PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

THIRD QUARTERLY REPORT
1980-1981

MASTER

TO

THE UNITED STATES DEPARTMENT OF ENERGY

AGRICULTURAL EXPERIMENT STATION
UNIVERSITY OF PUERTO RICO, RIO PIEDRAS, PUERTO RICO

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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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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. Greenhouse-level screening for short-and intermediate-rotation grasses included further trials with legume species as potential nitrogen sources for the tropical grasses. Yields from four indigenous legumes were appreciably higher when planted in spring (May) than when planted in autumn (November).

Initial data were recorded from "second generation" energy cane studies established during 1980. Controlled variables include varieties, harvest interval, and nitrogen input. Yield data at 6 months indicate high but essentially equal growth rates among all varieties and N-variables. This is attributed to the use of a land rotavator during seedbed preparation — the first such application of this implement on Lajas Valley soils. Total green weights were in the order of 50-60 tons/acre, and millable stem weights ranged from 33 to 37 tons/acre, at the 6-months harvest. Dry matter yields ranged from 8 to 11 tons/acre. Juice quality values indicated a minimal sugar content at this stage of maturity. Fiber values ranged from 7 to 14%.

Field-scale studies were continued at the Hatillo demonstration site on the humid north coast and in the semi-arid Lajas Valley. For the 6-months harvest at Hatillo, total green weights for all treatments averaged 38.4 tons/acre. Variety US 67-22-2 produced 50.2 tons/acre. Millable cane yields averaged 25.3 tons/acre for all treatments and 34.7 tons/acre for variety US 67-22-2.

^{1/} Contract No. DE-AS05-78ET20071.

INTRODUCTION

The biomass production studies herein reported were initiated June 1, 1977 under sponsorship of the US Energy Research and Development Administration. They have continued with support of the US Department of Energy, Biomass Energy Systems Branch, 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 December 1, 1980 to February 28, 1981.

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. In the instance of sugarcane the plant tops and "trash" would be solar dried in the field while millable stems

are dewatered through crushing and extraction in a conventional sugar mill tandem. This is a deviation from traditional cane and cattle-feed production concepts 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 method and frequency — varies significantly from established procedures. On the other hand, major engineering advances in mechanized production and harvest operations within the sugar and cattle forage industries are being utilized with success for intensive production of tropical grasses as biomass energy crops.

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 is a continuation of the greenhouse, field-plot, and field-scale phases begun earlier.

TECHNICAL REPORT

A. GREENHOUSE STUDIES

1. Wild Legume Trials

Preliminary analyses of the energy expenditures for intensive sugarcane production (1) have indicated a disproportionately large energy input for nutrients, particularly for the elemental nitrogen provided in the form of

chemical fertilizers. Nearly half of the total energy inputs are accountable to elemental N alone (1, p. 70). There is considerable evidence that herbaceous crop plants can obtain at least part of their N requirements through intercropping or co-production with legume species (2, 3, 4).

Greenhouse trials reported for the previous quarter (5) included four legume species regarded as potential N sources for tropical grasses managed as energy crops. Each species is widely distributed in the wild in Puerto Rico and all produce moderate-to-heavy nodulation over short periods of time. The first experiment dealt with species of Leucaena, Phaseolus, Albizia, and Sesbania. Direct growth comparisons were made with one of the fastest-growing tropical grasses available, ie, Sordan 70A, a short-rotation species attaining maximum height and tissue maturation within 12 weeks after seeding. At least one of the legumes (Sesbania sp) evidenced a vigorous growth potential by comparison with Sordan 70A (5).

A subsequent experiment was performed to verify the legume growth potential and to determine whether the season of planting was a significant factor in their growth performance; none of these species have ever been planted as agricultural crops or experimental entities in Puerto Rico. Growth data for the first experiment, planted during the spring (May), and the second experiment, planted 6 months later in the autumn (November), are combined in Tables 2 and 3.

Several trends are evident for both green and dry biomass production (Table 2): (a) The legume species were far less productive when planted in autumn. Each species is quite clearly sensitive to Puerto Rico's "winter"; (b) Sesbania again was the most productive of the four legume species tested; (c) Sordan 70A produced more green weight but less dry matter when planted in autumn (ie, it was relatively less mature at each of the winter harvest

intervals); (d), Maturation trends in legume species were essentially equal for spring and autumn planting; (e) The legume Phaseolus lathyroides was as productive in winter as in summer when DM was measured on an individual plant basis (Table 3). Winter thus appears to have affected germination and seedling establishment rather than growth per se; (f), Plant height was restricted in all species by autumn planting; (g), Sesbania was the tallest of the legume species in both spring and autumn plantings, attaining about 73% of the corresponding Sordan heights as main effects (Table 3).

Although seasonal changes in temperature and daylength seem small in the tropics their effects on plant growth are probably underestimated. For example, Puerto Rico is often depicted as having a "year-round growing season". Yet, sugarcane experiences a major growth decline during Puerto Rico's winter while a lesser growth restraint is exerted on napier grass. Some of the growth decline might relate also to the Island's reduced rainfall during winter months. Vegetable crops are enormously sensitive to planting season in Puerto Rico and this is recognized by the layman and professional growers alike. It now appears that the indigenous tropical legumes will have to be examined closely in this respect whether they are planted as N-sources for tropical grasses or as biomass crops in their own right.

2. Mineral Nutrition

A nitrate-N nutrition experiment with sugarcane variety PR 980 was established during the autumn of 1980. Variable nitrate levels were administered in sand culture to evaluate the variety's N-response curve. As in earlier nutrition experiments with short-rotation and intermediate-rotation species (7, 8), the objective with sugarcane was to establish the slope of

the dry matter yield response to progressively larger amounts of N. Accordingly, nitrate-N levels were increased in a geometric progression ranging from 1.0 to 81.0 mequiv/liter, in nutrient solutions given three times per week over a time-course of 16 weeks.

All plants were maintained for 6 weeks with a standard nutrient solution containing low N (1.0 meq/l of NO_3). Two harvests were performed after 5 and 10 weeks of variable treatment, ie, when the plants were 11 and 16 weeks of age.

For both harvests, the green and dry matter yield data indicate a maximum growth response at around 9.0 meq/l of NO_3 (Table 3; Figure 1). On an individual plant basis there was little difference among variable N levels at 5 weeks; however, the second harvest indicated a broad range of DM responses with high N (81.0 meq/l NO_3) being clearly repressive. Maturation values (DM content) varied but little either among N treatments or harvest interval (Table 4). These data suggest that the sugarcane was much too immature to express a valid Saccharum species response to N variables of this magnitude. Alternatively, it is very difficult to propagate sugarcane to maturity via sand culture under glass.

B. FIELD-PLOT STUDIES

1. Second Generation Energy Cane

A "second generation" study on energy cane ^{1/} was established at the AES-UPR Lajas Substation during August and September, 1980. This is the project's last major experiment designed to demonstrate the upper yield potentials of tropical grasses.

^{1/} "Energy cane" is sugarcane managed for maximum growth (dry matter and molasses) rather than sucrose.

Essentially three "generations" of energy cane were envisioned at the project's onset in 1977: (a) Existing sugarcane varieties, developed for sugar, whose biomass yields could be improved by management practices oriented to growth rather than sugar; (b), existing varieties having superior biomass yield potentials but otherwise unplanted in the sugar-oriented commercial cane industries; and (c) new progeny to be bred specifically for the high DM yield attribute, with fermentable solids (molasses) as a major by-product.

From the seed sources available in 1977 three "first generation" 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. Equally important was the immediate availability of seed from Puerto Rico's sugar industry. However, without question, these varieties fail to represent the maximum yield potentials of Saccharum. A search has been underway since 1977 to identify superior biomass canes already extant in Puerto Rican and Federal collections. Seed expansion for a series of promising candidates was begun late in 1979.

2. Energy Cane Treatments

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

Variable harvest intervals underscore the need for more than one year to optimize Saccharum biomass. An important shortcoming of our previous energy cane work was a 12-month maximum interval between harvests, a reflection of commercial sugarcane management in Puerto Rico. At least 18 months are needed to maximize the total dry matter of sugarcane planted in the tropics. Of the three test varieties, US 67-22-2 and B 70-701 are "second generation" canes having enormous growth potential under PR conditions. PR 980 is a reference variety typifying the Island's commercial sugarcane. For "first generation" canes managed as biomass crops, about 400 lbs of elemental N are required per acre year. The new N variables will indicate the degree to which this quantity might be reduced (or profitably increased) in varieties specifically selected for dry matter and molasses. The N source is ammonium sulfate in a 16-5-10 fertilizer formulation administered incrementally at 3-month intervals.

3. Yields; First 6-Months Harvest

(a) Green Matter: Total green weight values at 6 months were surprisingly high for all treatments while indicating a relatively superior growth performance by variety US 67-22-2. However, also quite surprisingly, there were no appreciable differences among the variable N treatments (Table 5). Millable cane yields were also high at 6 months (Table 6), averaging nearly 34 tons/acre for all treatments. There were no appreciable differences among varieties and N variables. It is noteworthy that Puerto Rico's commercial cane industry averaged only 26.6 tons cane per acre (TCA) for the 12-month crop in 1980.

On an individual plant basis, total green weight values again showed little variation among varietal and N treatments (Table 7). Millable stem weights were moderately lower for variety US 67-22-2 (Table 8). The latter variety displayed a notably massive green canopy at this period, with the green-leaf area extending down to the soil surface. The principal varietal difference at this time was a perceptively greater height of B 70-701. The stem length for this variety averaged 41 and 57 percent greater than for PR 980 and US 67-22-2, respectively (Table 9). Stem length was not affected appreciably by variable N.

Varietal differences were also evident in the number of harvested stems per acre (Table 10). Stubble counts indicated a moderately greater density of plants for the two "second generation" varieties (US 67-22-2 and B 70-701) which averaged over 45,000 stems/acre, as opposed to about 38,000 stems/acre for PR 980. The latter figure is also relatively high for 6-months old cane in a "plant" crop.

(b) Dry Matter And Plant Maturity: Dry matter yields were slightly higher for varieties US 67-22-2 and B 70-701 than for PR 980 (Table 11). The highest yield was 11.1 short tons/acre, produced by US 67-22-2 under a "low" N regime of 200 lbs elemental N/acre year. The lowest yield was 8.0 short tons/acre year, from PR 980 under "high" N (600 lbs elemental N/acre year). For the most part there was little difference in yields among the variable N regimes. By way of reference the PR sugar industry produced about 9.0 dry tons/acre in 1980 as an Island-wide average for 12-month cane.

The maturity of all of the cane harvested at this period, as evidenced by DM content, was quite low (Table 12). DM content averaged 16.9% for all treatments at 6 months, whereas approximately 25% DM would be expected at

12 months and 30% or more for an 18-month gran cultura crop. Maturity was slightly higher for variety B 70-701, and within the "low" N regime of each variety (Table 12). These maturity values suggest that all plants were responding to an abundance of water and available N irrespective of varietal and N-fertilization regimes.

(c) Juice Quality: Further evidence of the plants' total commitment to growth at this time was the very low qualitative values obtained for raw juice. For all treatments, Brix and Pol values averaged 5.4 and 1.4, respectively (Tables 13 and 14). The values from variety B 70-701 were lowest for both parameters; however, varietal differences at these levels of magnitude have little meaning since there was very little in the way of extractable fermentable solids contained in this cane. Rendiment levels were near zero for PR 980 (Table 15), and negative values were recorded for the varieties US 67-22-2 and B 70-701. The poor quality of this cane was anticipated. Similarly, quite respectable yields of fermentable solids and sucrose should accrue at the 12- and 18-month harvest intervals, at least on a per-acre basis, even if the quality of individual plants remains low.

(d) Fiber And Trash: ^{1/} Fiber content was generally quite low, ranging from 7.1 to 13.8% (Table 16). There were no consistent differences among variable N regimes. Fiber was moderately higher in the two second generation varieties than in PR 980.

^{1/} "Trash" in this instance includes only leaf and leaf-sheath tissues that had detached from the stem and fallen to the ground. It does not include materials still adhering to the stem.

Trash yields averaged slightly less than 1.0 ton/acre for all treatments (Table 17). This amounted to roughly 10% of the total dry matter yield at 6 months. Trash values should increase to about 20-30% of total DM yield for the 12-and 18-month harvests. Variety B 70-701 produced slightly less trash than US 67-22-2 and PR 980. There were no consistent yield responses to the variable N regimes.

(e) Lack of N-Fertilization Response: The minimal response to increasing N fertilization is attributed to two factors: (a) The incorporation of organic matter into the soil (old bales of Sordan 70A, approximately 2 tons/acre) at the time of seedbed preparation, and (b), conditioning of the upper root zone with a land rotavator prior to seeding. The organic matter was added to help maintain soil structure during the subsequent 3-year period of intensive production operations. Up to 80 pounds of N/acre could become available from this source within one to three months via N mineralization. Perhaps more important was the thorough rotavation of the seedbeds' upper 6 to 8 inches. The Fraternidad soil series of this region are notably heavy and plastic and excessive compaction of new seedbeds is a common occurrence. The rotavation of this site was the first use of such an implement in the Lajas Valley. It provided a light, freeable structure at the time of planting. Recompaction of the soil occurs gradually through the effects of rainfall plus the traffic of labor and machinery. It is believed, however, that the soil's native fertility contributed more effectively to the plants' establishment and early growth performance than was formerly possible. Unfortunately, no control plots were retained as a check against rotavator effects. A subsequent cane planting (seed expansion for variety US 67-22-2) planned for mid 1981 will include soil rotavation as a controlled variable.

C. FIELD-SCALE STUDIES

1. Energy Cane Irrigation; Hatillo Site

The project's original work plan called for at least one major study with sugarcane somewhere on the Island's humid north coast. During the spring of 1980, a favorable opportunity arose for establishing such a study when a retired landowner offered CEER the use of 30 acres near the northwest coastal town of Hatillo. An energy cane demonstration study was planted there during July and August of 1980. Land preparation and planting operations were described in a previous quarterly report (6). Additional work was performed at the Hatillo site during the second quarter (5). This included subsoiling treatments, post-emergence weed control, and overhead irrigation of early-juvenile plants.

Although the Hatillo site is situated in a semi-humid region, a need develops for supplemental irrigation each January, at the onset of the area's dry season. Irrigation can be performed to great advantage during four or five months of the year even though private planters there have rarely done so. To sustain maximum growth of the energy cane study, flood irrigation was initiated in February of 1981, using a 2000 gpm Rainbow Company pump to obtain water from the Camuy River which adjoins the experimental farm. The pump is portable, diesel powered, and equipped with a 30 ft. intake tube with screened foot-valve. A 30 ft. discharge tube is also transported with the unit for convenient placement of the pumped water.

The Hatillo site was leveled, land-planned, and bordered to receive the seasonal irrigation water as part of the land preparation operations in 1980. Water is provided to approximately 2/3 of the planted area, the remainder

being divided into control plots of unirrigated energy cane and unirrigated conventional sugarcane. It is calculated that roughly one additional ton per acre of energy cane will eventually be harvested for every acre inch of water provided during the Hatillo dry season.

2. Initial Yields At 6 Months; Hatillo Site

The principal harvest interval for this study is 18 months. It is intended to demonstrate the disproportionately larger yields to be gained through delay of energy cane harvest by 6 months, ie, by use of the "gran cultura" cropping system rather than the 12 month "primavera" system employed for most of the sugar industry's cane. In the meantime, as an indicator of crop development, cane samples amounting to 600 ft² from each of the study's four experimental fields are being harvested at 6 months and 12 months after planting. The 6-months data are included in this report.

(a) Green Matter And Millable Cane: The field demonstration plots at Hatillo include three management variables using the project's standard high biomass variety, PR 980: (a) A low-tillage control in which cane is essentially allowed to grow wild after being assisted in its establishment; (b) a "Sugar Corporation" control in which the cane is managed according to procedures used by Puerto Rico's cane sugar industry; and (c), energy cane management in which the same variety is encouraged to produce maximum biomass rather than sugar. There is one additional plot consisting of two acres of variety US 67-22-2, a "second generation" energy cane receiving the same energy cane production inputs as PR 980. This is a varietal expansion planting designed to increase seed for the eventual replacement of variety PR 980. For the initial growth measurements, 1000 square feet of each PR 980 treatment and 400 square feet of US 67-22-2 were harvested at 6 months of age.

Total green weight yields varied but little among the three PR 980 treatments which averaged 34.5 tons/acre (Table 18). Variety US 67-22-2 produced about 45% more green matter at 50.2 tons/acre. Millable cane yields were slightly higher for energy cane (24.0 tons/acre), but for this parameter also the three PR 980 treatments were essentially equal (Table 19). Again, US 67-22-2 produced the highest yield at 34.7 tons/acre, about 56% higher than the PR 980 average. Top weights (representing the non-millable green canopy and immature internodes) averaged 7.6 tons/acre for PR 980 and 12.3 tons/acre for US 67-22-2 (Table 20).

Trash yields similarly varied but little among treatments (Table 21). In this study, "trash" refers to leaf and leaf-sheath tissues, both green and partially desiccated, which were still adhering to the stem at time of harvest. These were stripped off by hand in order to obtain millable stem weights. Under mechanized harvest conditions (with a Klass whole cane harvester), these tissues would be largely removed in the field by a powerful air blast. The "tops" (Table 20) would be removed by a vertically-adjustable set of circular discs, or "topper", which is also a component of the Klass harvester. The topper's cutting level is under direct control of the machine operator; hence, the precise point of topping is a matter judgement and considerable skill of the man operating this machine.

(b) Dry Matter Yield: Dry matter yields were unremarkable and essentially equal for the three PR 980 treatments, averaging 6.0 tons/acre (Table 22). Variety US 67-22-2 produced 8.8 tons/acre, or 47% more than the PR 980 average. The unspectacular DM yields were largely a function of the low maturity of all cane at this point in the study. Dry matter content, averaging 17.5%, was nearly equal for each of the four cane plots (Table 23).

(c) Plant Height And Density: There were some small variations in plant height among the three PR 980 treatments, ranging from 4.7 to 5.4 feet (Table 24). The average height of US 67-22-2 was perceptibly lower at 4.1 feet. The principal feature of this variety which accounted for its superior yields was an ability to produce a greater number of stems per planted area. Hence, within six months after seeding, US 67-22-2 had produced 46,000 stems/acre, some 50% more than PR 980 which averaged 30,700 stems/acre (Table 25).

D. BREEDING

1. Seed Expansion; US 67-22-2 and B 70-701

The selection and planting at Hatillo of US 67-22-2, the first "second generation" clone selected for field-scale seed expansion, was described in a prior report (6). It has been maintained there as an energy cane with sufficient production inputs to maximize its growth potential. The relatively good growth performance of this variety to date has been discussed above. At approximately 9 months of age, most of this cane will be harvested and used exclusively for further seed expansion at the AES Lajas Substation. Sufficient cane will be retained uncut at Hatillo to monitor its yield performance at 12-and 18-month harvest intervals.

The new seed expansion plots at Lajas will include another "second generation" selection, the S. spontaneum clone B 70-701. The latter cane has indicated very superior growth performance in breeding plots at the AES Gurabo Substation. At this point in time it appears to be an exceptionally tall and erect cane with high fiber content and total DM yield. Its sugar qualities are unremarkable.

2. New Crosses; 1980-1981 Breeding Season

Eight new crosses were performed in 1980 having the high biomass attribute as the principal objective for hybrid progeny. All crosses were performed by Mr. T. L. Chu at the AES Gurabo Substation.

Eleven parental clones were used in five breeding lines (Table 26). Four of the clones served both as female parents (contributing the somatic chromosome number) and as male parents (contributing the gametic chromosome number). These include PR 68-335, PR 67-1070, the S. robustum clone 57-NG54, and a wild S. spontaneum hybrid from Río Piedras (S. sp. RP). The use of 57-NG54 represents a long-desired entry of S. robustum germplasm into the AES-UPR cane breeding program.

An approximate total of 5,000 seedlings were produced by these crosses (Table 26). Of special interest is the contribution of both US 67-22-2 and B 70-701 as male parents in crosses with NCo 310. These are the two "second generation" clones already selected for seed expansion as energy canes in their own right. About 1150 seedlings were obtained from these crosses (items 7 and 8, Table 26). The most prolific progeny yield was obtained from the crossing of PR 68-1220 (female parent) with the hybrid PR 67-1070 x S. sp. RP (male parent). Some 2000 seedlings were obtained from this cross.

The total number of seedlings produced by these crosses is small by reference to major sugarcane breeding programs throughout the world. However, the quality of parental stock and breeding line selection for the intended purpose is very high. For this reason the probability of obtaining new progeny with interesting biomass attributes is good.

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FIGURE 1. DRY MATTER YIELD OF SUGARCANE SUPPLIED WITH VARIABLE NO_3 IN SAND CULTURE AND HARVESTED AT 5 AND 10 WEEK INTERVALS

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. RELATIVE GROWTH RATES OF SORDAN 70A AND FOUR LEGUME SPECIES PLANTED IN SPRING (MAY) AND AUTUMN (NOVEMBER)

Species	Green Wt. (g), At Harvest Week And Month Of Planting ^{1/} -							
	Week 6		Week 12		Week 18		Mean	
	May	November	May	November	May	November	May	November
Sordan 70A	2,970	2,682	2,745	3,103	2,175	3,048	2,630	2,944
<u>Leucaena leucocephala</u>	425	109	792	310	1,370	467	862	295
<u>Phaseolus lathyroides</u>	1,005	483	1,277	693	1,745	248	1,342	475
<u>Albizia lebbeck</u>	215	44	510	103	1,132	178	619	108
<u>Sesbania sp.</u>	1,237	814	1,842	1,155	2,729	1,408	1,936	1,126
Mean	1,170	826	1,433	1,073	1,830	1,070	1,478	990
Dry Wt (g)								
Sordan 70A	633	303	882	705	933	930	816	646
<u>Leucaena leucocephala</u>	93	20	344	72	515	165	317	86
<u>Phaseolus lathyroides</u>	188	58	261	129	347	93	265	93
<u>Albizia lebbeck</u>	51	11	137	26	297	50	162	29
<u>Sesbania sp.</u>	256	115	565	245	599	391	473	250
Mean	244	101	438	235	538	326	407	221
Percent Dry Matter								
Sordan 70A	21.2	11.3	32.1	22.7	42.8	30.5	32.0	21.5
<u>Leucaena leucocephala</u>	21.9	18.1	33.3	23.4	37.6	35.3	30.9	25.6
<u>Phaseolus lathyroides</u>	18.8	12.0	20.3	18.7	19.8	37.4	19.6	22.7
<u>Albizia lebbeck</u>	23.9	25.2	26.8	25.2	26.2	27.9	25.6	26.1
<u>Sesbania sp.</u>	20.6	14.1	24.6	21.2	25.9	27.7	23.7	21.0
Mean	21.3	16.1	27.4	22.2	30.5	31.8	26.4	23.4

^{1/} Growth data per planted area, approximately 60 ft.²/species/harvest.

TABLE 3. RELATIVE GROWTH OF SORDAN 70A AND FOUR LEGUME SPECIES PLANTED IN SPRING (MAY) AND AUTUMN (NOVEMBER)

Species	Oven-Dry Wt (g/Plant), At Harvest Week And Month Of Planting ^{1/} -							
	Week 6		Week 12		Week 18		Mean	
	May	November	May	November	May	November	May	November
Sordan 70A	10.4	4.6	16.1	12.2	17.0	17.6	14.5	11.5
<u>Leucaena leucocephala</u>	1.3	0.2	5.0	1.1	6.9	1.8	4.4	1.0
<u>Phaseolus lathyroides</u>	2.2	1.5	3.8	4.2	4.3	5.0	3.4	3.6
<u>Albizia lebbeck</u>	1.0	0.3	2.2	0.6	6.5	1.0	3.2	0.6
<u>Sesbania sp.</u>	2.8	1.4	6.8	3.3	6.9	5.6	5.5	3.4
Mean	3.5	1.6	6.8	4.3	8.3	6.2	6.2	4.0

Plant Height (cm)								
Sordan 70A	165	120	208	172	198	181	190	158
<u>Leucaena leucocephala</u>	66	24	98	66	126	77	97	56
<u>Phaseolus lathyroides</u>	102	75	114	108	103	107	106	97
<u>Albizia lebbeck</u>	29	16	53	17	93	26	58	20
<u>Sesbania sp.</u>	98	78	140	128	177	140	138	115
Mean	92	63	123	98	139	106	118	89

TABLE 4. GROWTH PERFORMANCE OF IMMATURE SUGARCANE SUPPLIED WITH VARIABLE NO_3 IN SAND CULTURE, AND HARVESTED AFTER 5 AND 10 WEEKS OF TREATMENT³

Week	NO_3 (meq/l)	g/Planted Area — ^{1/}		OD g/Plant	% DM
		Green	Oven-Dry		
5	1	339	80	4.2	23.6
	3	483	103	4.7	21.4
	9	667	135	4.9	20.1
	27	623	128	5.2	19.8
	54	688	146	5.6	21.2
	81	642	141	4.6	21.9
	Mean	574	122	4.9	21.2
10	1	446	107	6.8	23.9
	3	659	141	7.1	21.2
	9	1153	246	11.0	21.3
	27	1140	242	10.6	21.4
	54	1145	245	10.4	21.3
	81	703	147	5.7	20.9
	Mean	874	188	8.6	21.5

^{1/} Approximately 60 ft².

TABLE 5. TOTAL GREEN WEIGHT FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	GM (Tons/A), At Month <u>1/</u> -			Mean
		6	12	18	
PR 980	200	49.9			
	400	53.8			
	600	51.0			
	Mean	51.6			
US 67-22-2	200	60.1			
	400	60.9			
	600	61.5			
	Mean	60.8			
B 70-701	200	52.1			
	400	52.9			
	600	56.3			
	Mean	53.8			

1/ Each figure is the mean of four replicates.

TABLE 6. TONS MILLABLE CANE PER ACRE (TCA) FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	TCA, At Month $\frac{1}{-}$			Mean
		6	12	18	
PR 980	200	33.1			
	400	35.0			
	600	36.6			
	Mean	34.9			
US 67-22-2	200	33.7			
	400	36.4			
	600	31.3			
	Mean	33.8			
B 70-701	200	31.6			
	400	31.4			
	600	37.1			
	Mean	33.4			

1/ Each figure is the mean of four replicates.

TABLE 7. GREEN WEIGHT OF WHOLE PLANTS FOR THREE CANE VARIETIES
UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Plant Wt (Lbs), At Month —			Mean
		6	12	18	
PR 980	200	2.97			
	400	2.96			
	600	2.55			
	Mean	2.83			
US 67-22-2	200	2.45			
	400	2.56			
	600	2.31			
	Mean	2.44			
B 70-701	200	2.80			
	400	2.98			
	600	2.97			
	Mean	2.92			

1/ Each figure is the mean of four replicates. Six plants were harvested per replicate.

TABLE 8. WEIGHT OF MILLABLE STEMS FOR THREE CANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Stem Wt (Lbs), At Month $\frac{1}{-}$			Mean
		6	12	18	
PR 980	200	1.97			
	400	1.93			
	600	1.83			
	Mean	1.91			
US 67-22-2	200	1.37			
	400	1.53			
	600	1.17			
	Mean	1.36			
B 70-701	200	1.69			
	400	1.77			
	600	1.96			
	Mean	1.81			

$\frac{1}{-}$ Each figure is the mean of four replicates. Six plants were harvested per replicate.

TABLE 9 . LENGTH OF MILLABLE STEMS FOR THREE CANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Stem Length (Ft), At Month <u>1</u> / -			Mean
		6	12	18	
PR 980	200	4.63			
	400	4.56			
	600	4.17			
	Mean	4.45			
US 67-27-2	200	4.29			
	400	4.14			
	600	3.62			
	Mean	4.01			
B 70-701	200	6.16			
	400	6.27			
	600	6.44			
	Mean	6.29			

1/ Each figure is the mean of four replicates. Six stems were harvested per replicate.

TABLE 10. STEM COUNTS FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Stems/A (Thousands) At Month <u>1</u> / ₁			Mean
		6	12	18	
PR 980	200	39.4			
	400	40.1			
	600	35.8			
	Mean	38.4			
US 67-22-2	200	46.3			
	400	46.3			
	600	44.4			
	Mean	45.7			
B 70-701	200	46.0			
	400	43.7			
	600	45.7			
	Mean	45.1			

1/ Each figure is the mean of two replicates.

TABLE 11. DRY MATTER PRODUCTION BY THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	DM (Tons/A), At Month — ^{1/}			Mean
		6	12	18	
PR 980	200	8.7			
	400	8.8			
	600	8.0			
	Mean	8.5			
US 67-22-2	200	11.1			
	400	9.6			
	600	9.6			
	Mean	10.1			
B 70-701	200	9.6			
	400	9.6			
	600	9.3			
	Mean	9.5			

^{1/} Each figure is the mean of four replicates.

TABLE 12. DRY MATTER CONTENT OF THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	DM (%), At Month - ^{1/}			Mean
		6	12	18	
PR 980	200	17.5			
	400	16.4			
	600	15.7			
	Mean	16.5			
US 67-22-2	200	18.4			
	400	15.8			
	600	15.6			
	Mean	16.6			
B 70-701	200	18.4			
	400	18.2			
	600	16.6			
	Mean	17.7			

^{1/} Each figure is the mean of four replicates.

TABLE 13. BRIX VALUES FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	°Brix, At Month <u>1/</u> —			Mean
		6	12	18	
PR 980	200	6.16			
	400	5.80			
	600	5.58			
	Mean	5.85			
US 67-22-2	200	6.14			
	400	5.27			
	600	5.57			
	Mean	5.66			
B 70-701	200	4.40			
	400	4.93			
	600	4.30			
	Mean	4.54			

1/ Each figure is the mean of four replicates.

TABLE 14. POL VALUES FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Pol Reading, At Month <u>1/</u> -			Mean
		6	12	18	
PR 980	200	2.13			
	400	1.80			
	600	1.68			
	Mean	1.87			
US 67-22-2	200	1.90			
	400	1.40			
	600	1.15			
	Mean	1.48			
B 70-701	200	0.88			
	400	0.93			
	600	0.80			
	Mean	0.87			

1/ Each figure is the mean of four replicates.

TABLE 15. RENDIMENT VALUES FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Rendiment, At Month $\frac{1}{-}$			Mean
		6	12	18	
PR 980	200	0.05			
	400	0.17			
	600	0.34			
	Mean	0.19			
US 67 22-2	200	-0.33			
	400	-0.66			
	600	-1.10			
	Mean	-0.70			
B 70-701	200	-0.99			
	400	-1.35			
	600	-1.05			
	Mean	-1.05			

1/ Each figure is the mean of four replicates.

TABLE 16. FIBER VALUES FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Fiber (%), At Month ^{1/} -			Mean
		6	12	18	
PR 980	200	9.02			
	400	7.13			
	600	8.81			
	Mean	8.32			
US 67-22-2	200	10.21			
	400	10.01			
	600	9.16			
	Mean	9.79			
B 70-701	200	9.11			
	400	13.82			
	600	8.75			
	Mean	10.56			

^{1/} Each figure is the mean of four replicates.

TABLE 17. TRASH YIELDS FOR THREE SUGARCANE VARIETIES UNDER VARIABLE N AND HARVEST REGIMES

Variety	Elemental N (Lbs/Acre Yr)	Tons Trash/Acre, At Month ^{1/} -			Mean
		6	12	18	
PR 980	200	0.84			
	400	1.19			
	600	0.99			
	Mean	1.01			
US 67-22-2	200	0.96			
	400	1.01			
	600	1.13			
	Mean	1.03			
B 70-701	200	0.74			
	400	0.62			
	600	0.79			
	Mean	0.72			

^{1/} Trash that had detached and fallen to the ground. This does not include trash adhering to the stems and requiring removal by the cane harvest machine or by hand stripping.

TABLE 18. TOTAL GREEN WEIGHT YIELDS FOR ENERGY CANE HARVESTED AT
VARIABLE INTERVALS; HATILLO PROJECT

Treatment	Tot. Green Wt. (Tons/A), At Month —			Mean
	6	12	18	
Control (Low Till)	36.7			
Control (Sugar Corp.)	30.8			
Energy Cane	36.0			
Var. US 67-22-2	50.2			
Mean	38.4			

TABLE 19. MILLABLE STEM YIELDS FOR ENERGY CANE HARVESTED AT VARIABLE INTERVALS; HATILLO PROJECT

Treatment	Millable Cane (Tons/A), At Month --			Mean
	6	12	18	
Control (Low Till)	23.2			
Control (Sugar Crop.)	19.3			
Energy Cane	24.0			
Var. US 67-22-2	34.7			
Mean	25.3			

TABLE 20. TOP WEIGHTS FOR ENERGY CANE HARVESTED AT VARIABLE INTERVALS; HATILLO PROJECT

Treatment	Top Wt. (Tons/A, At Month —			Mean
	6	12	18	
Control (Low Till)	9.9			
Control (Sugar Corp.)	6.4			
Energy Cane	6.6			
Var. US 67-22-2	12.3			
Mean	8.8			

TABLE 21. TRASH YIELDS FOR ENERGY CANE HARVESTED AT VARIABLE INTERVALS; HATILLO PROJECT

Treatment	Trash Wt. (Tons/A), At Month -			Mean
	6	12	18	
Control (low Till)	5.8			
Control (Sugar Corp.)	5.1			
Energy Cane	6.1			
Var. US 67-22-2	6.2			
Mean	5.8			

TABLE 22. DRY MATTER YIELDS FOR ENERGY CANE HARVESTED AT VARIABLE INTERVALS; HATILLO STUDY

Treatment	DM (Tons/A), At Month <u>1/</u> -			Mean
	6	12	18	
Control (Low Till)	6.4			
Control (Sugar Corp.)	5.7			
Energy Cane	5.9			
Var. US 67-22-2	8.8			
Mean	6.7			

1/ Oven-dry, approximately 6% moisture.

TABLE 23. DRY MATTER CONTENT OF ENERGY CANE HARVESTED AT VARIABLE INTERVALS; HATILLO STUDY

Treatment	DM Content (%), At Month —			Mean
	6	12	18	
Control (Low Till)	17.4			
Control (Sugar Corp.)	18.4			
Energy Cane	16.5			
Var. US 67-22-2	17.5			
Mean	17.5			

TABLE 24. PLANT HEIGHT FOR ENERGY CANE HARVESTED AT VARIABLE INTERVALS; HATILLO PROJECT

Treatment	Plant Height (Ft), At Month —			Mean
	6	12	18	
Control (Low Till)	5.4			
Control (Sugar Corp.)	4.7			
Energy Cane	4.9			
Var. US 67-22-2	4.1			
Mean	4.8			

TABLE 25. NUMBER OF STEMS PER ACRE FOR ENERGY CANE HARVESTED AT
VARIABLE INTERVALS; HATILLO PROJECT

Treatment	Stems/A (Thousands), At Month -			Mean
	6	12	18	
Control (Low Till)	31.4			
Control (Sugar Corp.)	28.4			
Energy Cane	32.5			
Var. US 67-22-2	46.0			
Mean	34.6			

TABLE 26. CROSSES FOR BIOMASS PERFORMED DURING THE 1980-1981 SUGARCANE BREEDING SEASON

No.	Cross		Breeding Line	Number Of Seedlings (Estimated)
1.	PR 68-355 x 57-NG54	X	<u>S.</u> sp. (RP) F ₁ (<u>S.</u> <u>rob.</u>) x <u>S.</u> sp.	250
2.	PR 68-355 x 57-NG54	X	PR 67-1070 x <u>S.</u> sp. (RP) F ₁ (<u>S.</u> <u>rob.</u>) x F ₁ (<u>S.</u> sp.)	250
3.	PR 67-1070 x <u>S.</u> sp. (RP)	X	PR 68-355 x 57-NG54 F ₁ (<u>S.</u> sp.) x F ₁ (<u>S.</u> <u>rob.</u>)	500
4.	PR 68-1220	X	PR 67-1070 x <u>S.</u> sp. (RP) BC ₁ (<u>S.</u> sp.)	2,000
5.	PR 70-3364	X	PR 980 x <u>S.</u> sp. (RP) BC ₁ (<u>S.</u> sp.)	700
6.	PR 69-3061	X	PR 980 x <u>S.</u> sp. (RP) BC ₁ (<u>S.</u> sp.)	260
7.	NCo 310	X	B 70-701 BC ₁ (<u>S.</u> sp.)	800
8.	NCo 310	X	US 67-22-2 BC ₂ (<u>S.</u> sp.)	350
Total				5,000