month ^{1/} -						Total Yield
		2	4	6	8	10	12	
2 Months	Plant	0.4	1.2	1.2	0.8	1.7	1.2	6.5
	First Ratoon	1.0	0.7	0.6	0.2	0.5	0.3	3.3
	Second Ratoon	0.3	0.2	0.1	0.1	0.2	0.1	1.0
	Mean	0.6	0.7	0.6	0.4	0.8	0.5	3.6
4 Months	Plant		3.4		3.6		4.1	11.1
	First Ratoon		5.6		1.7		4.6	11.9
	Second Ratoon		3.0		1.4		2.0	6.4
	Mean		4.0		2.2		3.6	9.8
6 Months	Plant			8.6			8.0	16.6
	First Ratoon			12.8			9.2	21.8
	Second Ratoon			6.3			5.1	11.4
	Mean			9.2			7.4	16.6
12 Months	Plant						25.5 ^{2/}	25.5 ^{2/}
	First Ratoon						33.6 ^{2/}	33.6 ^{2/}
	Second Ratoon						27.8 ^{2/}	27.8 ^{2/}
	Mean						29.0	29.0

^{1/} Mean values for three varieties and two row spacings.^{2/} Trash included.

TABLE 18. DRY MATTER CONTENT FOR THE PLANT CROP AND TWO RATOON CROPS OF SUGARCANE HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Crop	Dry Matter Content (%) At Indicated Month ^{1/} -						Mean
		2	4	6	8	10	12	
2 Months	Plant	16.3	16.2	18.8	18.3	21.7	25.1	19.4
	First Ratoon	15.8	18.3	18.9	21.6	19.1	19.2	18.8
	Second Ratoon	14.4	14.1	14.0	13.4	19.8	19.9	15.9
	Mean	16.5	16.2	17.2	17.8	20.2	21.4	18.0
4 Months	Plant		13.7		18.0		22.5	18.1
	First Ratoon		16.6		21.6		20.5	19.6
	Second Ratoon		19.2		16.7		18.2	18.0
	Mean		16.5		18.8		20.4	18.6
6 Months	Plant			19.9			22.7	21.3
	First Ratoon			21.5			24.1	22.8
	Second Ratoon			23.4			18.3	20.9
	Mean			21.6			21.7	21.7
12 Months	Plant						28.3	28.3
	First Ratoon						31.0	31.0
	Second Ratoon						26.7	26.7
	Mean						28.7	28.7

^{1/} Mean values for three varieties and two row spacings.

TABLE 19. DRY MATTER YIELDS FOR THE PLANT CROP AND TWO RATOON CROPS OF THREE SUGARCANE VARIETIES HARVESTED AT 2-AND 4-MONTH INTERVALS

Harvest Interval	Variety	Crop	Dry Matter Yield (Tons/Acre) At Indicated Month ^{1/-}						Total Yield
			2	4	6	8	10	12	
2 Months	PR 980	Plant	0.5	1.4	1.2	0.7	1.5	1.0	6.3
		First Ratoon	0.7	0.4	0.3	0.2	0.5	0.1	2.2
		Second Ratoon	0.1	0.1	0.1	0.1	0.1	0.0	0.5
		Mean	0.4	0.6	0.5	0.3	0.7	0.4	3.0
	NCo 310	Plant	0.4	1.2	1.4	0.8	2.1	1.4	7.3
		First Ratoon	1.4	1.1	1.0	0.4	1.1	0.6	5.6
		Second Ratoon	0.6	0.4	0.2	0.2	0.4	0.1	1.9
		Mean	0.8	0.9	0.9	0.5	1.2	0.7	4.9
	PR 64-1791	Plant	0.4	1.1	1.2	0.8	1.6	1.1	6.2
		First Ratoon	0.9	0.6	0.4	0.2	0.5	0.2	2.8
		Second Ratoon	0.2	0.1	0.1	0.1	0.1	0.0	0.6
		Mean	0.5	0.6	0.6	0.4	0.7	0.4	3.2
4 Months	PR 980	Plant		4.0		3.8		3.9	11.7
		First Ratoon		5.4		1.6		3.7	10.7
		Second Ratoon		2.4		1.3		2.0	5.7
		Mean		3.9		2.2		3.2	9.4
	NCo 310	Plant		3.2		3.6		4.6	11.4
		First Ratoon		6.2		2.1		5.8	14.1
		Second Ratoon		4.2		1.8		3.0	9.0
		Mean		4.5		2.5		4.5	11.5
	PR 64-1791	Plant		3.0		3.5		3.7	10.2
		First Ratoon		5.4		1.4		4.2	11.0
		Second Ratoon		2.4		1.1		1.6	5.1
		Mean		3.6		2.0		3.2	8.8

^{1/} Based on mean values from replicated 1/50 acre plots. Each figure is the computed mean of two row spacings.

TABLE 20. DRY MATTER YIELDS FOR THE PLANT CROP AND TWO RATOON CROPS OF THREE SUGARCANE VARIETIES HARVESTED AT 6-AND 12-MONTH INTERVALS

Harvest Interval	Variety	Crop	Dry Matter Yield (Tons/Acre) At Indicated Month ^{1/} -						Total Yield
			2	4	6	8	10	12	
6 Months	PR 980	Plant			9.2			8.4	17.6 ^{2/}
		First Ratoon			11.3			9.1	20.4
		Second Ratoon			5.5			5.4	10.9
		Mean			8.7			7.6	16.3
	NCo 310	Plant			8.4			7.9	16.3 ^{2/}
		First Ratoon			12.6			10.3	22.9
		Second Ratoon			8.6			6.3	14.9
		Mean			9.9			8.2	18.0
	PR 64-1791	Plant			8.3			7.4	15.7 ^{2/}
		First Ratoon			10.5			8.3	18.5
		Second Ratoon			4.8			3.7	8.5
		Mean			7.9			6.5	14.2
12 Months	PR 980	Plant						24.7	24.7 ^{2/}
		First Ratoon						34.1	34.1
		Second Ratoon						26.1	26.4
		Mean						28.4	28.4
	NCo 310	Plant						26.4	26.4 ^{2/}
		First Ratoon						33.6	33.6
		Second Ratoon						30.5	30.5
		Mean						30.2	30.2
	PR 64-1791	Plant						25.4	25.4 ^{2/}
		First Ratoon						33.1	33.1
		Second Ratoon						26.6	26.6
		Mean						28.4	28.4

^{1/} Based on mean values from replicated 1/50 acre plots. Each figure is the computed mean of two row spacings.^{2/} Trash included.

TABLE 21. TRASH YIELDS BY THREE CROPS OF SUGARCANE AND NAPIER GRASS PROPAGATED WITH VARIABLE ROW SPACING ^{1/}

Species	Variety	Crop	Trash (Tons/Acre) At Row Spacing -		
			150 cm	50 cm	% Change
Sugarcane	PR 980	Plant	5.45	5.97	9.5
		First Ratoon	7.56	6.60	-13.7
		Second Ratoon	7.71	7.49	- 2.8
		Mean	6.91	6.69	- 3.1
	NCo 310	Plant	3.16	4.57	44.6
		First Ratoon	5.20	6.36	22.3
		Second Ratoon	4.40	4.59	4.3
		Mean	4.25	5.17	21.6
	PR 64-1791	Plant	3.07	4.13	34.5
		First Ratoon	5.27	5.95	12.9
		Second Ratoon	5.11	5.00	- 2.1
		Mean	4.48	5.03	12.2
Napier Grass ^{2/}	Merker	Plant	2.73	2.67	- 2.1
		First Ratoon	2.57	2.87	11.6
		Second Ratoon	4.42	3.92	-11.3
		Mean	3.24	3.15	- 2.7

^{1/} Twelve-months harvest.

^{2/} Standard and narrow row spacings for napier grass were 50 cm and 25 cm, respectively.

TABLE 22. DRY MATTER PRODUCTION FOR THREE CROPS OF SUGARCANE PROPAGATED WITH VARIABLE ROW SPACING AND HARVESTED AT VARIABLE TIME INTERVALS

Harvest Interval	Crop	Total DM (Tons/Acre) At Row Center ^{1/}		
		150 cm	50 cm	% Change
2 Months	Plant	5.8	7.3	25.8
	First Ratoon	3.5	3.4	- 2.8
	Second Ratoon	1.0	0.8	-20.0
	Mean	3.4	3.8	11.7
4 Months	Plant	9.8	12.2	24.4
	First Ratoon	11.6	12.1	4.3
	Second Ratoon	7.2	5.5	-23.6
	Mean	9.5	9.9	4.2
6 Months	Plant	14.5	17.0	17.2
	First Ratoon	21.7	19.6	- 9.6
	Second Ratoon	11.9	10.9	- 8.4
	Mean	16.0	15.8	- 1.2
12 Months ^{2/}	Plant	25.4	25.6	0.7
	First Ratoon	35.5	31.7	-10.7
	Second Ratoon	27.8	27.9	0.3
	Mean	29.6	28.4	- 4.0

^{1/} Each figure is the computed mean of three varieties.

^{2/} Trash included.

TABLE 23. DRY MATTER YIELDS FOR THE PLANT CROP AND TWO RATOON CROPS OF NAPIER GRASS HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Crop ^{1/}	Dry Matter (Tons/Acre) At Indicated Month -						Total Yield
		2	4	6	8	10	12	
2 Months	Plant	2.1	1.4	3.0	0.9	4.0	1.3	12.7
	First Ratoon	2.4	2.6	1.9	0.9	2.6	1.5	11.9
	Second Ratoon	2.0	1.3	1.4	1.3	2.4	1.1	9.5
	Mean	2.2	1.8	2.1	1.0	3.0	1.3	11.4
4 Months	Plant		5.7		8.4		8.5	22.6
	First Ratoon		9.7		5.5		9.9	25.1
	Second Ratoon		7.7		5.3		9.4	22.4
	Mean		7.7		6.4		9.3	23.4
6 Months	Plant			13.1			12.4	25.5
	First Ratoon			13.6			19.4	33.0
	Second Ratoon			8.5			15.5	24.0
	Mean			11.7			15.8	27.5
12 Months	Plant						19.3 ^{2/}	19.3 ^{2/}
	First Ratoon						25.8 ^{2/}	25.8 ^{2/}
	Second Ratoon						19.4 ^{2/}	19.4 ^{2/}
	Mean						21.5	21.5

^{1/} Mean values for one variety and two row spacings.^{2/} Trash included.

TABLE 24. GREEN MATTER YIELDS FOR THE PLANT CROP AND TWO RATOON CROPS OF NAPIER GRASS HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Crop ^{2/}	Green Matter (Tons/Acre) At Indicated Month ^{1/} -						Total Yield
		2	4	6	8	10	12	
2 Months	Plant	16.0	8.8	19.4	5.8	21.5	6.2	77.7
	First Ratoon	19.1	16.1	12.8	5.2	17.6	9.7	80.5
	Second Ratoon	12.4	8.3	11.5	10.9	15.9	8.2	67.2
	Mean	15.8	11.1	14.6	7.3	18.3	8.0	75.1
4 Months	Plant		21.6		25.7		26.5	73.8
	First Ratoon		33.4		22.3		35.2	90.9
	Second Ratoon		22.9		29.7		36.3	88.9
	Mean		26.0		25.9		32.7	84.5
6 Months	Plant			40.7			33.6	74.3
	First Ratoon			39.2			51.6	90.8
	Second Ratoon			31.7			57.0	88.7
	Mean			37.2			47.4	84.6
12 Months	Plant					55.1		55.1
	First Ratoon					63.4		63.4
	Second Ratoon					67.5		67.5
	Mean					62.0		62.0

^{1/} Trash excluded.^{2/} Mean values for one variety and two row spacings.

TABLE 25. DRY MATTER CONTENT FOR THE PLANT CROP AND TWO RATOON CROPS OF NAPIER GRASS HARVESTED AT VARIABLE INTERVALS

Harvest Interval	Crop ^{1/}	Dry Matter Content (%) At Indicated Month -						Mean
		2	4	6	8	10	12	
2 Months	Plant	13.4	18.2	15.4	15.5	18.6	21.5	17.1
	First Ratoon	12.4	16.1	14.8	16.3	14.8	15.8	15.0
	Second Ratoon	15.8	15.9	12.6	10.8	14.6	13.2	13.8
	Mean	13.9	16.7	14.3	14.2	16.0	16.8	15.3
4 Months	Plant		26.3		32.8		32.5	30.5
	First Ratoon		29.0		24.9		28.0	27.3
	Second Ratoon		33.7		17.8		25.9	25.8
	Mean		29.7		25.2		28.8	27.9
6 Months	Plant			32.2			33.7	33.0
	First Ratoon			32.0			35.9	34.0
	Second Ratoon			26.7			26.2	26.5
	Mean			30.3			31.9	31.2
12 Months	Plant						30.1	30.1
	First Ratoon						36.2	36.2
	Second Ratoon						32.6	32.6
	Mean						33.0	33.0

^{1/} Mean values for one variety and two row spacings.

TABLE 26. DRY MATTER PRODUCTION FOR THREE CROPS OF NAPIER GRASS PROPAGATED WITH VARIABLE ROW SPACING AND HARVESTED AT VARIABLE TIME INTERVALS 1/

Harvest Interval	Crop	Total DM (Tons/Acre) At Row Center —		
		150 cm	50 cm	% Change
2 Months	Plant	12.7	13.2	3.9
	First Ratoon	11.8	12.0	1.6
	Second Ratoon	9.4	9.2	-2.1
	Mean	11.3	11.5	1.7
4 Months	Plant	21.5	23.7	10.2
	First Ratoon	26.2	24.0	-8.3
	Second Ratoon	22.4	22.4	0
	Mean	23.4	23.4	0
6 Months	Plant	25.4	23.3	-8.2
	First Ratoon	33.5	32.5	-2.9
	Second Ratoon	24.6	23.2	-5.6
	Mean	27.8	26.9	-5.3
12 Months	Plant	19.3	19.2	-0.5
	First Ratoon	25.3	26.3	3.9
	Second Ratoon	19.9	18.9	-5.0
	Mean	21.5	21.5	0

1/ Variety Common Merker.

2/ Trash included.

TABLE 27. STEM DENSITIES FOR THE PLANT CROP AND TWO RATOON CROPS OF SUGARCANE AND NAPIER GRASS HARVESTED AT INTERVALS OF TWO TO TWELVE MONTHS

Species	Crop	Stems/Acre (Thousands) For Month -				Mean
		2	4	6	12	
Sugarcane ^{1/}	Plant	92.8	122.5	80.7	65.5	90.4
	First Ratoon	71.5	115.6	83.9	98.6	92.4
	Second Ratoon	7.9	75.4	105.7	105.2	73.6
	Mean	57.4	104.5	90.1	89.8	85.5
Napier Grass ^{2/}	Plant	136.9	123.3	157.6	118.7	134.1
	First Ratoon	203.9	303.5	281.2	175.0	240.9
	Second Ratoon	221.4	343.5	276.8	208.5	262.6
	Mean	187.4	256.8	238.5	164.1	212.0

^{1/} Mean values for three varieties and two row spacings.

^{2/} Mean values for one variety and two row spacings.

TABLE 28. SEASONAL INFLUENCE ON DRY MATTER YIELD BY THREE CROPS
OF SUGARCANE; 2-MONTH HARVESTS

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

TABLE 29. SEASONAL INFLUENCE ON DRY MATTER YIELD BY THREE CROPS
OF NAPIER GRASS; 2-MONTH HARVESTS

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

TABLE 30. SEASONAL INFLUENCE ON DRY MATTER YIELDS BY THREE CROPS
OF SUGARCANE AND NAPIER GRASS; 4-MONTH HARVESTS

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

TABLE 31. PRODUCTION INPUTS FOR AN ENERGY CANE DEMONSTRATION ON A HUMID ALLUVIAL PLAIN;
HATILLO, PR 1/.

Input	Treatment —		
	Energy Cane	Standard Control	Low-Till Control
Seedbed prep.	Standard	Standard	Standard
Seeding rate	Double-seeded	Single-seeded	Single-seeded
Row spacing	Standard (150 cm)	Standard (150 cm)	Standard (150 cm)
Variety	PR 980	PR 980	PR 980
Herbicides	Pre-& Post-emergence	Pre-& Post-emergence	Pre-& Post-emergence
Nitrogen	600 lbs/acre/18 mo., in three increments	150 lbs/acre/18 mo., applied at planting	No fertilization
Water	Irrigation plus rainfall	Rainfall only	Rainfall only
Harvest	18 mo. gran cultura	18 mo. gran cultura	18 mo. gran cultura

1/ Planting completed August 27, 1980.

TABLE 32. DRY MATTER YIELD FROM NAPIER GRASS FIELD PLOTS MECHANICALLY-HARVESTED AT 6 MONTHS OF AGE; FIRST-RATOON CROP.

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

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

^{2/} Observations based on subsequent production of new shoots.

TABLE 33. PRELIMINARY PERFORMANCE EVALUATIONS FOR THE M-C ROTARY SCYTHE-CONDITIONER OPERATING AT TWO CUTTING HEIGHTS IN NAPIER GRASS AGED SIX MONTHS

Cutting Parameter —			Fuel Expenditure —					Estimated
Height (in.)	Area (acres)	Time (min.)	Liters	Gallons	Gal/Hour	Gal/Acre	BTUs/acre ^{1/}	Horsepower ^{2/}
8-10	1.38	66.75	10.0	2.65	2.38	1.92	268,940	35.72
1-2	0.69	42.47	7.0	1.85	2.62	2.69	376,460	39.30
1-2	0.69	32.33	6.0	1.59	2.95	2.31	322,700	44.24
1-2 in. Combined	1.38	74.80	13.0	3.44	2.76	2.50	349,580	41.43
Combined Total	2.76	141.55	23.0	6.09	2.58	2.21	309,260	38.74

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

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

TABLE 34. PERCENTAGE INCREASE IN FUEL EXPENDITURE AND HORSEPOWER FOR LOW CUTTING AS OPPOSED TO HIGH CUTTING; ROTARY SCYTHE TEST ON SIX MONTHS OLD NAPIER GRASS.

Fuel Expenditure	% Increase
Gallons	29.8
Gallons/Hour	15.9
Gallons/Acre	30.2
BTUs/Acre	30.2
Horsepower	15.9

TABLE 35. SUGARCANE SEEDLINGS SELECTED FOR BIOMASS YIELD EVALUATION; AES-UPR LAJAS SUBSTATION, AUGUST, 1980.

Cross	Percentage		Number Of Seedlings —	
	Female	Male	Planted <u>1/</u>	Selected <u>2/</u>
3	F 160	x US 67-22-2	966	7
5	PR 68-330	x US 67-22-2	371	12
6	PR 67-1070	x US 67-22-2	160	7
12	US 67-22-2	x PR 68-3041	1240	36
16	US 67-22-2	x F 160	270	5
17	PR 68-3041	x US 67-22-2	741	25
Total Seedlings			3,748	92

1/ Planted during 1979 at the AES-UPR Gurabo Substation for initial seedling evaluation.

2/ Planted August 14, 1980, at the AES-UPR Lajas Substation for second-stage evaluation. Plots are 5' x 20' and unreplicated. Superior selections from this group will be planted in 1981 in 20' x 20' plots.

FIGURE 1. Sugarcane "trash", consisting of sugarcane leaf and leaf-sheath tissues that have aged, desiccated, and detached from the sugarcane stem. For variety PR 980, illustrated here at 12 months of age, much of the trash adheres to the stem. Over 20 percent of the total DM yield by PR 980 consists of trash.

FIGURE 2. Napier grass at approximately four months of age. At this stage it is no longer suitable for cattle feed, but dry matter is accumulating rapidly. By six months of age the DM content will approach 35%. Suitable equipment appears to be available for the mowing (conditioning), solar-drying, and bulk-baling of such plants in the open field.

FIGURE 3. Sugarcane breeding facilities at the UPR Agricultural Experiment Station near Gurabo. The AES-UPR sugarcane breeding program is primarily concerned with conventional sugarcanes bred for high sucrose. Since 1977 a limited number of crosses have been made with high biomass yield as the primary objective among new progeny.

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