CEER-B-173

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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE

ENERGY SOURCE

FINAL REPORT

June 1, 1977 ~ May 31, 1982

To

?THE UNITED STATES DEPARTMENT OF ENERCY

Oak Ridge Operations Office, and Division of Solar Technology

?Bioaass Energy Systems Branch

Washington, D.C.

CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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by

Center for Bnergy and Environment Research

University of Puerto Rico

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[ENERGY SOURCE

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FINAL REPORT

June 1, 1977 ? May 31, 1982

PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE

ENERGY SOURCE

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assreact 2/

A Soy

xr study on the production of sugarcane and related tropical

er: ?energy crops vas completed with all objectives attained.

Begun in 1977 with screening of candidate grasses at the greenhouse Level, the project progressed to field-plots and then to mechanized field-scale production technologies emphasizing maximum total dry matter yield at ?inimun cost on a continuous, year-round basis. Final cost and energy balance analyses indicate that tropical grasses are unquestionably an economic and reliable energy resource vith multiple benefite vhen managed specifically as energy crops in a tropical environment.

Gulminating in an "energy cane? concept for optimal fuels and feed-stocks production, the S-year study underscored two points: (a) Revised amagenent technologies that eaphasize growth rather than sugar storage, ind {b), multiple species integration for year-round supply of fuels and feedstocks to Dionassqutilizing industry.

Through revised management, sugarcane yields in the order of 83 short tons/acre year were attained for whole green cane (as opposed to 27 short tons/acte year for conventional sugarcane in PR). Sugarcane fanaged in this way is now depicted as energy cane, or "first-generatio

?energy cane. "Second-generation? energy cane, consisting of revised f1eld

managenent technologies plus varieties specifically selected for biomss

1L/ ABS-UPR, CEER-UPR, and UPR Mayaguez Faculty.

2/ Contract Nos. B0-77-C-05-5422, ET-78-S-05-5912, and DE-ASOS~78ET20071.

aes-UPR project no. C-i61).

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Produced over 110 short tons/acre year. Production costs were slightly

Ihigher than $1,000/acre year but less than $10.00 green con. Recover~

le energy yields vere in excess of 450,000,000 BTUe/acre year at costs

under $2.00/million BTUs, Combined values for fuels (pegged to fuel oll

at $33.00/barrel) and high-test molasses (at §0.76/galion) exceed $3,000/

acre year for second-generation energy cane.

?A major component of the energy cane concept was the development of

alternative tropical grass species as supplemental biomass soure:

Consisting of generic-level relatives of Saccharum, these are thin-stemed,

{Abrous, non-sugar bearing grasses vhose entire product ion, harvest, and post-hatvest dewatering management 1s performed directly dn the field.

?Type species for this group include Sordan 7OA ("short-rotation", harvested at 10-12 week fntervals) and napier grass ("internediate-rotation, harvested fat 4-to 6-nonth intervals). This component of the project was highly Successful with all operations effectively mechanized.

?Tropical grasses production as energy craps 18 seen as an econoni viable enterprise for regions having tropical agriculture capabilities Ie 1s particularly attractive for relatively advanced tropical societies, Such as Puerto Rico, with heavy reliance on sported fossil eaeray- Considerable "fine tuning" potential remains for future energy cane manage- st amount of vork remains in the breeding of "third

Beneration? energy canes. Certain components of the completed DOE project are being continued in Puerto Rico under UPR and Commonwealth sponsorship.

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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A. RENEWABLE

ENERGY SOURCE 1/

NTRODUCTION

were initiated June 1,

THE BIOMASS production studies herein reports

1977 as 2 contribution to the biomass energy program of the UPR Center

for Energy and Environment Research (CEER). This research dealt vith

sugarcane, tropical grasses related to sugarcane, and other tropical

6 having large grovth potentials on a year-round basis. Its basic

ers

premise 4. that such plant materials can be produced as a renewable,

domestic source of fuels and chemical feedstocks that will eubsticute

for fossil enesgy forms that are currently imported at enormous expense.

?A. PROJECT OBJECTIVES

Primary objectives include: (a) Determining the agronomic and

economic feasibility of mechanized, year-round production of solar-dried

Antensive managenent of sugarcane and napier grass

and (b), ex

potential sources for intensive biomass production. A secondary

objective concerns the selection and breeding of nev Saccharum progeny

having superior biomass productivity as their principal attribute.

nation of altemate tropical grasses

SCOPE OF THE PROJECT

nd mechanized produc

Eaphasie vas directed tovard a highly-iatensive

solar-dried forages. This ts a deviation

tion of tropical gr:

$-05-5912, and DE-ASOS~788720071..

A/ Contract Nos. EG-77=6-05-5422, ET

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from conventional cane and cattle feed production in that total dry matter rather than sugar and food components was the principal salable coamodity. Management of production inputs ? particularly water, nitrogen and can Aidate spectes, 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

Andustries have been utilized to the eaxtoun extent possible for dry

bioaass production.

Optimized production operations require the identification of a few select clones and the conditions required for their management in an economically-realistic operation, This vas accomplished in three phi Ancluding greenhouse, field-plot, and field-scale {nvestigations (Table 1). A fourth plase, comercial-industrial operations, follows logically but was beyond the scope of the present project.

The tropical grasses have never before been evaluated under condi- Lona such that biomass energy would be the principal salable product. As 4 consequence it vas necessary to screen a broad range of candidate cultivars. Under certain circumstances existing sugar-and fber-producing

Varieties say excel also in total bionass yield, but it is generally rec

ognized that the grovth attribute has not been fully intensified in the

hybridization programs that led to the present-day varieties of comerce

vy

a. 2)

no longer produced comercially, "noble" or pure intraspecific clones,

srior selections from wild populat ton

?the germplasm from which modern genotypes have been assembled. A screening

technique was adopted for this purpose in which botanical, physiological,

and agronomte attrtbut

Screening studies have therefore included older hybrid varteties

and more primitive forms bearing

were evaluated in a stepwise program involving

greenhouse, field-plot, and field-

ale trials. In certain respects this

was a tropical application of the herba

ous spectes screening concept

formulated by the DOE Fuels From Biomass Program (3).

A/ Numbers in parenthesis refer to relevant published Literature. Coaplete

Eteations are listed on pages 67-72

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A breeding program designed to intensify the biosass-ytelding attributes

of Saccharum and related species 1fes beyond the scope of this project.

?Thorough breeding studies would require and justify a sepat

This vould include the screening of candidate pat

te project.

sntal types, a physiol~

opical phase to synchronize flowering periods at the intergeneric level,

and baste genetic rs

wearch to "break" some serious constraints operating,

to prevent the exchange of gersplasa anong Saccharum spectes and between

Saccharum and allied genera (4). At a very modest level some Limited

»

a few obviously desirable parent clones that have suitable flowering

\ding vas included in the present project. This vork was confined to

characteristics and which can be Incorporated without inconvenience into

lan on-going breeding program. Certain progeny originating with the AES~

UPR sugarcane breeding program were also evaluated as long-rotation 2!

biomass candidate:

Under such circumstances some prospect {s created for

tthe enargence of superior new progeny at very Little expense.

(C. STATEMENT ON DATA PRESENTATION SEQUENCE

?this report covers the period June 1, 1977 through May 31, 1982, the

entire contract period for the vork under this project title. Some of the

longer-term experinents were not initiated until after July 1, 1977, and two major experiments are continuing to provide data after the May 31,

1982 termination date. The latter experiments are being maintained

?through the {1rst-ratoon crop with CEEK-UPR funds.

TECHNICAL REPORT

?A. GREENHOUSE STUDIES

?The project's greenhouse phase was concerned with the screening of

candidate tropical grasses and the response of superior cultivars to growth

Anput and management variables. Much information of this nature is obtained

?T/ Categories of tropical-grass candidates for blomnss production are

Aecussed in detail on pages 37-40

---Page Break---

ne

?more rapidly and cheaply than {s possible under field conditions. Green

are not definitive in the sense that direct f1eld respons

and cultural recomendations can be stated, but perhaps two-thirds of the

total data package needed for a herbaceous candidate can be gathered in

this way. For Saccharum and related species ordinarily propagated in populations of 30,000 te 300,000 plants per acre, the greenhouse offers level of precision for control of the individual plant that 1s not remotely possible in the field (5). This method vas used in Puerto Rico for its economy of project resources; under temperate-climate conditions it offers fan economy of tine since field work 1s seasonally Limited to four or five favorable months per yes

how

Greenhouse Methods

ALL plants vere props

pots, or in 1:1 or 2:

galvanized drums, Sand culture offers precise control of water and nutrient

ited either by sand culture in glazed, 4-gallon

mixtures of sofl and cachaza contained in 10-gallon variables. Soil-cachaza mixtures are convenient media for determining

relative grovth rates, grovth curves from germination to the young-adult

stage, responses to chemical grovth regulator

recutting of candidates having superior grovth potentials, Most candidates

were established with stem cuttings of uniform size, age, and vigor. A

few candidates such as ovect sorghum varieties and che sorghum x sudan grass

?and tolerance to frequent

hybrids were established with true Insects were controlled with

weekly applications of Malathion. All plants received controlled vater

?and nutrient supplies at levels not rate-limiting for growth.

ALL first-year experiments eaployed the interspecific ¥/ sugarcane

hybrid PR 980 as a reference clone having recognized excellence as @ high

tonnage producer. In this capacity PR 980 was not satisfactory. Its major dry matter accumulation begins after 6 gonths and the project required

some cultivars that will do this as early as two to three aonths after

sua offtcinarun (9/16) x $. spontaneus (5/16) x $. sinense (2/16).

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planting. Also, several Saccharum imports and AES cane breeding progeny were identified as tonnage producers superior to PR 980. Subsequent reference clones were selected from the specific category of candidates under serutiny, te, Sordan 70-A for short-rotation candidates, napier

er

hybrid for the Long-rotation category.

18 (var. Merker) for intersediate rotation, and a suitable $. spontaneum

Harvest intervals vere varied in accordance with the stage of screening and biomass parameters under investigation. Prelistnary production tests ?aay tnvolve only a single harvest at a convenient point in the species?

rand period of groweh. Definitive grovth curves require sultiple harvests during che plant?

initial three or four months of grovth. Grovth-regulator trials require sampling at precise intervals following chemical penetration.

?The principal biomass parameters included total green weight, éry weight (oven dried to about 6% moisture), and dry matter content (Z DM). Leaf samples, including the entire blades of leaf ranks +1 and +22/ were Andesally harvested for foliar mineral analyses. Ia some early experinents Leaf samples vere harvested for blade-area and chlorophyll determinations.

Biomass production characteristics evaluated during the project are presented in Table 2

Total Growth Performance

Initial candidate evaluations for cotal grovth included 25 Saccharum aad two danthug clones in unceplicated trials (Table 3). Several com

mercial hybrids and Saccharum species compared favorably with PR 980 under

greenhouse conditions. Additional features under observation vere germin:

tion (rate and percentages of planted cuttings), early growth rate:

?and insect tolerance, and erectness. The Folloving clones were selected

disease

for seed expansion and further grovth evaluation: Chunnee, Natal Uba,

US S6-19-1, Tainan, NG 28-219, Saretha, and the SES clones 231, 317 and 327.

1/ The upperaoet leat bearing a fully-energed deviap is designated "#1".

ia sugarcane this is the youngest fully developed leaf. Progressively

older leaves are designated +2, +3, etc., ville progressively younger

leaves, still energing froa the spindle, are 0, ?1, -2, ete.

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The first clearly outstanding candidate to emerge in the project was a sweet sorghum x sudan grass hybrid produced by the Northrup-King Company (6). Marketed under the trade nase "Sordan 70-A", this hybrid hhad shown excellent growth potential as a cattle forage on Puerto Rico! arid south coast (7). Two observation trials were performed in the green

ous

fone a direct comparison against the Saccharum standard, PR 980, land a second comparison against three eveet sorghun variet i "Meridian" series (471-5, 472-2, and H72-3). The sweet sorghua variety Rona and the noble sugarcane Badilla, together with PR 980, vere al included in the latter trial. In both experiments Sordan 70-A easily out-Produced PR 980. The sweet sorghum varieties similarly exceeded PR 980 4a dry matter production over a time-course of 30 days (Table 4). Each of the aveet sorghum varieties have given good yield performances in an

earlier AES project investigating their suttability as seasonal substitutes

for sugarcane in Puerto Rico (8, 9). However, none of these varieties

of the

equalled Sordan 70-A in early green matter production or the rapidity of

ts conversion to dry matter.

In a subsequent greenhouse trial Sor:

rans (var. Common Merker), two imported napier grass hybrids (PI 7350

?and PI 30086), and PR 980. Repeated harvests at 6-veek Intervals again

emphasized the early growth potential of Sordan 70-A (Table 5). The napler

varieties excelled over longer periods of tine, None of the candidates

showed particularly favorable dry matter contents when harvested at 6-veek

sn TO-A vas compared with napier

intervals (Table 6). Dry matter values in excess of 20 percent would be desirable at this time. As discussed elsevhere (pp. 7 & 8). Sordan 70-8 will convert rapidly co dry matter between 8 and 10 weeks after sceding,

while napier varieties require about 15 weeks for dry matter accumilation

£0 accelerate appreciably.

The two napier hybrids, PI 7350 and PI 30086, have shown excellent yield potentials in cattle forage experiments conducted in the mountainous interior of Puerto Rico (10). In chose studies they had out-produced Common Merker by up to 70 percent in annual dry matter yield. Greeahouse Feoults wore less encouraging (Table 5); however, yields for PI 30086 compared quite favor:

Ty with Common Merker. oth hybrids were transferred

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t

to the arid Lajas Substation for fteld-plot evaluations, and in subsequent

years were included in {4eld

sale yield and harvest equipment evaluations.

dan 6s

?And Sorghum tlybrids

A series of sudan grass and sorghum hybride developed by the North-rup-King Company (the "Nk hybrids) were thought to have high productivity Potentials for the CEER-UPR terrestrial biomass program. These varieties were developed as cattle grazing and ensilage feed sources for hot, dry climates (6). From this series the sorghum x sudan grass hybrid Sordan Yrh had already shown exceptional promise for Puerto Rico's cattle forage industry on the Island's arid south coast (7, 11). Sordan 70-A is tech ically a cross between a asle sterile kafir~atlo sorghum and an R sudan

frase Line produced by Northrup-King via « Piper x Sweet Sudan cross (12).

Two other MK candidates were subsequently evaluated within the project's

and Millex 23, 2

Grouth-resistant Pearl millet hybrid. The reference variety was Sordan 70-A.

Additional candidates screened during the project's second and third years

Aneluded Trudan 5 and the Norchrup-King sorghum stlage hybrids NK 300,

NK 320, MK 326, and NK 367, Ordinarily the test variety would have to

?exceed Sordan 70-4 in dry nutter production by a significant factor to be

Greenhouse phase; Trudan 7, a true hybrid sudan gras

retained for field evaluation. Hovever, oving to the range of drouth and

Ps

that one or more varieties could successfully extend the Puerto Rico habseat

for this type of biomass candidate without having greater productivity than

Sordan 70-A.

st resistances carried by the NK hybrids, 4t vas concluded (correctly)

4, Growth Curve Evaluations

Initial project emphasis was on candidate grasses suitable for frequent

Fecutting and managesent as solar-dried forages using convestional fora

?aaking machinery. A candidate's growth performance during the first 2 to

4 months of its annual grovth curve is of decisive importance. Growth

performances over time-course of 5 months were measured for 16 varieties

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froo a

genera Saccharun, Urtanthus, and Arundo (Table 7). Arundo 4s a

tropical grass found in the wild along streams and irrigation canals on

?the Island's south coast. Sordan 70-A was also included in this group.

In terns of dry mattor production per individual plant, Sordan 70-A clearly exceeded PR 960 during the initial evo wonths (Figure 1). This clone flovered hi

were available after the second month. With reference to total yield per Planted area (about 60 ft), the S. spontaneum clones SES 231 and SES 327, the S. sinense clone Chunnee, and Acundo donax all compared favorably with PR 980. Sintlarly, the thick-stemed varieties Crystalina and H 37-1933, although exceeding PR 980 on an individual plant basis, produced less dry matter per planted area oving to poorer plant densities. An unidentified wild clone thought to be a S. spontaneum hybrid ¥/ also produced superior growth during the first evo months.

Wily between 5 and 8 weeks and no reliable growth data

Moisture determinations for months 1-5 indicate a rapid dehydration of Sordan 70-A during the second sonth. It was rapidly beconing a mature plant within 8 weeks after seediny

An the search for fast-growing species requiring frequent cutting and drying. Such species should not only produce a quick yield of green matter, Which is largely vater, but also convert rapidly to dry aatter.

This 48 an extremely positive factor

Moisture values for thin-and thick-stemed varieties vere comparable up to the ?41fth month (Figure 2). At this time the more primitive thin-stemmed plants revealed greater dehydration than Saccharum hybrids and Crystalins (§. officinarun). The unidentified S. spontaneum hybrid produced 9 dehydration pattern internediate between that of PR 980 and Sordan 10

4 positive factor in this elon

s favor.

Growth curves encompassing a time-course of 3 months have been plotted from the sorghun varieties M715, M72-2, M/2-3 and Roma, together with Sordan 70-A, Badilla, and the reference cane hybrid PR 980 (Figure 3).

A/ Subsequently confirmed as an S. spontaneum hybrid which apparently Nescaped? fron a geraplasm collection maintained by AES-UPR ducing the 1930"

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The superiority of Sordan 70-A for rapid initial growth and an early con version to dry matter is clearly evident. On an individual plant basis, Sordan 70-A had produced by 4 weeks as such dry matter as PR 980 would

produce in 12 weeks, Noma is also a superior candidate in this respect.

5. Growth-Regulator Studies

(@) Growth Inhibitor Kesponses: Ie has been shown that the plant growth inhibitor Polaris (Wonsanto Agricultural Products Co.) produces growth in- We in sugarcane when applied in low concentrations a¢ an aqueous foliar spray (13). At the onset of this project St was felt that biomass yields from tropical grasees aight be increased by this means at very Little expense. Initial trials were made using Juvenile sugarcane propagated by sund culture. The Monsanto products Polaris and CP 70139 were tested at ub-

repressive concentrations on G-wecks old plants of the variety PR 980, The objective of such trials is to produce a persistent sncreai

of growth
activity through a mild chemical "shock". Positive responses were obtained with Polaris adainistered as aqueous foliar sprays containing 50 to 300 ppm active ingredient (Table 8). These concentrations are roughly 1/10 to 1/50 of those required for optimal action as a chemteal ripener on the sane

variety. Internode measurewents (Figure 4) suggest a greater persistence of the Anhsbttor!

stimulatory effect than would be possible with a plant growth hormone euch as gibberellic acid. This persistence is also affirmed

by direct weight measurements taken at 6 and 12 weeks following chemical application (Table 8). The Monsanto compound CP 70139 produced growth rep

sion rather than growth increases.

Polaris was compared with several other plant growth inhibitors during the third quarter. These included Mon 8000 (Monsanto), ACR 1093 DA (Dr. R. Maag, Ltd., Dielsdorf, Switzerland), and Embark (3M Company). The test

concentration was 100 ppm active material, the level at which Polaris appears:

most effective. Embark increased growth at a level comparable to Polaris for the first 6 weeks after treatment while the other candidate saterials reaained growth inhibitory (Table 9). The effects of each mater~ ial simflarly persisted through the subsequent 6 veeks. The extended duration of the grovth-stimulatory effect 1s itself encouraging. Under

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fdentical conditions, growth stimulation in the same variety with the growth hormone gibberellic acid (GA,) seldom persists more than 4 or 5 weeks (15).

When used as a chemical ripener the action of Mon 8000 is identical to that of Polaris with the exception that Mon 8000 produces its effect at lover concentrations (13). Hence it was thought that concentrations appreciably lover than 100 ppa might also produce growth increases, This seened to be borne out ina subsequent trial where 10 and 25 ppm active Mon 8000 produced green weight increases of 17.6 and 27.9%, respectively (Table 10). Moreover, the number of harvested stems vas also increased

by the chemteal when used at these levels.

(b) Tillering Responses: The effects of Mon 8000 on increased stem

production were relatively small; however, the grovth inhibitor Eubark

(3M Company) has # pronounced capacity to incre:

fe tillering in sugarcane

?These effects were noted in earlier trials vhere the material was tested

?26 a chemical ripener and during the present project when Enbark was

compared with Polaris

for its tillering effects at concentrations ranging from 25 to 300 pra

active material (Table 11), Shoot production was inereased by all Eabark

treatments, the saxisun effect being recorded at 50 pp

tion virtually doubled the nusber of shoots per plot.

2 grovth stimulant. Esbark wae further evaluated

This concentra~

The ability to tiller, te, to produce a large number of steas from a single crow, is probably a genetically-controlled factor in the tropical grasses. Within che genus second stem while sweet corn varieties usually retain the tillering feature, In Saccharu

fteld corn varieties rarely produce a

sone clones tiller heavily almost from the moment of germination while others are reluctant ever to do so (16). A majority of clones increase tiller production roughly in proportion to the frequency

of harvests. The use of chemical growth regulators that encourage tillering could be of value in several ways to bionass energy planters:

(a) In any siven planting the aaximum stem population per acre could be attained earlies

(b) ess seed would be needed; (c) where technical o engineering

factors prohibit the narroving of row centers the intré

?row plant popula~

tion could be increased as an alternative; and (4), superior biomass

---Page Break---

-ue

producing candidates that are othervis

to tiller might be retained by chemical means, The latter example appears

Gisqualified oving to an inabilicy

eo be the case at present with a S. spontancus hybrid having excellent

Browth potential but a persistent difficulty in establishing a satisfactory

population.

Wile interesting, trials vith growth regulatory chemicals

?means of increasing bioaass yields vere dfscontinued after the project's first year. Field equipment today simply ien't adequate to simulate under {eld conditions the greenhouse-level treatments discribed above. This is the sane constraint hich has prevented full development of "chemical ripeners? in the comercial cane industry. Precision administration of hormone-1ike materials does renain an option for future study with tropical grass energy crop

(c) Theoretical Role of Pl:

stimulation with plant hormones such as gibberellic acid have not given

satisfactory results with sugarcane (14, chap. 12). Very pronounced growth

ners

f Growth Regulators: Direct grovth

occur as a temporary response vhich is lost after 2 of 3 joints are laid dom. Gibberellin effects can be prolonged by multiple tr

ge (17, 15). However, this is

followed by a slackening of grovth until sub-normal levels are attained (18). The net effect is little or no increase in sugarcane tonnage, of increases too small to justify material and treatnent costs.

oF split applications of any given dot

Certain plant growth repressants used as chemical ripeners for sugar~ cane produce growth stimulation when adninistered in very low concentra- tions, Polaris and Enbark will produce this effect as will 6-azauracil (29) and several other analogs of pyrimidine, The function of such Fesponses is not clearly understood, but 4t is reasonably certain that the growth control mechanisus for sugarcane have sufficient flexibility to ?comand? increased growth activity when the presence of an inhibitory chemical is sensed by the plant. This may be viewed as @ compen

the plant for ?anticipated? grovth stresses, or perhaps a more efficient usage of existing growth mechanians and of grovth resources already available to the plant.

ition by

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Whether plant growth increases of an appreciable magnitude can be

produced by growth inhibitors remain to be detersined. ALl of the Polaris

concentrations used in the first experiment vere too low to increase

juice quality (Table 12). There is little Likelihood that any ripener used

im thie concontration range vould offer increased sugar as an added

benefit. On che other hand, the Folaris concentration required for optinal

biomass yield incre:

level required for optimal ripening. Under field conditions the quantity

13 An sugarcane (100 ppm) is only about 1/30 of the

of Polaris needed to ripen one acre of sugarcane should suffice to increase growth in about 30 acres. Low material costs and the improved prospects of achfeving adequate plant penetration operate in favor of using grovth regulators in this manner for bionase production if any appreciable yield Amprovenent can be demonstrated. The possibilities for seasonal grovth improvenent or for the breaking of stresses imposed by adverse climate, oisture, or nutritional regines 2/ alo varrant consideration.

?An added advantage would derive from the coadainistration of grovth regulators with another material already required by the biomass crop. Under PR conditions, short-rotation tropical forages vould require a foliar insecticide application some 3 or 4 vecks
Arrigations at about 4 and 8 weeks. Foliar urea ts already adninistered ?a5 a supplenental N source with overhead irrigation water (7). Future experinents vith growth regulatory materials on tropical grasses could include their coadainistration with pesticides

fter planting, and overhead

nd/or urea.

6. Regrowth Studies

Initial data collection on plant regrovth rates was initiated during

the project's first year. Th

land quality of ratoons (shoots) produced by established crows whose tops

Ihave been harvested; (b), the number of new stems produced, 1

at which @ single-eye cutting will expand into a sultiple-stea crow; and

(e)y the persiotence of vigorous regrovth over an extended period of time.

fe moasurenents determine: (a) The vigor

the rate

A/ Gtbberellic actd is most effective as a grovth stimulant in sugarcane

Shen plants are undergoing some degree of physiological stress (22, 23)-

---Page Break---

Many tropical grasses have a natural tendency to form "bushes" as they are repeatedly cut back. Exceptions to thts aay include the unidentified S. spontaneum hybrid discussed earlier in this report and the S. sinense clone Mandalay, both of which appear to produce only single

shoots when the primary stem is harvested. Vigor of the regrowth 1s of equal concern. Even anong hardy species such as P. purpureum a serious shock 1s experienced when the top/root ratio 1s drastically altered tn chis manner. The variety Common Merker, for example, usually produces

only weak and yelloved shoots for about two weeks after harvest before ite vigorous grovth habit and green color are reestablished (20).

Persistence of vigorous regrouth 1s of even greater concern. Ideally, ehis project would have identified several clones within each category

of tropical grasses chat would withstand repeated recutting over a period of many years. In the upshot, one napier variety (PI 7350) and one Jong-rotation cane vartety (US 67-22-2) were show to have this attribute.

None of the short-rotation grasses have this characteristic.

7M

Nueeteton

Tuo biomass nutrition experiments vere initiated during the project's first year. One experiment relates to a nutritional disorder observed in napter grass during the initial f1elé-plot trials at the AES-Lajas Sub-

station. It was tentatively identified as a manganese deficiency in a

greenhouse experiment with the same variety (Common Merker) propagated by sand culture, AL1 nutrient solutions vere prepared with ACS-grade salts ia once-distilled water. Two non-replicated blocks of plants were propagated

for 7 weeks, one block receiving @ complete nutrient solution while Ma was withheld from the other. Leaf freckling symptoms characteristic of the fteld disorder began to appear in spindle leaves of the sinus-¥a plants at 4 weeks.

Traces of the symptom also appeared in some plants of the control

group (receiving 0.5 ppm Ma), suggesting that the Mn requirement of this plant is considerably higher thaa the norm for tropical grasses. It és also possible that the field symptoms were not purely the result of in- sufficient Mn in the soil. Manganese disorders quite comonly relate to

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wa

Soil pH and iron levels which affect the availability of native Ma to plants (21).

A second nutrition experiment vas established during 1977-78 using Sordan 70\ as the test species. Variable aitrate-N levels were provided to establish the project's first nitrogen-response curve. Plants were propagated in sand culture with vater and all nutrient elements other than N held constant. The principal objective was to determine the slope of the plant's growth response when supplied with progreseively higher levels of N. Accordingly, N supplics wore increased in a geometric

progre

ment was deficient while aninteining sone Liaited growth; high N (81.0 ?neq/1) offered a vastly greater 8 supply than most tropical grasses can

sion from 1.0 to 81.0 milequivalents/Liter of N0,- The low-N treat~

uetlize. With sugarcane, for example, 10, levels in sand culture exceeding about 20,0 weq/1 are utilized only in the sense of ?luxury consumption? (14). For sugarcane, 9.0 meq/1 of NO, in sand culture are roughly comparable to a f4eld treatment amounting to 100-150 pounds of elesental N per acre year.

Growth da

recorded at 4 and 8 weeks after sceding are illustrated
40 Figure 5. At 4 weeks there wis Little response to NO, levels higher chan 3.0 meq/1, oving in part to the Lack of a root system suffictently developed in the young plants to make use of 20 much nitrogen. Large
ners

were obtained between 4 and @ weeks with 9.0 meq/1 of NO, being optinal. Nitrogen levels higher than this appeared to be growth-repressive.

Nutritional information gathered by the si

wé-culture technique is not

?directly applicable to field conditions; however, the form of the N-response

curve is a characteristic feature of the candidate cultivar whether 4t 1

arom in

vunder glass or in an open field, The response curve for

Sordan 70A is in fact a very favorable one. It indicates that there is

4 fairly distinct point beyond which no further gain can be expected from

increasing expenditures of nitrogen fertilizer, The situation would be

Af the plant had continued to respond to higher N

levels in a weakening first-order curve. In this case a net-energy balance

?much more complica

scenario for Sordan 704 vould require sone elaborate fteld-plot work to Pinpoint the correct cut-off level for applied N. It might never be determined with any appreciable precision.

---Page Break---

welable Motst

Regines

Variable irrigation studies were initiated in 1978 using a series of Northrup King hybrid grasses as test species (25, 28). These included Sordan 70A, Sordan 77, Tradan 5, Trudan 7, Millex 23, NK 300, and NK 326, Humid, ?normal?, and semi-arid conditions were sinuiated by variable frequency of watering. All plants were propagated in the greenhouse in 21:2 aixture of soil and cachaza, with Sordan TOA serving as the control variety.

Both arid and semi-arid moisture regines gave yield profiles that were distinctly different from normal, vhile essentially equal to one another (Figure 6). In the case of ?arid? plants the yield reduction was decisive;

very little production was recorded fron week 5 onvard. Alternatively, the NK variety Trudan 7, although repressed by arid conditions, significantly Out-produced the control variety Sordan 70A (Figure 7). Subsequent trials at the field-plot level verified that both Trudan 7 and Sordan 77 were Superior to Sordan 70A under water-stress conditions.

Importation and Quarantine of Candidate Tropical Gr

?A number of Saccharum clones and clones from both related and un- Felated genera were available in Puerto Rico for screening as biomass can~ Aidates when che project was initiated on June 1, 1977. However, the vast majority of clones from these genera reside outside of Puerto Rico, both

in the wild and in national and international collections. Mr. T. L. Chuy 8 project collaborator and 2 recognized authority on Saccharum and allied ?species, traveled to the US mainland during December of 1977 to evaluate

cultivars there as potential candidates for biomass screening in Puerto Rico, We visited USDA collections at Canal Point, Florida, at Houma, Loui~ Stana, and at Beltsville, Maryland. A total of 73 clones were identified wwitable candidates and arrangements were made for their shipment to

Puerto Rico, An additional 379 clones from Indonesia (1976) and 25 from

Now Guinea (1977) were observed at Beltsville; hovever, these were still

in quarantine and remained unavailable for testing in Puerto Rico.

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The first fourteen clones yore received from Houma during January,

1978, and were pla:

in quarantine at the AES-Gurabo Substation. This

?group greatly expanded the geraplasn selection for bioaass screr

Puerto Rico (Table 13). They arc all intergeneric or interspecific hybrids

representing parental miterial fron the genera Saccharum, Eecotloput, Sorgo,

?These clones and

ing in

Sclerostachya, Miscanthus, Erianthus, and Riptdiua 1

chose arriving in 1978 displayed an exceptionally robust growth habit and profuse tillering.

During che susmer of 1978 two shipments of candidate grasses vere Amorted into Puerto Rico and placed im quarantine at the AES-UPR Curabo Substation. These included a group of five clones from the USDA-World collec~ tion at Beltsvitle, Maryland, and a group of 32 clones from the USDA-World

collection at Canal Point, Florida (Table 15). The Beltsville shipment

consisted entirely of S. robustum clones, a species vbich has been notably lacking in Puerto Rico. The bulk of the Canal Point group were S. spontaneum clones. The latter group also includes gerspl:

Miscanthus, and Erianthus, together with the Saccharum species S. fusca, S.

Rarenga, and §. robustum.

?These candidates vere planted in soll-cachazs mixtures and all but one

from the genus Ripidtum /

gave satisfactory germination. Growth was adequate though unremarkable for

most clones. Several clones produced tassels late in Novenber and Decenber,

1978.

.charum species very rarely flover under greenhouse conditions,

but the late flowering trait could be a useful factor in ite om right

Since it would enable these clones to be crossed vith hybrid sugarcanes Which normally tassel at this tine 2/ The observed flowering could also be an artifact of the plant's greenhouse environment or their lat etme of planting.

1/ Ripidiua was formerly classified as an asiatic sub-group of Erianthus.

2/ The ougarcanes of comnerce tend to flower later than the more primitive Saccharum species. This 1s an unfortunate trait of considerable importance To Sugarcane breeders concerned vith utilizing the widest possible range of Saccharua germplasm in their hybridization programs.

---Page Break---

Wone of the imporced species vere found to be suitable for short-rota- elon cropping. They are regarded as candidates for long-rotat ion and minimim-tillage biomass crops. Certain of the Si

yeum species may compare

favorably with aapier gr:

and napter hybeté

sntermediace-rotat ion

candidates. They might also expand the planting zones of intermediate-and long-rotation species into semi-arid and arid regions too dry to sustain

napier grass and conventional sugarcane hybrids.

The principal objective of the clone~screening process was to find superior producers of dry biomass (fiber) for intensive propagation as solar-

aried forages. Added to this was the need for minimum-tillage candidates

that will survive and produce acceptable yields under arid conditions and

various types of marginal lands. This objective was attained.

B. FIELD PLOT STUDIES

Some field-plot work was conducted at the AES-UPR Substations of Gurabo

and Corozal, but most experiments were performed at the Lajas Substation in

the semi-arid Lajas Valley. This phase of the project began during July of

1977. Certain experinents established during years 4 and 5 are still under~

shouse? funding.

vay and are being completed with CEER-UPR "

1, Fleld Plot Methods

?The majority of the project's field-plot experiments were planted on

4 Fraternidad soil series, a moderately well drained soil which is highly

plastic when wet and crumbly when dry. If {a representative of much of

Puerto Rico's better agricultural lands. Plot size was ordinarily 1/50 acre and there were 4 to 6 replications of each treatnent arranged in a randomized block design. Controlled variables included species, varieties, row spacing, seodbed preparation techniques, seeding rates, fertilizer supply, water supply, harvest frequency, postharvest seedbed manageaent, and Longivity of established plant populations.

Hecopt in the variable irrigation treatnents,

11 plants received an "adequate" water supply, administered first by overhead sprinklers (at

---Page Break---

seeding) and later by flood (border) irrigation. Fertilizer vas ordinarily provid

2-to dononth intervals thereafter).

in three increments (one-third at planting and the remainder at

?The principal harvest paraseters for all experiments were total dry

matter (DM), percent aoiture, and total green matter (GM). These were

usually reported on a ?per acre" or ?per acre year basis. In some experi-

folfar samples vere

xy (N, Py Ky Cay Mg) and mtllable stems

were harvested for juice quality and sugar analyses. Also during the enersy

ments, particularly the later studies on energy cat

taken periodically for nutrient ai

cane studies @ sore detatled broakdomm was made of total DM on a plant

compositional basis. Hence, cane plants before oven drying were subdivided

/

into millable stems, inmature stems, green foliar canopy, detached trash

and attached trash.

2. Gurabo Substation Screening; US 67-22-2

?The project? field plot expertnents began at the humid AES-UPR Gurabo

Substation and rapidly extended to the Lajas Substation in the semi-arid

Lajas Valley. Subsequently, mst of the {eld plot work wis perforned at

Lajas. The

Saccharum spectes. This group consistsed of clones {aported for breeding

rly Work at Gurabo was an ot

jervat ion study of candidate

Purposes in 1976, and series of §

spontaneum and S. sinense clones that

had already show favorable biomass attributes under greenhouse conditions (26), The most significant result of chis trial was the emergence of the

?S. spontaneum hybrid US 67-22-2 as a superior candidate for biomass production (Table 14). In this and subsequent trials, US 67-22-2 consistently outperformed the control clone (PR 980) in total green and dry matter yield,

Percent germination, rate of development, stems per acre, canopy developsent, ?and regrowth vigor. It also equalled or exceeded PR 980 in sugar conten of millable stens and tons sugar per acre (TSA). Ultimately, US 67-22-2

3/ The term ?trash? herein refers to leaf and leef-sheath tissues that have ied and desiccated; some fraction usually adhers to the stem while the Temsinder drops to the ground.

---Page Break---

a9

became the standard ?second generation? energy cane !/ in the project" final years (25, 26, 27). By the close of the project this variety had become widely recognized both as source of sugar and biomiss and was undergoing seed expansion for plantation-scale production.

3. Firet-Generation Boergy Cane; Lajas Substation

Toroughout {ts long history

a cultivated crop, sugarcane has been

Planted for its yield of sugar rather than blomass. Yet, the plant itself, conbination of Saccharum species (usually mixtures of S. officinarum and S. spontaneus germplasm in modern hybrids) is a far better producer of biomass than sugar. Even the ?sveetest? varieties of commerce consist Foughly of 70% lignocellulosic matter and only 30% sugare ot fermentable Solids. Given adequate water nutrients, and a warn climate, the eveetest varieties will opt to grow ? to produce new shoots in an ever-expanding rom ? rather than accumlate sucrose. As a consequence, sugarcane normally yields more energy than 1s consumed in its production operations, ?eventhough it 1s not normally sanaged for optimal energy ytelé

?An Amportant goal of the field-plot studies was to detersine the increased tonnages of biomass that could be expected vhen cane As managed

for maximum biomass rather than sugar. One way of doing this 1s co select candidate varieties from existing comercial canes already available in larce quantities and to alter their production cechnologies accordingly. An alternative approach 1s the selection and breeding of canes apecifically created for the purpose of energy storage. In this project the firet ?approach was mandated by tine, resources, and the ready availability of

|. This phase was completed over a time-course of three yé

cs. The

results were highly remarkable; they foraed the basis for the "firet-

Seneration"energy cane concept initially revealed by CEER-UPR in a 1979 biomass syaposiua (29). Work began on ?second generation" canes during

the final two years of the project and continues at present under CEER-

UPR funding vith assistance from the Comsonvealth government (30).

A/ "Energy cane", a term coined locally in 1979, refers to cane managed For maximm biomass production rather than sugar.

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An important feature of the energy cane concept Ae the production of Lignocellulosic feedstocks on a year-round basis (31, 31). Although cane grows continuously throughout the year {t cannot be harvested during the tropical rainy

by heavy equipment. In Puerto Rico, biomass processing facilities could

json when sot! and scedbed structure 1s severely damaged not receive energy cane during the wettest four month of the year (ni

?August through mid December), and hence vould be denied the eritical

?bagasse? feedstock needed to maintain operations. In the present project

we attempted to close the anticipated gap in feedstock delivery by producing

5 that could be solarcéried in the ffeld, com

pacted, and stored until needed during the rainy season, This phase vas

ultimately successful. A ceries of fast-growing, thin-stemmed fibrous

alternative eropical gr

grasses were identified as suitable species for this type of operation.

?The most successful candidate, napier grase (Pennisetum purpureun), vas

initially confirued in this role during the studies on first-generation

4. nergy Cane And Napier Lajas

?The project's first major field-plot experinent was established during

July 1977, at the semi-arid AES-LaJas Substation. Controlled variables

included varieties, row spacing, and harvest frequency (Table 16). There

were three hybrid sugarcanes (PR 980, NCo 310, and PR 64-1791) and one napter grass variety (Common Merker). Each variety was recognized as a

Superior producer of biomass tonnage under Puerto Rico conditions.

(a) Procedures: Tis experiment was planted on a moderately well-drained Fraternidad Clay soil. Plot size was 1/50 acre and there were six replications of each treatment arrang lontzed block design. All clones received constant water and fertilizer levels at roughly double the comercial rates for this region. Fertilizer was applied in three incre-?ments; 1/3 at planting and 1/3 at 4 and 8 gonths after planting. Nitrogen in the form of ammonium sulface was supplied at the rate of 400 pounds

per acre year for sugarcane and 600 pounds for napier grass. Water was

provided as needed by flood irrigation delivering approximately 2 acre inches per application.

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2a

Mole plots consisting of a 600 square foot area vere harvested at

the appropriate interval, ic, at 2 sonths (stx times per year), at 4 months (chee times per year), at 6 months (two times per year) and at 12 months. Two subsamples of 10 plants each were harvested for dry matter determinations and foliar diagnosis of ¥, P, Ky Ca, and Mg.

?The nitrogen level for napier grass (600 ibs tines that of sugarcane in accordance vith the higher consuaption rates known for napier grass. Similarly, the standard and narrow rov centers for napier grass vere set at 50 cm and 25 cm, rather than at 150 om and 50 cm as was done with sugarcane. Mlarvest intervals of 2 and 4 months are # recognized advanta

were year) was set at 1.5

for napier grass whereas intervals of 6-months or more clearly favor sugarcane. Management practices that were equal for sugarcane and napter grass included the level, sethod, and frequency of irrigation, the timing and ethod of aultiple fertilizer applications, and all pest control procedures.

(b) Manganese Deficiency: Following the initial 2-month harvest,

foliar discolorations possibly indicative of nutrient deficiency appeared 4m some of the napier grass plots. At about 3.5 months, foliar symptoms siatlar to manganese defictency app.

red in virtually all napier grass

Plots. None of the sugarcane plots had foliar symptoms eventhough they received less fertilizer than napier grass. The symptoms in napier grass were greatly diminished or disappeared entirely at 4 months following a second application of fertilizer co which a saall anount of MnCl, had been added. This syaptom recurred only briefly during the remainder of the project and vas always responsive to small quantities of Ma, Subsequent greenhouse trials with Ma-free nutrient culture in sand culture confireed that the indicated syaptoas were associated with Yn deficiency.

5. The

Genes

1 Trends; Pi sion Energy Cane

In 1980 the first dat

for firet-generation energy cane, and for napier grass managed as an

for a complete cropping cycle becaze avatlable

?energy crop (35). For perennial tropical grasses the first year's tonnages

(plant crop) are usually lover than those of the ratooa crops (regrowth)

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in the years imediately thereafter. Puecto Rico's commercial cane industry

normally harvests the plant corp plus four or five ratoon crops before replanting the area. Napier grass is considerably more durable and may ©

fon a given site for decades before replanting or rotation 1s deesed nec

As the project progres

Wed, data trends were reported on a crop-by-crop,

year-by-year basis. In retrospect the decisive trends for such factors as green and dry matter yields and production costs can be stated far sore Succinctly as the J-year means of a complete crop cycle (35). Four distinct trends vere evident for cane and aapter gra:
close spacing to increase yields; (b) large DM yleld increases as harvest Frequency was reduced; (c), a moderate superiority of sugarcane variety

(a) A general failure of

NCo 310 over other first-generation energy canes; and (2), a superiority of the first-ratoon crop over the plant and second-ratoon crops. Second

ratoon yields vere intermediate between those of the plant and first-ratoon crops. The optimal DM harvest interval for cane was 12 sonths (the longest interval tested) ar

150 es for car

6 months for napter grass. Optianl row spacing was

and 50 em for napier grass

Om an individual crop basis, the highest ylelds were recorded for the firat-ratoon crop. The highest green matter yield for cane was 92.0 tona/ acre year, with 31.3 tons dry matter. For napier grass the highest green and dry matter yields were 88.9 and 22.4 tons/acre year, respectively. Cane quality wes low, on a "per sten" basis, but significant sugar yields were obtained on a per acre basis owing largely to the high tonnages of wlil- able cane. Piber concent averaged 16.42 for all varieties.

(a) DM 86!

Mean DM yields for three crop

years (plant crop plus two ratoon crops) underscored the teportance of allowing at least 12 months to elapse betuven cane harvests and 4 to 6 ?months between napier grass harvests (Table 17). Certain officials in the PR Sugar Corporation have proposed two annual harvests of PR cane (at G-month intervals) as a means of increasing cane yields. As indicated ta Table 17, this would have the effect of lowering DM yield by nearly half. The negative impact on eu

wr yield would be even greater since very Little

sugar accumlates in 6-months old cane.

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<2.

(b) DM Yields By Crop: The first-ratoon crop for energy cane vas the most productive crop, particularly for the 12-ponth harvest interval (the only practical interval of the four tested on cane). As indicated in

Table 18, yields froa the 2-aonth harvest interval declined drastically after the first year. As an average response of three varieties, cane was unable to vithstand frequent recutting of the above-ground plant. The 4-and 6-aonth harvests vere also causing yicld decline in the secood ratoon crop (Table 18). The 12-soath harvest interval was sizilarly giving reduced yields to the second ratoon, but in this case the yields were still superior to those of che plant crop.

(c) DM Yields Ys Row Spacing: Early data fros the plant crop had indicated some tonnage increases through the use of narrow row spacing

(50 em ve 150 en), but this effect was subsequently lost (24). As a 3-crop average the final yleld data coofirs that no gains were made by use of row spacings narrower than the 150 cm traditionally employed by the PR cane Andustry. The critical 12-month harvest interval actually produced less. cane with close spacing (Table 19).

The close spacing concept for increasing cane biomass had been inves~ Cigated by Hattelle-Columbus workers in the late 1970's (36). There is sone evidence that higher yields can be gotten by this means under Louisiana cane-groving conditions. It does not appear to be feasible in Puerto Rico. or in Florida (37). In addition to higher planting costs there would

be mjor increased damage by harvest machinery. Even the tradit{onal

S-foot spactag in Puerto Rico does not allew sufficient space for equipaent tires and tracks to pass without sone injury to the cane stubble and young

shoots.

By the project's final year we felt that cane stem population could be optimized by increased stem density within the row. This can be accosplished by higher seeding rates or by use of varieties having a prolific tillering characteristic such as the ?second generation? energy cane variety US 67-22-2

Our final energy cane plantings have involved increased distances between

row centers (up to 8 feet) as a seans of avoiding mechanical injuries to the cane crows, It appears chat this approach 1s justified by the reduced planting costs coupled with non-stgniffeant reductions tn yleld. It is

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=m

predicated upon the avilabitity of # heavy-tillering variety such as
US 67-22-2 (see pp. 58-60).

(a) Teash DM Yields: A significant component of the sugarcane plant 4s the leaf and leaf-sheath fraction which accumulates during the course of a 12-month crop. This fraction amounted to more than 5 tons DM per

acre year for energy cane, and more than 3 tons for napier gra:
year averages (Table 20). Row spacing varts
on trash yield, The cane variety PR 980 produced moderately greater yiel
) than did the varieties NCo 310 and PR 64-1791. It
should be noted that a trash DM yield of 6.0 tons/acre year exceeds the

as 3+

les had no appreciable effect

(over 6 tons/acre ye

entire yield of whole plants for most spectes being examined as biomass

resources today.

(e) Seasonal Influences On Yield: The project's experinents were

performed at near sea level at 18° north latitude. This is « tropical

Nonethe-

there vere clearly seasonal variations in the productivity of both

setting widely recognized for its "year-round groving season?

tes

cane and

?The 2-month interval from January 15 to March 15 was the Least productive for both sugarcane (Table 21) and napier grase (Table 22). This is attributed to the relatively cool nights in Puerto Rico during this

Period. Because this interval also falle within the Island's dry 9:

sone claim can be made that the grovth reduction was a result of reduced water supply. This is at least a contributing factor, for eventhough the ?experinents vere irrigated 4 {s mpractical to simlate completely the

region's natural rainy season by this means.

?The 4-month harvest interval corresponded roughly with three seasons im Puerto Rico: Late huntd sumer (July 15 to November 15), semi-arid "winter" (Woveaber 15 to March 15), and early humid summer (March 15 to July 15). For both sugarcane and napier grass the season least suitable for growth was the semi-arid winter (Table 23). This was clearly evident

for the two ratoon crops of each species. In the case of sugarcane nearly

hhalf of the ratoon crops? total annual yield was produced in a 4-nonth period

---Page Break---

from July 15 to Noveuber 15. The inportance of the war, humid, late summer mouths to sugarcane growth has been recognized for many years by cane planters cecking to maxizize sugar yield. Hence, the Teland's ?gran cultura" crop vas alvays planted by early August, thereby enabling the cane to pass through evo late sumer growing

sons before being harvested at 16 to 18 months of age. The sane principle could be managed with even greater effect in @ future energy-planting enterprise designed to maximize cane biomass tonnages.

(£) Quality: Sugar And Fermentable Solids: Energy cane sanagenent practices vere designed to maximize biomass tonnage rather than sugar yield. Relatively poor juice quality vas obtained for the plant and firet-ratoon crops. Second ratoon cane shoved some improveaent but nonetheless would

be regarded as substandard in most cane suger industries. Sucrose content 7.2% for all varieties and row spacing (Table 24). Variety

PR 64-1791, at standard row spacing, produced

average

average

4x gucrose. Fiber content

16.4 percent, @ value which 1s not exceptionally high.

Witle the quality of the first-generation energy cane vas lov, it was nonetheless equal to or better than that of Puerto Rico's comercial sugar Andustry. Comercial sugarcane in Puerto Rico today rarely yields sore than 8% sucrose. This 1s a consequence of @ whole series of field and factory problems which 11¢ beyond the scope of our discussion. However,

At must be noted that cane grow for biomass cannot be faulted for low yields of sucrose oF fermentable soltds uhen the!

acre" basis. For the Year 3 crop the three test varieties averaged 5.18 tons sugar/acre (TSA) at standard row spacing and 5.71 TSA for narrow row spacing (Table 25). By contrast the PR sugar industry produced less than

2.2 TSA in 1980 (38). The Government 's Long-term goal of 3.0 TSA (39) 1s

virtually unattainable under present conditions in the Island's sugar

Industry.

In the managenent of "energy cane", fernentable solids have been

depicted

?8 major byproduct rather than the primary objective of crop

production (30, 31, 32). In Puerto Rico, especially when world prices for

raw auger are low, sucro

would be sold co the Island's rum industry as a

128 (syrup). As recently as che autuan of 1981

component of high-test sol:

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= He

sucrose values appeared constant at arouné 13 cents/pound, and high-test molasses was periodically priced as high ax 95 cents/gallon,

During periods of high sucrose values it could be profitable to recover

part of the sucrose for local or foreign sales. One

uns of doing this would be to retain the "first strike" (containing perhaps 602 of the recover-

able sucrose in cane juice) for raw sugar sales. The balance of the sucrose

would remain is the molasses, This would be sold to the PR rum industry a5 a somewhat lover quality "bigh-test" molasses.

(g) First-Generation Cos

production were perforaed in 1980 on the basis of firs breakdom of production input charges is presented in Table 26. These figures pertain to a fantly-omed, 200 acre operation yielding 33 oven-dry tons of biomass per acre year. The most expensive equipment itess, a vhol: cane harvester and low-bed truck, would be hired from the PR Sugar Corpora:

Preliminary cost analyses for energy cane

ratoon yields. A

tion together with the equipment operators. In an energy-cane industry such

Atens would probably be family owned, in vhich case the operation and main~

tenance costs would be appreciably lower. Both water and fertilizer charges

mainly

?owing to potentially large consumption differences as varietal and ecol-

are entered moderately higher than project data actually indicat

ogical life zone factors. Total costs, including delivery to the wm

Ling

site, amounted to §25.46 per oven-dry ton, or about $1.70 per million BTUs. By way of reference, Puerto Rico was paying about $4.30 per aliiion BTUs in early 1980 for petroleum boiler fuels.

In an energy cane scenario about 68 percent of this dry matter would be burned as botler fuel. The remainder would be extracted as fermentable solids during the cane devatering process and later sold as constituents of high-test molasses. Neither raw sugar nor refined sugar sales are anticipated. The fermentable solids from one acre of energy cane ({e, vith yields of 33 0D tons/acre), vould be valued at $1,500 to 2,000 dollars if marketed today (1982) a high-test molasses.

?The Puerto Rican emphasis on molasses rather than boiler fuel is quite eal and probably Justified, fum is one of Puerto Rico's leading sources

of revenue, yet her molasses fecdstocks are increasingly derived from foreign suppliers. Puerto Rico was one of the world's major mola:

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=a

exporters in 1934 (40) but declined to an 88% dependency on imported molasses by 1980 (41). Because of this, local interest in the energy cane herein described is directed mainly tovard its molasses yield potential rather than ts role as a renevable donestic boiler fuel.

Production cost estimates for conventional PR sugarcane were also computed in 1980 for direct comparison with energy cane estimates (Table 27). Sogarcane cost estimates were based on data obtained from Central Aguirre for the 1979 milling season. They probably constitute @ "best cas

" for

Production operations in the current PR sugar industry as a vhole. As

Indicated tn Table 27, production costs for energy cane vere higher than sugarcane in five areas: Seedbed preparation, si

operation

sd, fertilizer, harvest

and delivery of harvested cane. Energy cane seed and fertilizer expenditures were double those of conventional sugarcane. Harvest operations and cane delivery expenses vere §7 percent higher, and seedbed pre-aration costs were 50 percent higher. It should be noted also that the Sugarcane cost estimates pertain to a private planter (or "Colono") for ?who the major machinery items are rented rather than self-owned.

The overall cost for producing a ton of energy cane was 4& percent higher than conventional sugarcane, Hovever, the decisive difference between the two management scenarios lay in the total dry matter yield per acre year (Table 27). Energy cane yield exceeded sugarcane by factor of about 3.7. Hence, the increased cost of "pushing" sugarcane, ie, to maximize total biomass rather than sucrose, was more than comper

red by

feven larger increases in dry matter yield. As a result of its relatively low productivity the PR sugar industry cane cost in the order of $65.00/00 ton, or about $4.31/ailiton BIve.

(h) Baergy Balances

performed during 1980 using the first-ratoon crop means for varieties PR 980, NCo 310, and PR 64-1791. These varieties averaged 33 0D tons/

acre year for the first-ratoon crop. Energy input estimates for this

Preliminary energy balance analyses were

material are summarized in Table 28.

Total energy inputs for first

generation energy cane production were

im the order of 28 x 10° s1U/acre year. Energy output amounted to 279 x

10° rU/acre year (Table 29).

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28

?The latter figure was computed on the assumption that gost of the fermentable

solids fraction of the total éry matter yield vould be extracted at the sugar ill. The extracted fermentable solids azount to about 640 1bs/0D ton of energy cane. This figure is based on a recorded mean Brix value of 13.1°

for energy cane juice and an assumed 80% extraction at the mill, In this instance only 1,360 pounds of dry matter/OD ton, or 22.4 tons/acre, will be used as botler fuel. On a steam recovery basis, assuming 852 efficiency for

4 vtility boiler, an energy output/ingut ratio of 9.95/1 18 obtained (Table 29).

Sone authors have simply divided the total calorific value of their annual 0D product by the total production energy input (42). By this method

?energy cane would have an energy output/input ratio of about 17.7/1.

It ds instructive to note that nearly half of the cotal energy expenditure was for mineral N alone (Table 28). Hence, while the favorable energy balance obtained to date is mainly a reflection of high DM yield, future inprovenent of chis balance can be gained both by increasing yields and by reducing the Anput of mineral N. One means of lovering N input 1s to apply the element as 4 soluble component of the irrigation water, particularly water applied via trickle frrigation (43). The increased efficiency of lower N supplies should

conpensate for the relatively inefficient plant usage of dry fertilizer ad-
inistered in larger anounts to the soil surface. Another potential neans
of lowering mineral N expenditures is through increased usage of N-fixing

legumes tn conjunction vith bionase

ray crops. A Large number of under:
ucilized tropical legumes have been identified for possible use in this
context (44, 45).

6. _Second-cene

on Energy Gane (PlantGrop)

The project's first three years work with energy cane, from 1977 to
1979, delt exclusively with existing sugarcane varieties originally established
in Puerto Rico for the purpose of sugar planting. Their revised management as
biomass resources led to vs

ely greater yields of dry matter, sugar, and fermentable solids, vhile production costs were lowered on a "per ton? basis. However, it vas also recognized from the onset thet the canes then available

were not entirely suitable for planting as energy crops. They were the

---Page Break---

first of three ?generations? of energy canes, including: (a) Existing sugarcanes of comerce whose bionass yields could be improved by sanage- ment practices oriented to growth rather chan sugar; (b), existing clones having superior biomass yield potentials but otherwise unplanted in the Sugat-oriented consercial cane industries; and (c), aew hybrid progeny to be bred specifically for high biomass attributes (total dry natter and

fermentable solids).

The first plantings of second-generation energy cane vere made in 1980, with primavera and gran cultura yield data becoming avatlable 4a 1981 and 1982, respectively. The performance of these canes together with cultural modifications and production costs 1s herein reported.

(a) Varieties: Since 1977 a search has been undervay for Sacct

clones having superior attributes as biomass energy crops (48). Two out~ standing candidates vere identified asong imported materials maintained as Potential breeding stock at the AES-UPR Gurabo Substation (49). One is a Barbados variety (B 70-701), having excellent growth characteristics and bbigh fiber content but little aptitude for producing sugar. The other,

Us 67-22-2, eimtlarly hi

uniform germination and forms a massive stool complex within a year after

outstanding grovth potential. It has a rapid

Planting (up t0 90,000 stems/acre). It is also a relatively "sveet" cane Whose sugar yield usually equals or exceeds that of the comercial inter specific hybrid PR 980.

The search for superior candidate varieties s vith UPR and Commonwealth oupport. This includes the breeding of hybrid progeny from crosses

ueilizing both B 70-701 and US 67-22-2 as parental clones (49). A seed

?expansion program for US 67-22-2 1s undervay at the AES-UPR Lajas Substation.

?This variety te expected to be the

the remainder of the 1980's

tandard? PR energy cane for at least

(©) Agronote Yodifteat ton:

?energy cane is a fLeld-plot study having 27 treatments with four repiica~

tions arranged in a randomized aplit-plot design (Table 30). There are

three prinary treataents (harvest frequencies at 6=, 12-,and 18-nonth

Dy three subcreatments (varieties PR 980, US 67-22-2, and 8 70-701),

The first planting of second-generation

---Page Break---

30+

and three sub-subtreataests (vectable nitrogen at 200, 400, and 600 1bs/ acre year of elemental N). Row cpacing is constant among all treatments at standard 60-tnches. Irrigation 2* also constant at approximately 54 acre inches/year administered as needed via border irrigation in 2-tnch increments.

Variable harvest intervals underscore the need for more than one year to optimize Saccharun bicmass. An important shortcoming of the first-genera-

tion studies was a 12-month am

mm interval between harvests, a reflection of commercial sugarcane management in Puerto Rico. At least 18 gonths are thought to be needed to saxin{ze total dry matter in energy cane. Of the three cose varieties, US 67-22-2 and Bb 70-7OL are second-generation canes

PR 980 de a reference

varkety typifying the Island's comercial igarcane. for first generation

having enormous growth potential undor PR conditions

canes managed as biomass crops, about 400 ibs of elemental 8 are required

per acre year, The nev N varfables were designed to indicate whether this

quantity aight be reduced (or profitably increased) in varieties specifically

selected for dry matter and solasses. The N source 4s ammonium sulfate in

16-4-8 fertilizer formulation administered incrementally at 3-moath intervals.

Two completely sew inputs not received by the first-generation cane

snclud

and (b), subsoLling the planted seedbed to a depth of about 20 inches.

These inputs required additional equipment and fuel, and hence increased

(a) Rotavation of tho seedbed with # heavy-duty land rotavator,

production costs to cone extent. These costs appear to have been more than

compensated hy increased yields (see pp. 33-36)

(e) Muole Gane Yields:

including attached trash but not detached tra:

Yields of hole cane (willable stems plus tops,

) exceeded 100 short tons/

acre year for each second-generation variety (Table 31). Total GM yields,

including millable steas, tops, attached trash and detached trash, averaged

118.4 tons/acre for all treatments.

?The highest single yield for 12 months was 130.3 cone/acre, recorded

for variety US 67-22-2 receiving 400 1b elesental N/acre (Table 31). There

was little variation between varieties and N levels. This is attributed in

Pare co the use of the heavy-duty land rotavator in the seedhed preparation

for all plots.

---Page Break---

-n-

The highest yield for the 18-soath plant crop vas 164.5 tons GM/scre, recorded for vartety US 67-22-2 (Table 32). This figure ts the average of three N levels. It exceeded varietiee 8 70-701 and PR 980 by approximately 30 tons GW/acre. As show in Table 32, the delaying of harvest from 12 to 16 months gave large increases of tops and trash (74.0 and 94.4 percent)

but only sederate increases of milinb!

(27.8 percent).

Actually, in terme of total GM, the highest yield was gained by com Dining three 6-oonth harvests (Table 33). Here variety US 67-22-2 gave a cumulative yield of 186.2 tons/acre, about 22 tons/acre sore than a single harvest at 18 months. However, this is a deceptive figure owing to the

Telatively high soicture content, lov yields of éry matter, and low ytelds of millable eteme by 6-nonths old cane. Moreover, production costs are appreciably higher for 6-month cane since three harves

are required

rather than one.

(@) Millable Stens: The highest yield of millable cane (topped, gran~

cultura cane) vas produced by variety US 67-22-2. This azounted to 137.1

tons/acre (Table 34), approxiaately 20 tons/acre more than three 6-nonth

harvests combined, Also, the 6-moath old stems, though ?afllable", vere

of vastly lover quality than the 18-sonth old cane.

(e) Dey Matter (OM): Total dry uatter yleld (oven-dry basis) is the

Single most iuportant parameter in the assesement of energy cane performance.

?The "deceptive" green matter trends noted above (Table 33) are completely reversed in the light of dry mattor yields (Table 35), Hence, a single hharvest at 18 months ytelded 20 toas more DM/acre than three 6-month harvests combined (59.5 vs 39.5 dry tons/acre). Among varieties, the Dighest yield was again produced by US 67-22-2, some 65.7 tons DM/acre (table 35).

Anong variable N regimes che highest DM yield was recorded for US 67-22-2 receiving 600 Ibs N/acre year (Table 36). Some 69.1 tons/acte were harvested. This vas only 7.6 tons more than was obtained from 200 Ibs Ns none of the varieties responded appreciably to increasing N supply.

Unlike green aatter, which increas:

by about 32 percent between onthe

12 and 16 (Table 32), dry matter incresses exceeded 50 percent during the

---Page Break---

~~

Same period (Figure 8). Soth IIS 6722-2 and B 70-701 gained DM at a higher rate during the final 6 mouths thas during the first 12 months (Table 37). ?This 18 a critically important tector. Le suggests that an energy planter could maximize his yields chrough harvost delay, vhile minimizing his annual production custs by the sano practice.

(£) Trash: re ts eigniticant thas over 23 tons/acre of the maxtaum

u of trash (Table 38). This fraction

consists of dead leaf snd ?eat-shoath rissues either adhering to the cane

PM yteld was harvested In the

stem or detached ant tying oc

12 ground. Such materials are normally

burned in the field a5 2 proharvest operation for conventional sugarcane. From energy cane they will bz harvested and credteed to the crop's total yield of Lignocetielosie dry matter.

(>

Little qualitative chinge betwee: woathe 12 ané 18. The somewhat higher

Le Solids: Jusce quatiry anslyges (Table 29) tndteate

sugar ylelds/acre at 18 months wers iv vireue of the higher tonnages of nillable stems/acre, AYso evident 1. the Aistinct tafertor?ty of variety B 70-701 as a sugar producer (Iuble 39). with aa average purity value of 64.1, this variety would have ELffteul*y being accepted at the efit as a Sugar source. As enersy cane it would bs milled in any case to lower its

soisture content.

The consistent lack of gun! itativw gains between soathe 22 and 18 was ancieipated by virtue of the contieing growth impure received in the form of water and fertilizer applications. Conventional sugarcane, managed for seximum sugar yield, woud

during the final § sonthe.

been expected on ar individual plant basia, though aot necessarily on a per

ve rocelved neither fereittzer nor irrigation

Stgniftcantiy larger sugar yfelds would have

acre basis.

(h) First Ys Second

are available to date, the yiclé

ids: Although only plant crop data

?reares of second-generation energy cane

lover the corresponding first-generation yields are remarkable (Table 40).

Total green matter vas incroased by £

1 percent, dry aateer by $0.7 per

cent, and detached trash by 86.7 percent (I2-aonth harvest). The percentage

---Page Break---

3B

of dry matter in second-generacion cane was mderatety lover, suggest ing.

?chat these plants vere somethat Jess aatuce at 12 moachs. There were also

Slightly fever stens/acre for

cond=ganeration sane (Table 40).

Mean sugar yields were also hi

for second-generation energy cane

(fable 41). These trends reflect moderately higher rendinent values

yell as higher connages of willebie cane. Im these averaged data the very door performance of variety b Tu~ii) vas offset by the superior yields of Us 67-22-2 and PR 980,

(4) Second- Generation Production Costs

The initial cost analysis for wwe was prepared in January of 1980. Tt vas modified in the sumer of 1980 when thirs-yes: date were obtained and used to compute

first-generation eneray

a final 3-crop average for first-generation production costs. Cost daca for second-generation cane have changad in zeaponse Lo three factors: (a) Cost Anereat reflecting higher sea! voiues of production inputs; (b) cost Sncreases reflecting inflation of the US dollar and (ec) cost decreases reflecting increased productivity of che energy cane operation.

Weally, the production costs for energy cane should be computed against the average product

ty of a complete cropping cycle, te, the average of chree corp years, ae vas done with Ftrst-generation cane. However, only the

Plant crop data are currently available for second-generation energy cane

For this reason the present revision {s preliminary and admittedly a biased

ssment favoring higher than real oroduction costs

Table 42 summarizes production inputs and thely coste for firet-and Second-generation energy cane, cagether with the percent change of these costs during the 24-nonth interval from January of 1980 to January of 1982.

The costs of dectsive ycoduction Inputs (transportation, fertilizer, harvest operations) have increased appreciably during the pact tvo years, largely because of increased energy values and inflation of the US dollar. ?These increases have amounted to roughly 1 percent per month for agricultural operations in Puerte Rico. The largest percentage cost increase is entered for scedbed preparation (Table 42), whece a land rotavation process ot used for first-generation energy cane 1s included. Expenses such as that of exploying a farm manager have wot increased oving to the decline of Puerto Rico's job marker

---Page Break---

~ me

Total cost estimat:

for a 200 acre energy cane operation are in the order of $205,000/year, an increase of 22 percent since 1980. The cost per acre of energy cane simtlarly increased by 22 percent. Tt would cost today over §1,000/acte year to produce a crop of second-generation energy cane. Alternatively the cost per ton of energy cane dropped from $10.12 in 1980 to $9.33 in 1982, a decline of 7.8 percent, With detached trash included the cost vould be $8.81/ton of cane, This results from the

Ancreased yield obtained with second-generation cane (110 tons/acre year) fas opposed to first-generation material (83 tons/acre).

Reckoned simply as a combustible fuel on a dry weight basis at 15 aillion BTUs/oven-dry ton, with 38.6 tons harvested/acre year (excluding,

detached trash) the fucl value of this cane is approximately §1.88/ui11ton aru

Puerto Rico is currently paying over $6.00/miIlion BTUs in the fors of no. 6 fuel of} (July, 1982). Obviously, one cannot continue ind: to offset inflation and rising fuel costs with increased productivity. How ever, the pricing of a biomass fuel belov §2.00/atllion BTUs indicates that energy cane 4s the most econonically viable substitute for ofl in PR today.

Anitely

Subsequent cost a: wre expected to indicate lover production costs for second-generation cane, This projection is based on the following:

(a) Proportionately lover costs for gran cultura biomass owing to the

delay (spreading) of harvest and delivery expenses; (b) proportionately

higher DM yields from gran cultura cane: (c) higher

From the Firat and second ratoon crop

yeolute DM yields

and (4), lovering W supply fros

400 to 300 or 200 Ibs/acre year. In addition, the delivery charges reckoned

in the prior analyses might be excessively high ($3.00/green ton/3 miles

of haul, or approxinately $8.60/dry ton). Actual delivery charges from

Hatillo to Central Coloso, a highvay distance of 25 miles, vere §5.50/

?green ton in March of 1982.

(4) Energy Inputs And Recovery: Second generation production inputs

vith attendant energy expenditures are sumurized in Table 43, Fully half of the energy inputs derive from comercial fertilizers (14.76 atllion

BrVs/acte year). Som 90 percent of the fertilizer energy input is attribut-

able toe

fuel (9.85 afllton BTUs/acre year). Fuel expenditur

sntal N alone.

A second major energy expenditure ts for diesel

increased by about

---Page Break---

5 percent over first-generation energy cane oving to the use of a heavy duty land rotavator 1a seedbed preparation. Because mich of the yield increases obtained from second-generation cane derive from taproved seed-bed preparation, the Land rotavation input is probably justified in terme of increased energy yield. For exauple, as indicated in Table 44, the total

jed chat of

the first generation by over 58 percent (453 ve 286 million BTUs/acre).

BYU recovery/acre year for second generation energy cane exct

(k) Net Energy Bal

US 67-22-2, and B 70-701 are summarized in Table 45. Variety 8 70-701

indicates the most favorable energy output/input ratio at 16.5, vhile PR 980

is least favorable at 13.7. These ratios are based on a mean nitrogen ta-

Put of 400 ibs elemental N per acre year. The critically decisive importance

of N supply to the crop's net energy balance 42 shown in Table 46 vhere

?energy output/input ratios reflect the 200, 400, and 600 pounds per acre of

elesental N actually supplied in this study. Hence, a very superior ratio

As obtained with 200 Ibs N/acce (19.7) as opposed to 600 Ibs N/acte (12.5).

nees: The net energy balances for varieties PR 980,

Variety B 70-701, though a poor sugar producer, 48 the superior

variety examined to date as a boiler fuel. In terms of total dry botler fuel, bofler fuel as a percentage of total biomass yield, total higher

heating values of boiler fuel, and heating value of displaced fuel of1,

B 70-701 exceeded appreciably both PR 980 and US 67-222. The actual fuel could be conventional bagasse (49-512 soisture), partially-dried bagasse, or 4 processed fuel product derived from bagasse (for example, AGRI-FUEL? at 6% moisture).

(Q) Molasses And Fiber

(combustible DM) and fermentable solids produced per acre by second-genera: tion energy cane were quite considerable (Table 47). Assuming 9.5 Ibs fermentable solids/gallon of high-test molasses (HTH), over 2,000 gallons MM were being produced by varieties PR 980 and US 67-22-2, and over 1200 gallons/acte by variety 8 70-701. At the current price of $0.76/gallon WMA, the annual molasses value exceeded $1800/acre for US 6722-2, $1600/ acre for PR 980, and $900/acre for B 70-701 (Table 47).

By sonth 12 the quantities of fiber

---Page Break---

The value of fiber vas reckoned at $0.04/oven-dry pound. This figure 4s pegged to the current price of no. 6 fuel ofl ($33/barrel). At this J price the per acre value of fiber at 12 months averaged over $1,900 for Pk 980, over $2,000 for US 67-222, and $2,200 for B 70-701. Combined valu for TY and fiber were dn the order of $3,863 for US 67-22-2, $3,606 for FS 980, and $3,160 for 8 70-701 (Table 47)

(w) Energy Gane Benefits For PR: Puerto Rico urgently needs a local molasses supply for her rue industry and a domestic fuel substitute for

taported ofl (50, 51, 52, 53). High-test molasses is the preferred fermanta-ton substrate of Island rum producers. The combustible fibrous residues

can be burned direct or processed into higher-quality fuels and feedstock

?The prospects appear good that sugarcane management for energy, te, for HTM end fiber, 1s a potentially profitable enterprise for Puerto Rican cane

planters.

Given 70,000 acres for future cane industry, 2/ehe production of

energy cane as herein desertbed vould eliminate entirely the taportation

of molasses and thes

cane fuels frow 70,000 acres vould eliminate a significant fraction of the

Additional benefits include the reestablishsent of

vould be some molasses left over for export. Energy

Island's of] import:

cane palating as a profitable enterprise in Puerto Rico, 2/tnereased rura?

employment, and, when coupled with other tropical grasses, an extension of

annual mil) operarion from 2.5 months to 11 months.

1/ The Puerto Rico Government has allotted 70,000 acres for sugar planting

in tts "Modern Agricultural Flan For Puerto Rico" (39).

2/ The PR Sugar Corporation anticipates an $85,000,000 Loss during 1982. J

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FLELD-SCALE STUDIES

Mield-scale experisents follow logically from greenhouse and field~

plot studies. Their y 14

(a) To simulate, under plant

ton-level conditions, che production inputs that had appeared most proaising

under greenhouse and field-plot conditions, and (b), to evaluate mechaniza~

tion factors thet becom: operational under plantation-level conditions.

The project's Fieid-phose studios vere initiated at the AES-UPR Lajas Substation. During the fino) two 5

5 these were extended to a private Farm near Hatillo on the humid north coast. Sone 30 acres vere made avail~ able there for energy cane research by Mr. Jost B. De Castro, the farm's oumer. During the project's final aix gonths the field vork also extended to government-leased Lands near Cabo Rojo. Approximately 50 acres vere made available for ceed-expansion of che varkety US 67-22-2, together with

row spacing and seedbed proparaticn stuaies with the sane var:

As indicated above, the project's field work involved increased Sizing of production inputs previously identified under smaller-scale but prectsely-controlled conditions, and the introduction of farm machinery that had not been used in the preceeding trials. Experimental production inputs extended to the field or fara size included candidate varieties, seedbed preparation, row spacing, seeding rates, fertilizer levels and incremental application, irrigation sethods and levels of water applica tion, and frequency of harvest

?The introduction of fara machinery {s necessary for the translation

of these inputs from

labor-intensive regive (under field-plot conditions)

to a labor-extensive regine which {s effective both agronomically and

economically. For the aost part the use of iaplesents and machines offers

4 work performance that Ls qualitatively superior to hand labor, in addt-

thon to a vastly greater scale of magnitude. For example, a correctly-

adjusted and operated grain drill can seed a Sordan-type species with greater

Precision than a skilled laborer. However, in one dectstvely eritical

area, machines have never quite equalled the hand laborer in terns of vork

---Page Break---

precision and quality. This ts in the harvest of the cane plant. Even where mechanization has succeeded, mich hax been lost in the milling qualities of harvested cane (11). In Puerto Rico, where mechanization efforts were largely unsuccessful, the lack of suitable cane harvest

?machinery, wore then any other factor, has led to the deaise of sugar

planting as an economte enterprise (34).

Alternatively, the use of snchinery has nade possible 2 vast range of production technologies that were rever posetble, let alone economle, with hhand labor. This is particularly true of the harvest and post-harvest

devatering of fibrous tropical grasses (nupier grass, Sordan, ete.). Such cannot be shipped to a cugar ill for devatering, but they can be

speci

solar dried directly tn the fleld with grea: effece, This requires the use of machinery for "conditioning" the grasses, for raking them, for turning over the drying windrows, and for compacting the dried biomass for econonie handling, transportation, and storage. None of these steps can be staulated with hand labor at any cost

Field-scale trials vere perforsed in ftel4s canging from 2 to 25 acres

in size. While still smali by plantation standards 2/, chese offered

realistic conditions for the measurement of fuel consuaption, horsepover

requirements, and ability to accommocate high tonnages of standing biomass.

To a large extent the effect sven

© of forage-naking ?mplenents can be

?sessed on plots as smail

2 acres} virtually all of the gr:

tioning, solar-drying, and baling trials in this project were performed on

unreplicated plots of 3 or 6 acres tn size.

Less accurately measured 1s the lony-tere durability of machinery

tested in this miner. Hence, it was necessary to report data ond to

Grau conclusions on machinery performance based on as Little as 10 hours

of operating time. A future energy-planting operation could require hundreds of hours service from the same eachine.

?/ Future energy plantations for tropica) grasses are expected to range in Size from a minimum of 7,000 acres for energy care to 2,500 acres for napier grass (30).

---Page Break---

Mtematively, the relatively brief trials on a University fara represent a more severe test of machinery than one would expect with

equal time on a full-size energy plantation. In a consercial, industrial scale operation, each mechanized t.

k would be assigned to equipsent operators having special training and accumulated expertise with a specific unit. For example, on @ aapier grass plantation, at least one driver would operate a rotary scythe full tine, another man would operate a baler full time, vitle others would concentrate on equally specialized tase. Such division of responsibility produces equipment operators who become highly skilled specialists in the use and care of their specific machine

This As not the case on a University farm vhere a given driver 48 con einually

etgned to different machines in different projects.

Equally iaportant is the

to their charges and the farm operation as a vhole. The performance of a

eitude of equipment operators with respect.

self-employed farmer working from sunrise until after sunset to complete tasks that he understands must be completed can differ considerably from that of a University hand working 7.5 hours per day in a S-day week. With ut question, che effectiveness and performance of biomass product ton sachinery vill depend heavily on the teaining, skill, and personal attitude of the machinery operator. In the present project the quality of our equipment operating and maintenance personnel was about average for a land= Brant institution. It was considerably higher than average for the Puerto

Rican agricultural sector.

2, Scope Of Field-scale Studies

?An important goal of this project was to establish methods for the mechanized harvest and postharvest handling of tropical grasses propagated biomass energy crops. The scope of this task covered two major areas: (@) Production and harvest of thin-stemmed, fibrous grasses (short-and jectes), and (b), production and harvest of thick~

sntermediate-rotat ion

stemmed grasses (long-rotation species). The thin species, such as Sordan Tork and napier grass, vere to be solar-dried in the field as a means of

noisture removal. Thick-stenmed gr:

canes of commerce and the ?energy canes" developed {9 the course of this

are characterized both by the sugar

Project. Both mst be hauled to a centralized mill for devatering.

---Page Break---

?The scone of fieto-sinle studies uns further detines by the uses to

which the respective si satexories axe cirected, and the physteal mase

of material with which the catenuriee confront harvest machinery. Hence,

the Lighter, thin-stemn: ?e to be dried in the field,

baled, ang stored for ?oe Lignecellutosic fuels/feedstocks.

Fieroua crasecs

?They would cerve as substitutes for energy cane bagasse during 3 or 4

rainy soaths when eaergy cre cannot be harvested tn Puerto Rico (30, 31).

Conditions are favorable for thelr Survest, solar-rving, and storage from

roughly aid-deceaber to miuvAsgus? f% Puerto Rico's south coast. Alter

natively, energy cane would te >

reosted during the same 7 £0 9 months and

conveved étrectly co 4 centtaiived devetsrsep plant. Integration of the

grasses ond cane operations is depisred uchenactea!ly tn Figure 9.

?The erttice! hervesting tasie can se gerucod insu three categories

based on the denstty, o standing mass, of plant mterials confronting the

warvest machinery, and the perceataye of

Sher containe? by these materials

at che thse of harveot (34). Tae fret group deals with standing green

e/acre. Sordan TOA, a shore

rotation crop, is cnaractevistic of species having yields of this magnitude.

?The project's approach to such wateriats was te harvest them exclusively as

solar-dried forages. Within wie cazesory the auchincry tasks vary with,

the state of the erop's micurity, e, with olases having From 10 t0 12%,

fiber at six weeks to 2 to 35% taker at A second category deals

nsfacra. The

atoms in the order of 1 3 25 shaxt +

With standing Beomaue fu the orter 0 peeen

representative specter

se te moler Giass, an dancemedtate-rotation exop

whone dry matcer conten {+ nav imises between four and ex monthe after

planting. Again the erep's atate 0

or failure of harvests

mourlty is cricteal to the success

ninery. sarveeted at two months of age (8-12

moisture) napier grass actually offers ao neve difficulty than convent onal

catele forages. Ato:

wenths, offuctag 35% dry aatter and up to 50

green cons/acre of standing biowass, che harvesting task approaches the

upper capability Linits of extrting fovage-maicing equipment (54). Our plan,

rials as soler-dried "forages" also.

vas to handle such ne

Biomass crops offering nave than 50 green tona/acre comprise a third

category in terns of harvesting tacks. The characteristic species here are

the hybrid sugarcunes cf commerce and the eneree

soo having still greater

---Page Break---

ae

tonnage. There is no possibility of dealing with these plants as field-

dried forage crops. Not only {4 there an excessive mass of material con-

fronting the harvest michinery, but aio the thiekened cane stews do not lend themselves to solar drying, unless firut prepared by soe process of

milling and Juice expression, Project plans were based on @ combinat ton

of solar drying (for leaves and "trash" removed in the field) and alll

dovatering for the cane stalks. Bagasse iesuing from the sugar afll alght

also be solar dried and baled, or at least partially dried by stacking in

the open air.

3. Inset

Machinery Triais,

The project's earliest fteld-scale trials were begun with forage-aaking

achinery imported early in year 2. specific units included a Model 8700

Ford tractor (the only Category TI tractor then available in the UPR

College of Agriculture), an M-C rotary-scythe conditioner (Mathews Company

Model 9-E) having 4 9-foot mowing evath, a heavy-duty, side-delivery PTO

forage rake (New Holland Model 57), 2 Now Holland Model 851 Round Baler, and

f New Holland Model 393 "tub" forage grinder. The forage rake vas soon

supplemented by @ Farahand wheel rake and by both fronts

?mounted loaders capable of handling round bales wesghing up to 1500 pounds/bale

snd rear-tractor

(a) Rotary-Seythe Conditioner: Prelisinary tests vere made with the

rotary scythe using wild Johnson grass (Sorghum halepense) a8 a test material.

?This Implement does not cut of wow grasses as does a conventional sick

bar mower, but rather breaks off and ?conditions? the gré

?steel plates rotating at high speed with extremely powerful force /. The

conditioned saterial is deposited in windrows of adjustable width direct ly

behind the mover. The rotary scythe ie a thoroughly rugged machine (55)

Relatively few factors can inhibit its performance short of an inadequate

Power supply (tractors having less than about 90 hp), or the encountering of

Plant materials of sufficient mass to stop the blades or the tractor engine.

2/ An Alustration of his machine appears in an earlier report (25).

---Page Break---

No difficulty of any kind vas encountered in the fist trial with Johnson grass. This material amounted to roughly 10 to 12 green tons/acre. The rotary scythe vas moved to a second field vhere Johnson grass had grow wild for several years. The implement performed quite adequately, with the exception of "heavy" areas where accumating dead Johnéon grass had formed mats, approximately two to three feet thick. In such ar

vended to push ahead of the implesent rather than p

rotary scythe passed over material it was effectively conditioned vhether

the mats sometines

8 under ie. Once the

matted or not. This vas due to a slight curvature of the cutting blades which creates @ vacuum effect such that flattened biomass {8 dram up into

the rotating blades as they pass overhead,

This 4s a decisively tmportant feature to have in herbaceous biomass harvest systens which by nature will have a high proportion of prostrate (recumbent) materials. The tractor performed ?comfortably? in second gear with engine speed at 1800 rpm. There vere no apparent stresses on the ?Tractor's PTO and hydraulic systeus nor on the iaplenent's gear box and drive shaft. The uauel safety precautions for forage-making equipsent need to be observed. Special precaution must be taken againt standing or valking behind the rotary seythe when in operation. The rotating blades can strike

Loose stones, clods of soll, and other loose objects, throwing them backward

with considerable force.

(b) Trials with Sordan TOA: Sordan 7OA was the first biomass condidace

Scheduled for field-scale harvesting trials. Four blocks of approximately six acres each were planted at the close of the third quarter. Seeding rate was 60 pounds/acre, dritled in 9~inch row centers in two directions on the field. The planting of these Fields uns delayed approximately two months ?owing to atypically heavy rainfall in Decesber-Januery, 1978-79. Harvests for the respective blocks of Sordan JOA were perforsed at 6, 10, and 14 weeks after seeding.

Performance ratings for the rotary scythe are presented in Table 48.

The b-week old material presented no probleme of any kind for this michine.

The plants were coupletely upright and succulent. Initial concern that the

---Page Break---

Yelatively long stems (averaging 5 1/2 co 6 feet) 2/ might cause then to Fall backward over the ro.ary seytae, rather than forvard to pass under the rotating blades us intended, were unfounded, A11 of the upright sate-rial fe1l forvard without exception. Nor was there any tendency to form balls or mats in front of the mower, even when operating at higher tractor

gear speeds.

A mich worse set of 5

st conditions wes experienced for the 10-and Aieweek old crops, but the rotary scythe nonetheless gave a very satisfactory performance (Table 48). Extremely heavy ond unseasonal rainfall wss received intermittantly from week 8 through week 13. This caused moderate to severe Lodping in both the 10-week and 14-week od plants. in both instances mich

?of che Sorda: 708 was flattened to @ hetghe of 8 co 12 inches and was severely sated, thet 4s, the steus had crossed and interlaced in all directions. The

wEvested at 14 weeks had reuained in this condition up to five weeks.

During this interval, the eatted Sordan JOA was further interlaced with

hherbacoous weeds (beth vines and upright grasses) plus a regrowth of secondary

Sordan 70A plants stimalted by the heavy rainfall. Together with the at

normally soft seedbed, these conditions offered the worst possible circum

Stances that one can reasonably expect in harvesting short-rotation crops

However, the rotary scythe performed quite adequately. At no time was it

FY to stop and clear the machine 2/of patied grasses, and only

?occasionally vas ir necessry to shift into a lower operating gear.

A period of interaittant rainfall following the lO-week harvest caused

considerable difficulty An drying the conditioned btomas

followed the 14-week harv

baling within three days,

ood weather

wt. This material was solar-deied and ready for

1/ Wien mowing conventional cattle forages (as its manufacturer intended)

the rotary scythe will rarely encounter plant materials more than about

three feet high. Wence, the leading edge of the inplenent which strikes

the upright stems will Cause them to fall forward without problems. This

io not necessarily true of tropical grasses which are much taller and thicker-
stemmed, and vhich offer greater resistance to the rotary scythe.

2/ Such stops would have been an alsost continuous feature if we had attesped

To harvest the Ié-weck old material vith a sickle-bar aowr.

---Page Break---

= ah =

Baling operations for the solar-dried Johnson grass and Sordan TOA wore performed without encountcring sajor problems, Minor difficulties incident to hydraulic connections betueen the Baler (a New Holland product) and the project's Ford tractor were easily corrected, Because no one on the project staff vos directly familiar with the baler's operation, it was necessary to practice its handling on solar-dried veeds and Johnson grass.

For example, the correct amount of twine needed for a 1500 pound bale,

about 150 feet, wa

determined by criat and error. Such factors as the bater's best operating speed, the correct size and compaction of the bale, and the anount of twine needed to secure the bale for subsequent loading.

and transport operations are largely a matter of Judgement by the mchinery ?operator conironted with a specific set of condition:

(e) Napier Grass; Three Months

equipment is posed by napier grass, an intermediate-rotation species. As a cattle forage it 16 harvested at S-to 7-veek interval, vhen it 4s of relatively small size and succulent. At 3 months it is sonevhat more mature and fibrous; at 6 months {t is highly fibrous and "woody" with DM yield at a maximum.

A far greater challenge to harvest

Napier grass was submitted to mechanized harvest and forage-making ?operations forthe first time during year 3. Approximately four acres of Seonths old napier grass (var. Merker) vere moved with the MHC rotary Scythe conditioner. This material vas solar-dried and baled with the New Holland Model 851 round baler. At 3 months of age, the total biomass con fronting harvest machinery was only slightly greater than that of equally~ aged Sordan and there were fever stoms/ecre. The primary difference lay ia ass. These offer a sonevhat different and possibly mre difficult task for the stem-shattering

or "conditioning" properties of the rotary scythe. The solar-drying tasks

are definitely nore difficult oving to the greater thickness of napier gra

the mich thicker and more succulent stems of napier

sas. Raking and baling operations are algo complicated to some extent by

the relative coarseness of the dried material.

All of the harvest and post-harvest operations vere performed success- 5

fally, but they required somewhat more drying time and machinery work ¢ime

?than short-retation species such as Sordan and Johnton grass. Moving heights

---Page Break---

were varied from 2 to B inches. No crown injury was evident at the lower Stubble height, but 8-inch stubble posed some difficulty fer the forage rake ?An additional day was required for solar drying. Occasional stem billets could stilt be found that were pliable (containing 25 to 30 percent moisture) rather than brittle (containing 14 to 16 percent moisture). Round bales

were produced without difficulty. These were somewhat rougher in appearance

?than Sordan bales oving to protruding stem seguents.

(@) Napier Grass; Six Months: The ulcimate test of the rotary scythe-conditioner 1s encountered with 6-wonths old napter grass. Such material ts fm an advanced state of maturity with ary matter content approaching 35 Percent. Stems appear more voody than herbaceous and are succulent only {n the upper canopy area. Standing biomass {s in the order of 30 to 40 cons/ acre. Stands of grasses having greater mass than this would be approached with a sugarcane harvester rather than forage-naking equippent.

The first trials of the H-C rotary scythe on 6-nonths old napier grass vere performed in mid-March of 1980. The varieties Common Merker and PI_7350 were harvested at two stubble heights and two tractor speeds (Table 49).

Tre maximum engine speed vas approximately 1900 rpe for all tests.

Because the M-C rotary scythe vas designed to harvest forage crops that

are morphologically different from napier grass and harvested at less advanc Stages of maturity, several discrete kinds of problems were anticipated ?or this seplenent when operating in mature napier grass. Any one of these could eliminate the rotary scythe as a candidate harvester if it could uot be corrected by adjusting the implement, by modifying the implenent's desisn. or by modifying {ts mode of operction by options available to the tractor driver. Anticipated problem areas included the following:

(A) Bucessive height of napier grass, in the order of 9 to 12 feet,

428 opposed to a maximum of 2 to 4 feet for conventional forage crop

Stace the "cut" grat

js cust first fall forward and then be drawn back-

vard beneath the implement to be conditioned, the taller napier gr:

could not have been harvested had ic fallen backward on to the upper

surface of the rotary scythe. In the actual teste there was no tendency

for any material to drop backward on the implement!

surface. The

---Page Break---

Leading edge of the rotary scythe strikes the napler grass stem

with sufficient force to push them forward, even when operating

at the lowest cutting height. Moreover, the elongated stems were

forced forward sufficiently far into the standing grass to enable

chem to be draun back with ease beneath the rotary scythe. There

as no appreciable realignment of che stens, that ie, no turning

at right angles to the path of the implenent, which could lead to

bunching of the stens and clogging of the rotary acythe blades.

(AL) Ap Excessive mass of the napier grass, amounting to approx

imately 30 to 40 standing green tons/acre, as opposed to about 10

to 12 green tons je crop. Tt vas thought

that the additional mass confronting the implement might cause

its blades to becom clogged with bunched material; alternatively,

such material could effect a continual breaking of shear pins.

The latter are incorporated into the implement

intend:

damage. During the present teste there vas no clogging or

breaking of shear pin

ere for a typical fort

design and are

to shear off when overloaded to prevent more serious

The implonant's performance was generally rags

satisfactory when the tractor was operated in second gear, There

was a tendency for the rotary seythe to pase over or only partially

condition « small percentage of the stems. This was corrected by

shifting to low gear and increasing the tractors engine speed.

While outwardly slowing the harvest process, ie, the visible

the feld, the decisive

factor is the quantity of biomass being harvested per unit of

movenent of harvest machinery acrot

time. In 6-sonths old napier grai

the rotary scythe was con-

Aitioning biomass at full capacity when operated in the tractor's

low gear.

(441) Inadequate conditioning of the relatively woody napier

frase stems. Under normal circumstances the rotary scythe

?conditions? forage crops that are relatively imature, succulent,

and easily disintegrated. The forage plant 19 shattered by rep

ed

---Page Break---

wae

striking of the blades at distances of 4 to 6 inches along the

stem. This greatly enhances the solar drying of such materials

while

?ing the windroving and baling operations. Stems of 6=

ponths old napter grass vere quite effectively conditioned by

he rotary scythe, Solar drying proceeded normally. Approx

Amately one additional day was needed to attain 15% moisture

(four days for napter gra:

8 opposed to throe days for Sordan).

Increased drying time vas aainly a function of the greater stem

ehicknes

and total mass of material per acre for napier grass.

(4410) Inadequate preparation for raking and baling operations.

Mature napier grass plants are 3 to 4 meters long vith stems up

to 3 centimeters in dianeter. In order ¢o manage such mater?al

a8 solar-dried forages, it 1s necessary not only to shatter the

stems but also to reduce thes to shortened, pliable

gnents chat

can be raked into windrovs and fed successfully into balers for compaction (rectangular or cube bales) or organization into round

bales. In the pr

effectively.

ent trials these requirements were set very

In practice, the rotary scythe completely disintegrated

those stems offering the greatest resistance to the rotating

Dlades. In circumstances where shattering was incomplete

Godged plants, excessively heavy stands), the stens vere rendered

Flexible by partial shattering plus complete severing at fately

frequent intervals. Only rarely could one find a stem segnent

?exceeding 40 to 45 centimeters in length. The longer plant

Segments that remained intact?both tops and stess?ordinarly

bore severe bruises from repeated striking by the rotary scythe

blades. These were sufficiently pliable to pass through the subsequent raking and baling operations without difficulty.

(e) Raking And Baling; 6-Month Napier 6 The very excellent per-

formance by the rotary scythe-conditioner enabled us to solar-dry, rake,

land bale mature napier gr

lunmanageable with existing forage-naking equipment. Problems vhich did

8 which otherwise would have been completely

---Page Break---

arise related aainly to the excessive mse of material to be eanaged per

unit of working area. To some extent these problems were alleviated by

operating the tractor in low gear with increased engine speed.

?The rake initially used in these trials is a heavy-duty", PTO-driven

?node! but one designed for conventional forage crops offering 2 maximum of

about 5 dry tons/acre. At noraal raking speed (in second gear) the im -

plesent tended to slip over a significant fraction of biomass being raked

For the first time, This was corrected to sone degree by slowing the

Hing engine speed, by partially raising the

rake vhen laboring in heavy material, and by reraking the skipped areas. 7

After the windrove had been forned there vere no further difficulties in

raking, Se, vhen turning the windrove over a second or third time.

tractor to low gear and incr:

[A more serious problem was the frequent breaking of the rake's tines

?as they snagged against the napier grass croms. This vas especially true

fof high stubble (8 to 10 inches) but occurred in low stubble (1 to 2 inches) as vell. The crow of a mature napier gr:

plant offers considerable resistance, more Like the stuap of @ sapling tree than a conventional forage

Although tines are easily replaced, the rate of breakage on napier

grass stubble was prohibitive. Moreover, @ significant quantity of biomass

lying flattened between the stubble remained unraked.

Te was proposed, correctly, that the problems of tine breakage and un- | raked material could be eliminated by use of a different type of implement,

?one commonly described as a "heel" rake. This rake is not driven by a power take-off but rather operates through contact of its tines with the

ground surface. The tines are mounted on a series of independent vheele 4

which offer greater flexibility for penetration of a heavily-stubbled sur

face. A Farshand model rake was subsequently purchased for trials on solar-

dried napier gra

Baling trials on the 6-aonth old napier grass with a New Holland round]

baler proceeded normally. Although the napier grass stems were far heavier

than Sordan or conventional forage

up and weakened by the rotary scythe to be organized into round bales with-

out difficulty. As was the case vith the rotary scythe and rake, it vas j

necessary to operate the baler in low gear owing to the very large mass of

windrowed dry matter.

aes, they vere sufficiently broken

---Page Break---

(£) Napier Grass Yields; 6 Months: A series of 2-to G-acre harvests vere performed with napicr grass stands aged 4 to 6 months during the project's fourth and Fifth years. An dnteial triat with 6-months old variety "Merker" evaluated yields and crow injury that could be traced

to the rotary-seythe conditioner (27). Two moving heights were also examined, "high stubble? (8 to 10 inches) and "low stubble" (1 to 2 inches)

Overall dry matter yields averaged 9.3 tons/acre, with high stubbte and low stubble plots averaging 8.4 and 10.2 cons/acre, respectively

(able 50). A significant asount of conditioned biomass Lay flatte detween the stubble and could not be recovered vith the available forage rake. This implement, Like aost standard forage rakes, operates

Single uit driven from the tractor?s PTO eystem. When any portion of the rake is 1ffted by a plant crow, much of the entire rake is lifted and Passes over a layer of biomass untouched by the iaplenent's tines. Subsequent trials with the project's Farshand wheel rake (which gives @ clean Faking of all stems except those missed by the rotary scythe) indicated that from 15 co 252 of the solar-dried material had been left unvindrowed by the standard PTO-driven rab

Upon visual dnspection some of the stubble appeared broken and crushed by the tractor and rotary scythe. However, the same croms generally Produced an abundance of new shoots within a few days after moving. It is believed that 2 sufficient aumber of buds survive these operations to re-establish a normal plant stand even when sone of the buds are destroyed.

It {8 also possible that some Level of crom injury {s stimulatory to shoot production.

Midway through the third year of reharvesting at 6-month intervals, Fegrowth of Common Merker becaue pecceptively weaker and the nusber of

new shoots diminished progressively. ovever, the hybrid variety PI 7350 continued to respond with vigor and still does 0 today. From these observa-tionsit ts fele chat Comon Merker vill require replanting at about 3-year intervals if subjected toa continuous 6-aonth harvest regime, Sin{larly,

PL 7350 stands appear to be viable for at least 4 years under the same harvest regine.

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(e) Fue! Consumption And Estimated Horsepower: Fuel consuaption was

als» pea

weed for the napier grass harvests described above. These meosurunents refer to the total diesel fuel consused by 2 sodel 8700 Ford tractor (a category IIT, 120 hp unit), operating a M-C eodel 9-F rotary seyehe (9 foot sowing swath), both {dling and in actual movement on the

esnured test plot areay. They do not include aoveneat of the tractor and {aplement to and froa the (elds theaselves, Retinates of the horse-power utilized by the tractor were calculated from the fuel consumption figures in accordance with published Nebraska Tractor Test Data for the

model 8700 Ford tractor (Table 51).

Die

11 fuel consusption was somewhat lover than expected, ranging from 2.38 to 2.95 gallons/howr, 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 diese! fuel/hour). It should be A noted that the standing green blomiss confronting the rotary acythe (about 40 tons/acre) exceeded the sugarcane tonnages confronting cane harvesters 1n Puerto Rico today (approximately 27 tons/acre as an Island-wide average) Hence, the lover fuel consuaption for napier grass harvest was not func- J tion of lover biomass tonnage.

Lowstubble sowing utilized moderately more fuel chan high-stubble ?moving (Tables 51 and 52), This relates to the greater resistance offered by napter grass stems cose to the soil surface, and to the greater tonnage of biomass to be conditioned with low-stubble harvesting. Alter

It einintzes the

tendency of high moving to leave long, ragged stubbles which in turn com

plicate raking and baling operations, in addition to le

natively, lov-stubble moving does a mich cleaner Job

ving unharvested a

significant fraction of the standing green napter grass.

Horsepower usage by the 8700 Ford tractor ranged from 35.7 hp at high-stubble mowing to 41.4 hp at low-stubble mowing (Table 51). Perforsance data provided by the Ford Company indicate that this tractor can supply

about 95 gross hp at the power tal

?off with an operating engine revolu-

tion range of 1500 to 1800 rpm (56). Hence, leas than half of the cractor's work potential was being utilized in conditioning the 6-nonths old napier grass. On the other hand, it {s estimated that the rotary scythe itself, although an extrenely rugged teplesent, can utilize a maximus tnput of

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only about 60 hp without sustaining major damage (57). Excepttonally heavy stands of biomass, such as mature sugarcane or 12-months old aapier grassy could 1ikely place the rotary scythe work load in the 60 hp ange. There vould be no purpose in attempting this eince there are cane hacvescers

available to deal vith such materials.

4. Rotary Seythe Modif ications

Mechanized harvest studies for short-and intermediate-rotation grasses

have cence:

sd on three machinery units: (a) A rotary scythe-conditioner, Sonufactured by the Mathews Company; (b), a New Holland Company Round Baler; and (?), @ Farahand Cospany whee! rake. The rotary scyth

Of decisive Smportance in the handling of large tropical grasses as sola ried energy crops. Successful izplenentation of this unit would virtually

assure an adequate performance of successive machines needed to deliver 2

?conditioner 13

Solar-dried feedstock to the biomass processing or utilization ceater.

Rotary scythe trials on Sordan 70A and Johnson Grass delt vith a
maximum mass of about 20 tons/acre of standing green material. Yo signif-

icant probleas vere encountered and the machine completed the work it vas

designed to perfora, with napier grass, representing 40 to 45 standing
green tons/acre, the interior edge of the rotary scythe tended to 1i¢t from

the ground when p:

ing over exceptionally heavy or lodged clumps of grass.

Te was felt that this problea could be overcome by increasing the isplenent 's

weight. A second and sore serious problea lay in its tendency to drag sec~

tions of uncut grass along its interior edge. This occurred in lodged and heavily matted materials that vere intervoven ia a contiguous mass. Such materials extended invard into uncut grass up to several yards beyond the cutting svach edge. In upright stands or where only partial lodging had occurred the rotary scythe easily sectioned off the biomass tn normal suath segments

?The rotary scythe's problem in sectioning the heavy and astted aapier srass vas solved by fitting its interior cutting edge vith a parting knife takea from a Klass Model 1400 sugarcane harvester. The partiag knife constats of @ single 12-inch blade which rotates counter-clockwise against a heavy wetal plate and shears off inpeding steas in a scissors-like action.

---Page Break---

It is normally driven by a hydraulic sotor with a force of about 5 horse~ power. Fortunately, the heavy-duty construction of the rotary scythe offered - 4 0,25 inch metal plate to which the parting knife frame and supports could

be welded directly.

It wae necessary to adapt the parting knife's hydraulic Lines to the smaller dual remote outlets of the project's tractor. The lines thenselves extend directly backward from the tractor, over the top of the rotary scythe's Grive shaft and gear box, and then across the implenent's backside where

they remain free of entanglement with the conditioning grass stems. As

described in earlier reports, the tall grasses being conditioned with this

unit invariably drop forvard of tts 1

Hing edge and never backward over the

machine itself. Otherwise, neither the rotary scythe nor its affixed parting knite could perform their tasks in heavy tropical gr

In the tests made with this syst

cutting force of the parting knife was developed, te, as designed for opera~

ite performance in 6-months old

?has been very good. It clearly sections through dense matter

te does not appear that the full

tion on @ sugarcane harvester. Nonethel

rapier ge

and lodged aaterials vhere formerly a rather ragged division vas mai

coupled with uprooted and dragged croms of napier grass. Moreover, the rotary scythe cea

14 elevating above the ground in dense materials once the parting knife became operational. No supplemental weighting of the implement vas necesary. The parting knife with ace:

fortes weighs about 150 pounds so this in deself may contribute materially to the performance of the rotary scythe.

ale Drying And Storage

Naper grass harvest, drying, compacting (baling), and storage studies continued through project yeara 4 and 5. Mature atands of napier grass, | varieties Common Merker and PI 7350, were ?conditioned? in the field with the MC rotary scythe, solar-dried over a period of 3 to 6 days, baled with a New Holland "round" baler, and transferred to storage in a roofed, open-sided shed, Several trials have also been conducted with bales stored

to the open and exposed to rain.

---Page Break---

Seven post-harvest storage experiments were established before che close of the project. Completed experinents, utilizing 10 to 30 stored bales of about 1200 pounds cach, include the following: (a) Moteture-loss neasuremente from bales containing less than 20% eoisture at tine of storage

(two trfats): (b) moisture-loss seasurements from partially~

ry bales con-
taining about 35% woisture at time of storage; (e) soisture loss and Cemperature seasurenents in bales stored at less than 20% moisture;

(4) moisture content measurements in dry bales (less than 202 moisture) vtored out-of-doors (open-air storage); and (e), moisture determinations io partially-dry bales (approximately 35-40% moisture) in open-air storage.

Actual wessurenents were mide with # aoisture-sensitive probe and recorder ("Hay Moisture Detector", Empire Corp. no. 18252). This unit ts equipped with an acc

sory extension rod enabling the probe to be inserted to any depth desired in the round bales. It offers direct readings in per-

cent moisture with a precision of about 4 2 percent. Because of its ease of

operation a large number of readings can be taken quickly and a mean value computed for the entire bale.

(a) Motsture Changes In Stored Dry Bales: The initial two aoisture trials were perforned with napier grass varieties Merker and PI 7350. Solar-dried material vas placed in storage mediately after baling and

otsture contents were detersined at 48-hour intervals for the subsequent

2% days, Two trends were immediately evident: (a) Moisture content at first

incre:

4 (up to day 4) and then gradually declined from day 6 onward, and

(©), @ varietal factor was aoderately but persistently affecting moisture content throughout the 24-day period (Table 53).

The temporary increase in bale moisture content was at first chought to be an artifact but has recurred in all subsequent moisture-seasurenent series. Ite initiation apparently relates to the blomiss coepaction pro~ ce0e tself, Possibly tt is a function of mierobial action within the Revly-compacted bale. Neither the magnitude of moisture increase (2 to 32) or its duration (about 10 days) appear to be significant factors in the

future storage of baled napier grass as fuel or Iignocellulose feedstocks.

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Varietal differences in moisture contents (Figure 10) are explained fon anatomical Lines. Variety PI 7350 1s a chick-atemmed hybrid and less | readily shattered (conditioned) by che rotary scythe action. Ite drying time required for optinal baling is presumbly a day or two loager than for variety Merker. Given sufficient drying time in post-harvest storage, it is believed that all varieties would lose moisture to a common level dictated by ambient moisture conditions.

?An interesting feature of the post-baling moisture changes vas their apparent sensitivity co changing relative humidity. Although no direc: relationship was determined between bale moisture content and rainfall outside the storage facility, there is some evidence that moisture did increase, (or cease to decline) for 2-to 4-day periods folloving me urable rainfall (Figure 10). In this context the "dry" round bale (<30% moisture) appears to act as a "sponge" capable of absorbing enall ancunts

of water from the ambient atmosphere,

(b) Motsture Changes In Partially-Dey Bales: While solar-drying to J asbient moisture is both desirable and normal procedure, situations can arise where baling of pertially-dry grasses 18 necessary. This is partic

ularly true where harv

(August through Novesber), or unexpected rainfall has complicated normal

ry season conditions. Early baling might also be required to renove aging

operations are attempted during the rainy season

windrows that are shading out the newly.

stubble. A 10-bale experiment vas performed to determine the drying be

havior of napter grass bales placed in storage with higher than normal

rrging shoots from harvested

oteture contents.

?The average moisture content at time of baling was 31.5 percent

(Figure 11). During the subsequent 10 days, moisture increased to 34.5

percent and then began 2 general decline over the next 62 days to 18.4 4

percent. Sone Limited heating was evident in the bale's interior but did

Rot approach spontaneous combustion, possibly because of natural ventile

tion throughout the storage facility, There was algo evidence of sold but

?no appreciable decouposition occurred. :

?The following conclusions vere drawn relative to vet napier grass
baling under inclenent weather conditions: (a), Bales could be made and

---Page Break---

= 55

?stored with roughly 16 percont excess moisture; (b), such bales could
complete the drying process in storage; and (c), about three months tine
and good ventilation (12-16 inch spacing between rovs of bales stacked
three high) are needed to assure drying to an ambient soisture Level. The
90-day interval includes an initial 10-day period when vater content
increases by 3 to 4 percent.

(e) Moisture Changes In Qpen-Alr Storag
storing biomsss in such structures, biomass planters mst seriously con?

Owing to the high cost of

sider the option of open-air storage where local clisate conditions are favorable. Hay growers in large areas of the western US comonly stack their bales out-of-doors without cover or protection of any kind. Highly-compacted bales tend to resist moisture penetration. At worst, only the outer layer of

sun, and wind. Round bales such as those produced in this project are only

es nay be damaged by prolonged exposure to precipitation,

Loosely compacted (9-10 Ibs/ft*). Their behavior when exposed to weather variables vas an unknom factor.

?Two experinents were performed vith napler grass bales stored out-of-doors (Table 54). One experinent utilized part {ally-dry material (36.6%

moisture) and the other fully-éry aaterial (15.8% solsture). Moisture doterainatior

were made at 2-to J-woek intervals over a time course of 61 days. Two tnportant trendy were evident: (a) The partially-green bales Lost moisture during the first 28 days and remained constant at around 23 percent soisture thereafter, and (b), The dry bales gained aoisture during the first 16s days of open-air storage, but thereafter their moisture content declined to approximately the original level (Table 55).

The magnitude of moisture change for both bale groups was surprising. The semi-green bales lost 37% of their rotal aoisture within 28 days. More striking was their loss of 63% of the romovable water, that {s, soisture in excess of 15% (anbient moisture). The dry bales increased moisture by

nearly 55% during the First 14 days, This increase wae considerably larger than that observed for bales stored under a roof (Figures 10 and 11).

However, the stabilized moisture level (from 28 days onward) was only slightly higher than the original level at tine of baling.

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These results suggest that the storing of bales in « roofed facility

As not really necessary in the semiarid clinate of Puerto Rico's Lajas Vatley. Further to this, the open-air storage tests were performed during

th rainy season. It Is logical to expect that during the 8-aonth dry
seuson the drying of semi-green bales would be accelerated and the teuporary
gain of moisture by dry bales would be reduced.

?The project's original work plan called for at least one major study

with sugarcane somewhere on the Island's humid north coast. A site more

closely integrated vith private farms than is possible with Experiaent Sta~
ablishing
such a study during the spring of 1980, Mr. Jos& 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 cosstal tom of
Hatillo, The offer vas accepted and an energy cane denonstraton study was

established there during July and August of 1980.

tion lands was also desired. A favorable opportunity arose for

?The land itself 1s situated on @ deep alluvial plain bordered by the

Camy River. There

occupying about 40% of the site, and a poorly-drained Toa clay occupying

the remaining area. The soils appear to be at least four to six feet deep.

?The well-drained sections constitute an ?all weather" site insofar as most

sre two Soil series: A well-drained Coloso clay loan,

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 vild grs

Approximately 25 acres were moved with a rotary scythe, plowed, rotavated land-planned, Lined, and planted into three fleld-scale treatments: (a) An ?energy cane planting, of approximately 17 acres, in which intensive produc ton operations are denonstrated; (b), » control plot of about 2.5 acres

?managed as conventional sugarcane; and (c), a second control plot, about

6 acres, simulating the unnanaged wild sugarcane that had been occupying

the site until the sumer of 1980. In

ition, about 2 acres were planted

in the "second generation" energy cane US 67-22-2, as part of the seed

?expansion program for this variety. The energy cane planting 1s subdivided

Into irrigated and nonirrigated sections.

---Page Break---

(a) Plant Crop Wilds: ?teid-seale erfals at Haritio include both

Eseeteand aecond-gene

son energy cane varieties (PR 980 and US 67.

2-2,

respectively), plus supplenental ireigation as a controlled variable.

?There are tw control treatments sisulat ing ?standard? sugarcane (Sugar Corporation control) and minisun tillage (!ow-tili control). Yield ond quality daca were obta

wed rom 2000 fe? ares samples taken at tri-monthly intervals from moath 6 to 18.

?The main objective of this study was to doses

race the feasibility of producing 90 tons o* whole cane in a 18-sonth gran cultura crop. At that time there vas skepeicisw auong local <gronoisints and sugar officials 145 to vhether the 80-plus tonnages being reported for cnergy cane were in fact feasible (or even possible) on a field scale. By month 9 it w

evident that the 90-ton goal would be attained, Accordingly, no additional fertilizer was aduinistered after month 8, Vand no irrigation was provided after month 12. This change in aanagement emphasis was quite apparent im the subsequent yield da

(b) Maote Cane And Pry Matter: Four trends are evident tn the plant crop data from Hatillo: (a) Energy cene, both flxst-and second-generat ion varietts

| appreciably outyleided contcoi cane} (b) over 90 tons of whole green cane vere produced by wonth 12; (¢) relatively Little biomass vos

produced after month 12; and (4), the secomi-generation variety US 67-22-? was distinctly superior to variety P2 90. Also, the control yields were

consistently higher than expected. Tuie 4a attributed in part to an erro-neous inclusion of the

and rota

Cor An preparing the control seedbed.

THis Amplesent 6 aleost never used eit

F on Sugae Corporation lands or

private "Colono" farae

Yields of total green matter (Table $5) attained over 95 tons/acre

by month 12 An fire! Variety US 7-2-2 (second genera

elon) yielded about 125 tons/acte at 17 months; however, neither treatment

appreciably increased yield in che subsequent § months. Stailar trends

vere recorded for millable stens (Table 57), although saall yield gains

were made after 12 nonths.

?generation

Dey mutter also hat essentially maxinized by

A/ Four increnents of 100 Lbs eleseatat N each had been planned, te, at

Planting (beneath the seedpiece), and at monthe 4, 8, and 12.

---Page Break---

the twelfth month (Table 58). Variety US 67-22-2 was by far the superior producer, attaining over 50 tons DM by month 12, There was virtually no gain in total DM after that tine.

(©) Gane Quality And Sugar Yieud:

greatly among control and energy cane treatuente (Table 59). Rendinent

cane quality values did not vary

figures were generally low, even for 1S-aonth cane. Sugar yields vere high (by Puerto Rico standards) but this was a reflection of the generally high tonnages of atllable cane/acre. The highest sugar yield (TSA) was 9.2 tons/acre, produced by variety US 67-22-2 at 18 months.

?The withholding of vater and fertilizer after month 12 does not appear to have increased cane quality oF sugar yield appreciably (Table 59). In US 67-22-2, purity remained unchanged between 12 and 18 months and sugar Ancreased by only 1.4 tons/acre. The fiber content of US 67-22-2 vas perceptively lower than PR 980, being only 11.6% at 18 months. The US 67-22-2 vartety te widely regarded as a "soft" cane.

(@) Plane Density And Trash: The second-generation variety US 67-22-? Aisplayed a prolific tillering habit observed elsevhere in field-plot studies. Stubble counts, recorded trinonthly from 6 months onvard, indicate a persistent and dramatic increase in the uber of stems/acre (Figure 12). This is a highly desirable characteristic. It assures con plete occupation of the planted area and complete closure of the cane field canopy. It also provides for self replacement of eroms destroyed by harvest machinery.

?This variety is not only a prolific producer of stems. It also main- tains @ foliar canopy that 1s perceptively larger than normally seen in the sugarcanes of comerce. It is common to see an intact green canopy extending from top to ground level late as month 6 or 7. This propensity for leaf

production is later reflected in trash yields /, At Hat{l1o, by month 12,

A/ Cane ?trash? consists of leaf and leaf~eheath tisaues that have died and desiccated, and either renain adhereing to the mature stem or detach and drop to the ground.

---Page Break---

US 67-22-2 had accumulated over 23 toas of trash/acre (Tuble 60). Thin

equals the average wio

cane tonnage currently produced by the sugarcane

Colones in Puerto Rico (50).

2. Fleld-Pioe

A point of interest in energy planting 1s the contention by some ?authorities? that field-plot data are seaningless {f extrapolated to field-scale conditions. The assumption is that the precision control over Production inputs enjoyed at the small plot level is lost in the field, and hence the field productivity must be significantly leas. The present studies were not designed to test this thesis; however, the treatments

at Lajas (field plot) were established in the

woe Season and maintained

yentially the same sequence of Inputs as those at Hatillo (field scale), p Co the end of month 6 when further fertilizer increments were cancelled

Out of curiosity the primary yield trends of US 67-22-2 at the two Sites were plotted in Table 61. For total dry matter, the single most Amportant parameter, yields vere actually higher under field-scale condt- tions through the first 12 months. Millable cane yields were about 3% lower and sugar was 8X lower. This suggests that comparable managenent sives comparable yields vhether in the field or in field plots.

8. Energy In The Field Vs The Factory

The cane quality figures herein reported represent the cane condition within one day after harvest. For unburned whole cane these values are sustained at the mill for 3 to 4 days after harvest. Burned and chopped cane usually experiences a sore rapid quality decline.

The need for coordination betwen field and will opeations vas under~ Scored recently when the second-generation energy cane at Hatitlo vas being harvested. Average rendinent readings vere between 8.0 and 8.7 at the tine of harvest. However, the first load of cane, hauled 5 days later, gave «

Tendinent value of 5.9, while the final load, delivered 15 days harvest, gave a rendiment value of 2.9. Purity values had also declined

fer

@rastically. Such cane is not vorth its delivery costs as a sugar resource.

---Page Break---

As 4 source of Lignocellulosic feedstocks, or as 3 bofler fuel, the value

of this cane had disinished relatively Littic

Loss of poisture also occurs In harvested cane experiencing long,

aes

sys in delivery (Figure 13). The sogar slanter vould be paid for less tornage, and sugar extraction efficiency vould decline at the mill. As fan energy crop the loss of moisture in che [eld 1s not necessarily bad. lLeus water would need to be hauled shile the Lignocellulose fractton remained intact.

BREEDING STUDIES.

?Te genus Saccharum can be vieved as an enormous and largely untap

pool of geraplase bi

and Lignocel lulose (58, 16, 1, 2). A "secondary" but nonetheless important

{ing program that

to energe having

specifically biomass attributes. This vas accomplished vith very Limited resource inputs, in part through the use existing AES-UPR facilities for conventional sugarcane breeding, but primarily through the personal interest of Mr. T. L. Chu,a recognized world authority on breeding in the genus ring large potentials for production of both sugar

goal of this project was to establish a cune biomass bret

would enable at least a Lisited number of new proger

Saccharua.

1, Evaluation Of Local Germplasm So

Four local clones bearing "new" Saccharue geraplase vere identified

early in year 1 and evaluated as potential male parents in cross

suitable fer

spontaneue characteristic of Flovering soae 6 ro 8 weeks in advance of

with

le (aale-sterile) sugareanes (24). All exhibited the

comercial hybrid sugarcanes. Two of the S. spontaneum clones are found in the wild near Rfo Piedras. No attempt vas ever made to cultivate thom Alrectly a8 biomass candidates. A third wild clone, an unidentified 8. spontaneum hybrid, is a highly promising Siomass producer in its on

Tight. Throughout the course of the project this hybrid served as a highly-

?vioual example of massive grouth porential by wild, uncared for tropical

---Page Break---

=o

wa

8 (24, 48, 98). A fourth Saccharum clone, "Aegyptiacua", was avail~
able in collections maintained at Rfo Piedras and Gurabo.

2, Evaluation Of PR Breeding Progeny

For many years the AES-UPK canc breeding program has screened its

?new progeny with a view tovard increased sugar and tonnage yields, suit-
ability for sechanical harvest, dise

#e resistance, and regional adapt~
ability (59, 60, 61). Total biomass per se has not been a dectaive
Parameter in the selection of new sugarcane hybrids (62, 58). Nonethe-
less, a aunber of now canes have emerged chat do have exceptional promise

448 biomass energy producers, at least on the bi

1s of regional trials.

Some 15 of thi

were planted in a separate "nursery" to be used as paren-

tal clones in energy cane breeding.

3. Initial or

?The project's initial tvo ero srformed in Deceuber of 1977,

utilizing made-sterile female parents, and frozen pollen in an effort to

synchronize tasseling with that of the early-flovering S. spontaneus hybrid

described above. Although pollen tests by the starch-Sodine method had indicated a probable viability, only 5 seedlings vere obtained from these

suggesting that the freezing process vas almst totally destructive.

A more suitable method for flover synchronization in cane is the leaf-eriming method developed by Chu and Serapién (63, 64).

Vicimacely, a "cutback" technique vas adopted vhich successfully enabled us to utilize the wild §. spontaneum hybrid in crosses with noraal-flowering canes. By this method a select stand of wild material is cut off between May 15 and June 1. The subsequent regrowth 1s too young to initiate tassels at the clone's preferential photoperiod in August, but a Limited number of stens do initiate Clover primordia at about the same time that "late" comercial canes are doing so in Puerto Rico. This ?enabled us to obtain 5. spontaneua tassels during the period Novenber 25-

Decenber 15. Five crosses perforned by this means in the autum of 1979 sumarized in Table 62.

---Page Break---

4, Seedling Trials; Lajas Substation

The project's breeding phase aimed at producing new sugarcane progeny with superior biomass attributes was confined to the AES-UPR Gurabo Sub-station during the first three years. In 1980, 92 seedlings showing some preliminary evidence of high tonnage capability were transferred to the Lajas Substation for second-phase evatustion (27). They were planted in unreplicated, 5" x 20° plots.

A total of six cro:

vere represented, each made by Mr. T. L. chu during the autumn of 1979. All crosses vere part of the AES-UPR Sugarcane + Breeding Program, but in these instances there vere parental types involved

having important biomass attributes. Of special interest ts the 8. sponte-

neu hybrid US 67-22-2 which served as both female and male parent. Under

Gorabo conditions this clone has show very superior potential for the

production of both sucrove and total biomas

From this point onward sone

probability has existed for the emergence of "third generation? progeny

having bionass attributes superior to those of any prec

sding clone.

5. Second-Coneration Energy Caner

?The sugarcane varieties US 67-22-2 and B T0-JOL were iaported into

Puerto Rico from USDA collecttons in 1974 and 1977, respectively. The

purpose of these introductions, together with other basic breeding Laes

structured with new clones of

genetic base of the Ts

tial evaluation of the AES-UPR breeding collections, varieties US 67-22-2 +

Jum species, vas to broaden the

ind's sugatcane germplasm (58). Based on an ini-

and B 70-701 were identified as outstanding candidates for biomass cropping.

Vartety US 67-22-2 is a second generation (BC,) hybrid of the S. spontaneum clone Passoercean. It hae excellent germination, rapid early growth with strong tillering and ratooning capability, and an erect growth habit. It has a relatively low fiber content and average sucrose content. Plant crop data have revealed that variety US 67-22-2 produced the highest green matter yield at 130 tons/scre, with total dry matter at 41.9 tons/ acre. Only 25.0 tons/acre were obtained from first-generation energy cane (var. PR 980) in the plant crop.

---Page Break---

tm a seed-expansion study perforged at the Hatillo energy cane denon- stration fara, variety US 67-22-2 produced 125 tons/acre in total gr: matter for the L2-nonth harvest, as opposed to 108 tons/acre for variety

PR 980, Sugar yield exceeded 7.7 tons/acte for US 67-22-2 and 6.2 tons/ acre for PR 980. A seed-expansion program for US 67-22-2 ts currently lunderway at the AES-UPR Lajas Substation and at the Hatillo energy cane farm,

The clone B 70-701 1s a first generation S, spontaneus hybrid (F,).

He de characterized by exceptionally rapid grovth with good tillering and Tatooning ability, Tt has distinetly higher fiber and lover sugar contents. The average dry weight of B 70-701 at Hatillo was 37.2 tons/acre year, a8 compared to 41.9 tons for US 67-22-2. In view of its high fiber and low sugar values, variety B 70-701 appears to be a potential candidate for biomass production solely for fiber.

?Third-Generation Energy Canes

(a) Crosses Designed To Maximize Fiber: During the 1978 cane breeding season the cross US 67-22-2 x 8 70-701 was performed. Total fiber rather then eucrose or fermentable solids was the primary objective. The F, progeny from this cross exhibit an exceptionally vigorous growth habit plus a large number of stess per seedling. Twenty-four clones selected frow this cross, fogether with their parents, were planted in a replicated field trial at the AES-UPR Gurabo Substation during May of 1980. Highest yields were obtained from the progeny PR 79-1-10, amounting to 93.7 green tons and 30.6 dzy tons Per acre year, ae opposed Co 67.1 green tons and 21.5 dry tons/acre year

for ite fenale parent, variety US 67-22-2 (Table 63). It outyielded US 67-22-2 in tons of dry mattez/acre by approximately 43 percent. The ixpressive per~ formance in total biomass tonnage by PR 79-1-10 evidently resulted froa its high munber of stems/acre and remarkable stem height (Table 64). Two additional progeny in this experiment produced appreciably more dry matter chan

US 67-22-2, Le, by approximately 35 and 33 percent, re:
PR 79-1-3 and PR 79-1-5 (Table 63).

ctively, for

?Aa examination of qualitative values for these clones revealed that FR 79-1-10, PR 791-3, and PR 79-1-5 are cubstantially lover in Brix, pol, purity, and sucrose-percent-cane than the reference variety US 67-22-2

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(Table 65), This suggests that these three are potential candidates for

the production of combustible biomass while having Little prospect for

sugar of fermentable solide production.

(b) Crosses Maximizing Fiber And

Le Solids: During the past

four breeding seasons, beginning in 1978, an attempt vas made to develop

hnew energy cane varieties which could maximize both fiber and fermentable

of the crosses performed during

this period are presented in Tables 66 to 69.

solids. The parentage and breeding in

[A preliminary evaluation of progeny from the cros

Us 67-22-2, esther as a male of female parent (Table 66), indicates a nusber of selections having excellent growth cosbined with good Brix values. Yield data for these clones in 20' x 20" field-plot tests are expected to be avatlable by the sumer of 1982.

8 involving variety

so inpressive pecforeance ws obtained {ron hybrid progeny of the rose PR 70395 1 FR TI-1SI-137, which wee made during the 1979 breeding season (Cable 67). The clone PR 77-251-137 te an F, hybrid of the clones Os se-t4-t (2n= 80), Thatland S. spontmeun, ?This sugests tha the Thatlané §. spontaneun source ay provide excellent gerapaae for improving

yields 65).

cane bioma

7. Energy Cane Breeding Potential In

(a) 8. spontaneus Vo $. robustum: During the 1979 breeding season

additional crosses vere perforued which incorporated both growth and

spontaneum (RP)

» were crossed

quality attributes. An extremely vigorous clone of

and a clone of S. robustum (57 NC 54), both ?wild? elon

with the high-ylelding and good Juice-quality varieties previously developed

in the AES-UPR cane breeding program (66). A study was made on the perfora-

ance of the P, hybrid progeny of the tw wild Saccharum apectes, the primary

objectives of the progeny being high fiber and fermentable solide. Thirty

original seedlings saupled randoaly per cross were analyzed using the pol

B/ The parentage of PR 77-251-137 1s PR 67-1336 x US S6-16-4.

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ratio method. Each sample consisted of {ive millable canes harvested

approximately 12 months after planting.

An examination of frequency distribution for sucrose content in the

tours of hybrids rovented that the rebustus F, hybrids contained

sore sucrose than the spontaneum F, progeny (Figure 14). With reference

he

to Brix vaiues, the robustua F progeny demonstrated an even more remark-

able performance than the spontaneum F kybride (Figure 15). In terms of

fiber, the results indicate that far sore spontaneus Fy hybrids have

dtetinctly higher fiber contents than do che robustus F, progeny (Pigure 16).

The

sively for fibrous biomass, the first generation hybrids (F,) of S. sponta~

Preliminary results seem to suggest that, when breeding exclueum offer a better source of candidates than do those o!

robustus,

When breeding for both fiber and fersentable solids, the S. robustum F,

progeny might offer « better source of biomass candidate

1

©) S. apontaneus Hybrid Progeny; BC, Vs BC): In an atteapt to deter-

?mine the grovth potential for the BC, and BC, hybrid progeny of S. sponta~

eum, measurenents vere taken of stea height, stem diameter, and nuaber of

stens per plant for 100 original seedlings sampled randomly for each cross.

?These were recorded at approximately eight sonths after planting. stalk

volume per seedling ws

?then computed from avaslable data (Figure 17).

Im teres of stalk volune/i@/oo/seedting, the Bo of the cross NCO

310 x B 70-701 (¥, spontancum) indicated a far better performance than the

Bc, progeny of the cross NCo 310 x US 67-22-2

ic, spontaneum (Figure 17)/

Tre growth potential of two additional BC, progeny was also seen to be

greater than that of the BC) progeny (Figure 17).

(c) S$. cobuscum x 5. spontaneum: The same measurements

above were made for the hybrid progeny of the eros:

24 and #, robustua x 5.

described

Vy

1

1k

2 Fy robustus

spontaneum, RP. In terns of 61

A/ The parentage of F, robustus is PR 68-355 x 57 NG 54.

2/ The parentage of F, spontaneus is PR 67-1070 x S. spontaneua RP.

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volumes /io/seeding, the peopey of the ero

robustun x 5. spontaneum RP (Figure 18). The hybrid progeny of the reci-

procal cross of the former demonstrated @ nearly identical performance in

robustum x F, sponta~

terns of etalk volune/¥°/100/ceedi ings

All these initial results appear to suggt

species, $, spontaneum and $. roby

valuable source of genetic material in breeding canes for bloaas

st that two wild Saccharum

tus, should be regarded as the most

planting.

Nevertheless, they aust be incorporated into appropriate conventional

high yielding and good juice cane varieties in order to be able to produce

bona

candidates combining the exceptionally good vigor with high fiber

content and fairly good juice quality. The second-generation hybrid pro~

seny (BC,) of these two wild species appears to provide a better source

?of such biomass candidates chan either the first generation (F,) or ore

advanced-generation progeny of 8. spontaneum. Concerning the two primary

objectives (high biomass tonnage and high fermentable solids) for blonaee

candidaste:

FF progeny should be crossed back to the original clones of the two wild

spect

Ae As advisable that neither 5. spontaneum F, nor 8. robustum

F. StMMARY

A fbn

year study on production of sugarcane and related tropical

er

attained. Certain components of the study are continuing with UPR and

Puerto Rico Commonwealth funding.

energy crops was successfully completed vith all objectives

Originally a loosely-affiliated appendage of the ERDA "Fuels Fro

Sugar Crop

application of grasses management for fuels and Lignocellulosic

production. Neither sugar nor total fermentable solids vere ever primary

program, the Fuerto Rico work continued as a purely tropical

latocks

considerations, yet they figured prominantly in the emergence of the

study's most important new concept, te,

concept for

boiler fuels and molasses production.

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Eegentially a synthesis of

vised field management technologies,

?energy cane" production encompasses a range of thin-and thick-stenned

eropical grasses having the capability to cross with Saccharus species

as a common attribute. Sugarcencs of comerce played a major role in

this project, but primarily as sources of high biomass tonnage rather

than sugar. The co-production of related grasses, for the most part

{brous, thin-stemsed species having little sugar, provides @ continuous,

ye

solar-dried and baled in che Field white Saccharum components of eneray

round supply of dry Iignoce!lulose feedstocks. The latter are cane are still hauled to a centralized mill for dewatering.

Technologies were developed aad demonstrated for the production of tropical grasses as econonically-profitable enterprises. Although pro-

duction costs are moderately higher on a per acre basis than conventional

sugarcane planting, yields are vastly higher and costs correspondingly lower when reckoned on a per ton Lasis. For boiler fuel, solar-ried than $2.00/miL1ion BTUs, This is easily the most cost-effective fuel available to Puerto Rico today, and the only fone that is both renevable and dosestically produced. Syrup (high-test wolasses) costs less than 0.70/gallon as a by-product of energy cane pro-

grasses can be produced for 1

duction. From these studies it ?s concluded that tropical grasses are thoroughly viable energy crop comodities for tropical countries. They particularly attractive for tropical societies tke Puerto Rico where cades of social progress have intensified energy demand.

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APPENDIX

Figures 1-18

Tables 1-69

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Oy (meas)

FIORE 5. Nitrogencresponse curves for the short-rotation candidate Soréen

wer supplied in nutrient solutions to plants

propagated by sand colture (Incomplete data)

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Der MATTER (g/PLART)

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FIGURE 6. bry matter ylelde for eiahe ©

oder aiaulated

yal, sentnart

plcal grarnee

fed arid noteture

Fegines,? Each curve 1o derived fron the computed

Sttea"cf avon Saccharun and one Sorghos

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sso} Lo 325

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g 99%

$ 100

sox

50

24x

Oe a ie or Te

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FIGURE

Relationship of L2-and 18-eooth harvests to green and dry aatter production by second-genaration energy cane, Percentage Figures inéteate the celative ?shin im yield over the previous harvest period (la, BH yield at 18 aonths ?was SSE greater than at? 12 meatha, while GM jlald at 18 wonthe wes only 32 (Breater thes at 12 monthe).

---Page Break---

Stoor'Sractes

BIOMASS FUEL STORAGE

ncegeation OF Energy Cane And AORIMYUEL Technologies

?Gyris) and Foe

niowat 9,

For Year-Round Production Of highest ROL

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STEMS/ACRE. (THOUSANDS)

6 9 ww us 8

AGE OF CANE (MONTHS)

FIGURE 10. Number of steas produced/acre by energy cane

varieties PR 980 and US 67-22-2

---Page Break---

oxstine conteer (2)

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- 8s -

MOISTURE CONTENT (Z)

° 4 8 2 16 20 2%

?STORAGE TIME (DAYS)

Less Than 20% Moisture,

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? Projected Loss

nm | ??? Actual Loss

GREEN WE Loss (2)

Rt

° ? 8 12 16 20

DAYS AFTER WARVEST

FIGURE 13. GREEN WEIGHT LOSS FOR HARVESTED WHOLE STEMS oF

ENERGY CANE; 18 MONTH (GRAN CULTURA) HARVEST AT

HATILLO.

---Page Break---

?a ne

2

FIOIME 14. Frequency distribution for sucrowe (X) in 30 Fy hybrid

Progenies of each of 3 crosses: PR 960 x 5. spontansen

BE, FR 67-1070 x 8. spontaneus RP, and PR 66-355 5 Se

robustum $7-NC-54,

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FIGURE 15. Frequency distribution for ?Brix in 30 Fy hybrid pro-

Benies of each of 3 crosses: PR 980 x S. spontancua RP,

PR 67-1070 x S, spontaneum RP, and PR 68-355 x S.

57-86-54,

---Page Break---

FIGURE 16. Frequency distribution for fther (2) in 30

of each of 3 crosses: PR 980 x 8)

spontaneun RP, and PR 58-355 x §.

Fy hybrid progenses

weun Rb, PR 67-1070 x S.

S7-NEnS4,

---Page Break---

soseg ar omen stots)

Sam a

FIGURE 17.Frequency distribution for stalk volune in 100 hybrid progenies

of each of & crosses: NCo 310 x Fi S. sp.; NCo 310 x BC, S. sp.

PR 69-3061 x Fy S. sp., and PR 70-3364 x Fy S. ap.

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Sa ae a

FICURE 18, Frequency distribution for stalk volume in 100 hybrid progent

of each of 3 eros:

Fy (PR 68-355 x S7-NG~54) x Fy (PR'67H=1070

x 8. sp. BP); Fy 355 x S7-NG-S4) x S. gp. RP; and Fy (PR

67-1070 x 8. sp. RP) x Fy (PR 68-355 x 57-NC-54),

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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-Agronoatc

Field Scale Agronomic-Beonomte

Comercisl-Industrial Heonomte

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TABLE 2. BIOMASS PRODUCTIVITY PARAMETERS BEING EVALUATED

DURING THE PROJECT'S GREENHOUSE PHASE

Performance (Relative to Reference Clone

Paraneter PR 980) Required For Field Plot Phast

?Total Bionase Supertor

Growth Curve Superior

Regrowth Rate Superior

W Response Equal Or Superior

Water Response Equal Or Superior

Recutting Tolerance Supertor

Insect Tolerance Equal

Disease Resistance Equal

?Tissue Composition 1/ Equal Or Superior

Tillering Density Superior

A/ Total Ash, Silicate, Sulfur

---Page Break---

~ 94

?TABLE 3. RELATIVE GREEN WEIGHT PRODUCTION BY CANDIDATE

?TROPICAL GRASSES OVER A TIME-COURSE OF 7 MONTHS

?Total Green We. As % Of

Species Clone Reference Clone (PR 980)

PR 980 100

37-1939 124

co 310 120

Pa 2878 oe

Pindar aa

S. offteinarus Lahaina us

Blanca 46

Black Cheribon %

Crystal ina 126

65

Rayada %

Vellat 108

?$+ spontaneus Us 36-19-1 89

US. 5616-4 a1

SES 317 uy?

SES 327 322

SES 231 102

SES 84-A 31

Aegyptiacum 85

Tainan 96

S. sinense Seretha a

Chunnee 122

Natal vba a7

NG 57-83 ?

NG 28-219 67

NG 132 89

NG 28-7 78

---Page Break---

-95-

TABLE 4, INITIAL GREEWOUSE GROWTH RESPONSES OF EIGHT CANDIDATE

?TROPICAL GRASSES*

Total Growth (g/10 Plante)

Genus Clone Green Wt. Dry We. _% Moisture

Saccharum PR 980 105 ans

Pas 2878 80 164

Badilla 70 ans

Sorghus Sordan 70-4 330 32.0

Roma 280 25.5

?ns 201 20.6

M 72-2 220 2212

ns 210 22.6

+ 30 Days After Planting.

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~ 6

SURLE 5. ORY HATTER YIELOS FOR NAPLER GRASS, NAPIER HYBRIDS, AND SORDAY 70-4

PROPAGATED IN THE GREENHOUSE AND HAAVESTED AT INTERVALS. OF SUX WEEKS

as

ayriot '/ror production ince

Totat

coletvar Week 1-6 Week 7-12 Week 13-18 Held

ont os 0.38

Nepser Crass 0.75 0.60 0.50

Napier tybrid 7350 0.63 0.46

aptar Wybeta 20086 0.78 0.60

---Page Break---

?TABLE 6. DKY YATTER COTENT (1) FOR NAPIER GRASS, NAPLER HYBRIDS, AKO SoRDAL

TO-n WARVESTED AT LATERVALS OF 1X WEEKS

EDM For Production intervat }/_

cutetvar Week 1-6 Week 7-17 eek 018 Meas

PR 980 (Reference) 69 110 aa

Napier Gras 10.3 ws 49

Napier wybeis 7350 aa. wa? 3.3

us ne? as a3.

a 15.5 19.8 18.7

A Uneeplicated greeshouse trial,

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me 580

cryaeatinn

srs 07

se br

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evade danas ead seiection

?Soegbow Uivoeta Forate) Sodan rosa

1) Flowered at 5 00 6 wets

Green We (a/Plane) At tay =

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TABLE 8. GREEN WEIGHT RESPONSES OF IMMATURE SUGARCANE TO THE

PLANT GROWTH INHIBITOR POLARIS 1/

Response At 6 Weeks Response At 12 Weeks

Polaris (ppa) _/Plant Change #/Plant % change

° 263 ° as °

30 28 +10 3+

300 sr +8 +32

200 wt 403 +18

300 w+ a2 +20

400 265 ° ws 2

500 9-36 me - 28

2/ Variety PR 980. Applied

?weeks of age.

aqueous foliar

---Page Break---

= 300 =

TABLE 9. GROWTH RESPONSES OF IIMATURE SUGARCANE TO PLANT

GROWTH INHIBITORS

1/ Steen We (g/plant) At Deviation Frow

compound ¥ 6 Weeks After Treataent Control (2)

contro! 488 °

Polaris 62.2 + 28.0

Mon 8000 28.8 = 40.7

?GR 1093 DA 26.5 = 45.5

Babark one +272

?D/ Adaintetered as aqueous Collar epraye containing 100

ppm active ingredient.

---Page Break---

= 101

?TABLE 10, STIMULATORY EFFECTS OF WON 8000 ON TILLER (SHOOT) PRODUCTION

BY THWATURE SUGARCANE; 42 DAYS

EN

?Mon 8000 Green We./Plot Deviation Prom Control (2)

(ope) 2/ Tot. Shoote _g/Shoot Green We. No. Tillere

ee Gren WH Taller

© (Control) 3516 27.9 ° °

10 3842 32.8 16 9.3

25 4525 36.2 27.9 28.7

ET

J/ Applied as aqueous foliar prays to 10-weeke old plante, variety

PR 980.

---Page Break---

TABLE 11. STIMULATORY EFFECTS oF exanx 1/

PRODUCTION BY TYMATURE SUGARCANE

ON TILLER (sHooT)

applied 9 Yields At 42 Days After Treatment

Bebork (ppa) 2/ ??FAllere/Plot Deviation From Control ()

© (Control) ast °

Fa 192 +2

50 236 +95

300 23 +

150 2 +33

200 195 +2

300 202 +38

1/ A 3M Company product. 2/ Adninistered as aqueous foliar

?apraye to l0-veeks old plants, variety PR 980.

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TABLE 12. BRIX AND POLARIZATION VALUES POR IMMATURE SUGARCANE.

TREATED WITH THE PLANT GKOWTH INAIBITOR POLARIS 1/

Polaris Conc. (ppm)

°

50

100

200

300

400

500

Polaris Cone.

Moon Brix Values At Day ~

ui

° 42 4

0.3 ab aha

9.6 abe 27.2

B2e 28.4 a

Bsc 29.2 0

919 ab ee

oa 28.8 8

12a 29.3 a

A Variety PR 980. Applied As Aqueous Foliar Spray At 14 Weeks

OF Age.

2/ Mean values in the same colum bearing unlike letters differ

?significantly (P <.05).

not significantly different.

in common ai

?Mean values bearing at least one letter

---Page Break---

TABLE 13, INTERCENERIC TROPICAL GRASSES IMPORTED TO PUERTO RICO AS

CANDIDATE BIOMASS SOURCES IN 1978

Intergenerte Cross Clone Identification

Saccharum x Eccotlopus longisetous US 72-1304

US 66-301

Saccharum x Sorgo rex Us 61-66-56

Us 71-221

Saccharum x Sclerostachys fui us

Us

us

vs

Saccharum x Riptdiua sp. us

scharum x Miscanthus US 67-37-1

Saccharum x Erianthus contortus Us 66-163-2

Saccharua x $. spont. (Intrageneric) US 72-34-1

Ripidiue kanashirot x R. bengalense (Iatrageneric) US 61-37-7

R, Dengalense x R. bengalense (Intraspectftc) US 60-38

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or pow ?9 +9 eysv0m 28 posesnany

sasoe oot/t

Fy sna cua Toms HI EKO

?TSTS ?T owv AEIROIS ?S aLvaIOND Ae NOLLONOONE KELL Aad ?OE VE

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TABLE 15. TROPICAL GRASSES IAPORTED 1870 PUERTO FICO FOR EVALUATION AS BIOMASS

lone Spectes Planeing Bate Ronarks

28 Me 251 8

ts 57-898

stm 140 :

55 58-6 : :

Joly 20, 1978 FL, From Beltavitte

. " Ko Germination

bs 6-51 ss

Dg M-to-2

Elegane

bs seize

Sept. 30, 1978 FI, canal

Sts" 00 *

Us s)e2-2 *

Us S224 *

ol x. spontaneve

BS 67-31 &

Us 6ic35 Us Sens-3 5 st naren

U8 66c162-2 US SooS-8 x OS BETOEL

GG. fesca)? . eontortus) .

US 66-157 US 56-55 x Hol. 4826 *

(G. robusewe) .

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TABLE 16, CONTROLLED VARIABLES FOR INITIAL PLELD-PLOT STUDIES

IN THE LAIAS VALLEY, PUERTO RICO

???_?__Aanni i roo

Row Center Marvest Interval

Clone (Centssevers) (onthe)

PR 980 150 6 50 2, 4, 6612

Nco 310 150 6 50 2. 4, 6 612

PR 64-1791 150 & 50 2.4, 6 612

Napier Grass 50 6 25 2.4, 6612

OO

---Page Break---

TABLE 17

Interval

2 Months:

4 Months

6 Months

12 Months

= 108 -

MEAN DRY MATTER YLELD VS HARVEST INTERVAL

Tor. DM (ToNS/A/Yr) For

cane

307

9.9

16.2

29.0

Napier 4

ns

23.4

27.5

21.5

|/ Average of 3 varieties and 3 crop years.

12/ Average of one variety and 3 crop years.

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TABLE 18, BVERGY CANE YTELDS BY PLANT AND RATOON CROPS

Tons DM/Acre Yr, For Crop 2/ ~

Harvest

Interval Plant Ist Bat. 2nd Rats Mean

2 Months 6.2 3.5 1.0 36

4 Months uae. 6.6 99

6 Months 16.5 20.6 1 16.2

12 Months 25.5 33.6 27.8 29.0

Mean wee 1.7 14.6

1/ Average values for three varieties.

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> uo -

?TABLE 19. MEAN ENERGY CANE YIELDS BY VARTABLE Row spactnc 2/

harvest Tons DM/Acre Yr, At Row Center ?

Interval 150 ca 50 ea % Spacing

2 Months 3.8 a7

4 Months 9.9 42

6 Months 16.0 15.8 12

22 Months 29.6 28.4 4.0

Mean 146 15 -0.6

?A/ Average of 3 varieties and 3 crop years.

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-u-

?TABLE 20, MEAN TRASH YIELDS FOR CANE AND NAPIER Grass 2/

Tons/Acre, At Rov Center ?

Species variety 150cn 50cm 1 Change

Fane

Cane PR 980 6.81 6.69 - 3a

Noo 310 425 5.47 21.6

PR 64-1791 4.48 5,03 12.2

ee

Mean 5.21 5.63

a

Napier Merker 3m 3s. -27

a Le

?/ Average of 3 crop years.

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TABLE 21. SEASONAL INFLUENCE ON DRY MATTER YIELD BY THREE CROPS

OF SUGARCANE; 2-HONTH HARVESTS

2 Of Crop's Total Yield, For Crop ?

Period	Plant	Ist Hatoon	2nd Ratoon	Moan
July 15?Sepe. 15	en	30.3	29.8	Ba
Sept. 1S?Yov. 15	2.2	20.2	w.9	
Nov. 15-?Jan. 15	1a	10.0	15.5	
Jon, 1S?Mar. 15	6.0	9.9	9.4	
Mar. 15?May 15	as.t	20.0	20.4	

10.0 10.0 eat

May 1s?suly 15

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?TABLE 22, SEASONAL. INFLUENCE ON DRY MATTER YIELD BY THREE CROPS

OF NAPIER GRASS; 2-ONTH HARVESTS

4% Of Crop's Total Yield, For Crop ~

Period Plant Ist Ratoon 2nd Raton Mean

Joly 1S?Sepe. 1516.5 20.1 21.0 19.2

Sept. 15?Wov. 1511.0 21.8 13.6 15.5

Nov. 1S?Jan. 15 23.6 15.9 M7 18.1

Jan, 1S?Mar. 15 7.0 1s 13.6 9.3

Mar. 15?May 15 B14 218 25.2 26.1

May 1S?tuly 15 10.2 12.6 as a

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=e

TABLE 23. SEASONAL INFLUENCE OW DRY MATTER YIELDS BY THREE CROPS

OF SUCARCANE AND NAPIER GRASS} 4-MONTH HARVESTS:

Sugarcane

Of Crop's Total Yield, For Crop ~

Period Plant Ist Raton 2nd Raton Mean

July 15 ? ov. 15 30.6 ara 46.8 41s

Nov. 15 ? Mar. 15 32.4 14.2 21.8 22.8

Mar. 15-? July 1536.9 38.5 31.2 35.6

Napier Grass

July 15 ? Wow. 1525.2 33.6 36.3 on

Nov. 15 ?Mar. 15 47.1 2.9 23.6 27.5

Mar. 15 ? July 15

37.6 39.4 49 39.6

---Page Break---

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TABLE 24, JUICE QUALITY VALUES FOR THREE SUCARCANE VARIETIES

PROPAGATED WITH STANDARD AND RARROY ROU SPACING;

StcoeD BaToox enor

Bebe values, At Row Center ?

vartery oer 50cm E Ohanse

Pe 980 10.92 10.60 -29

Mo 310 ee se a

PR sb-i791 Wo. i120 a3

Px 960

eo 310

Pa 64-1791

Fiber

980 17.07 07

eo 310 16:30 ry

PR 6t-d791 tela 2

Parity

rx 960 19.96 a74s 9.3

eo 310 wes ale 208

Pa 6i-t791 312806 ae,

7 580 5.22

e310 oa

Pe skei791 10

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TABLE 25. TONS SUCROSE PER ACRE (TSA) FOR THREE SUGARCANE

VARIETIES PROPAGATED AT STANDARD AND NARROW ROW

SPACING; SECOND RATOON CROP; 12-MONTH HARVEST

TSA, At Row Spacing ~

variety oes 50cm Change

PR 980 5.22 5.56 6.5

Noo 310 6.21 3.79 - 6.7

PR 64-1791 2.10 5.78 -18.5

Mean 6.8 5.71 ~76

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Wa 2, econ or una rn Wo. we MATER renecron

Paooverion asrestac:? 12 yoetne

?Dr martin YUELo1 39 GD Tona/heres Ttat 4600 Taue®

PreLiminary Coot Aeayate

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2. Seedbed Praparation, a& 15.00/her6 3,000

3. tacee (800 hace Feet az 15.00/f8) 12,000

Seed (Yor Pane Crop Pie Two Matson Crops), Ttea/iate vere at 13.00/10 3.000

6. reretntzer, af 80.00/here 4,000

1, etesden, at 26,50/Aere 3.300

©. Marvent, tntleding tqtpamnt Ourees,

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9% bay Labor, 1 ta Year C2046 hee at 3.00709 2!

AL, Land Preparation 6 natntonanee (Pre-t Pot

22, Dalivery, at 7.00/R0n/9 atten of taut

Th sieoen

17 Waker wotch ta woe included tn etter conee

Total coat/tons (68,025 + 6600): 25.46

Yetal Coot alton Bde?? 25-46 © 13)""1.70

* cme ton of eh dry matter wuld contale approximcely 400 pounds of

fetmantabie solide. "Ar a0Y sueraction thie represents 200 route of

?ual to about 61 gallons sf high-cost wolanaee,

---Page Break---

TaMLE 27. PRELIMTWARY COST AMALYSIS FOR ENEROY CAL ve CONVERTIONL SUEAREANE PRUDLCGEGS 28

Pierro nico (979 potzaas)|

De Makers af 15.00/kere Hoot 12,000 12,000, °

4k. eer application, 48 68.00/here eae 9.600 9.400 °

3. Seed (Foe Plant Crop Hus Two Aatoon Crops) 2,500 3,000 10

6. rere 8,000 36,000, 10

2. Pentieiden, at 26.50/Acre 5.300 5,300 °

Mevefcipeet Depfeciat ions aber 12,000 20,000 ©

9. bey tabor, at 2.00%me 2/ son sous °

10, catetearton, a 5.00/80 1yo001,000 °

11, Land Preparation & maintenance (Peeck Fostotarveet) 600 600, °

12,_pettvery, for 3 ites of fast 2,70 ?

ia eaneoraly 105,768,708 ~?

16, anagenees 10H ot Gobtoral 16.57 15.275 ?

Total 6248 /0.D. Toet Sugarcane, $44.64

nergy canen 25:6

otal Catt atlion 3%

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TABLE 29. ENERGY INPUT AND RECOVERY FROM ENERGY CANE PRopucTrON 2/

Annual Energy Involvement

Parameter	me BU/Acre	?wm Kcal/Ha	BL Ott /ne
ouepur 2/	279.12	173.80	44.40
Input	17.48	6.46	
Balance	251.08	156.32	40.96

Output /Input 9.95 9.95 9.95

2/ Based on an annual dry matter yield of 33 OD tons/acre, less 640

?Ths/0D ton as extracted fernentable solids.

2/ Steam recovery basis. Assunes alternate source of steam is an

Slectric utility boiler having 85% efficiency using no. 6 fuel oil,

and with 6.287 mm BIU/bb1 of ofl.

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oan

TABLE 30, TREATMENTS AND HARVEST DATES FOR TRE SECOND GENERATION ENERGY CANE

STUDE AT AES-UPR LATAS SUBSTATION

ee eeeeeeEyS

Marvest pate, Ae racervar 2 ?

Hieneatel reese Pete, At Ia

vertery sfacre Ye) 6 Wonthe 12 Wott 18 Weathe

n 980 200 Feb. 1, 2901 Aug. 1, 2961 Feb. 1, 1982

Z : : :

Ws 6722-2 200 » -

600 . : :

3 ro-701 200 . . .

co : : :

1 For Plant crop only

---Page Break---

wan

ARLE 91. WHOLE CANE YIELDS FOR THREE VARIETIES RECEIVING VARIABLE SUPPLY; 12

MOTE

avast, PLT CaOP °

ons/tere, Por =

& Suppiy 2! Mitiabie, ?Attached Detached

Vertety ?_Goa/here Ye) __"Stena?? Tope ?Trea Trea Tost

me 900

us e7-a2-2 200 6 9

ico wry

600 323

ten ee

70-701 200 a6 26 p

tee n> x8 a

Wenn ws ua =

?7 ppplted tm 6 inerenente a? ietervais of 3 months, The first increment ver applica

?Ee a'band beneath the seedplece at planting. The N source wan sumoniun sulfate ts

IG-L-6 fertilizer ratio.

---Page Break---

oa -

TABLE 32, GREEN MATTER YIELDS FOR THREE FNERGY CANE VARIETIES HARVESTED AT

E2-AND L8-MONTAS AFTER PLANTING; PLANT CROP

Tot. GH (Tons/a), ae ?

Variety 12 Mosths 18 Monthe Tons Increase Increase

PR 980, 138.7 25.0 22.6

US 67-22-2 166.4 an a

8 70-701 asi 319 30:9

Mean 15.0 3 31.6

MiLlable Stems (Tons/A)

PR 980 97.8 118.2 20.4 20.9

US 67-22-2 98.9 aa 38.2 38.2

8 70-701 89.5 20:6 at 23.6

Hoan ~ 954 OSS~SSSCS~S

?Tops (Tons/A)

PR 980 3.9 7

38.4

US 67=22-2 16 21a 37.9

B 70-701 10:6 95.3

Mean io? 74.0

PR 980 109.9

US 67-222 : 92.1

3 70-701 z aut

Mean asi

J/ Excluding detached trash.

2/ Each figure te the computed mean of 4 replications and 3 W regines

13/ Tncludes both attached and detached trash.

---Page Break---

- am

TABLE 33. GM YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED

[AT 6-AND 18-MONTE INTERVALS; PLANT CROP y

GH Yterd (ons/A), At Month ~~

Variety 6 2 18

PR 980 51.6 66.6 49.3

US 67-22-2 60.8 %.0 515

B 70-701, 538 613470

teen Ba

PR 980 135.8

US 67=22-2 164.5

8 70-701 135.1

Mean 15.1 1465.1

A Includes utliable stens, tops, and attached trash, but

oes not include detached trash.

---Page Break---

TABLE MW. MILLAPLE CANE YTELD FOR THREE ENERCY CANE VARTETTES

HARVESTED AT 6-AND 18-MONTH INTERVALS; PLANT CROP

Millable Cane (I/A), Ae Month ~

Variety 6 2 18 Total

PR 980 34.9 17.4

US. 67-22-2 338 Seas 7.7

B 70-701 3425 407.2

Mean Moo 474 RT 16.1

Mem oa

PR 980 118.2

Us 67=22-2 wrt

B 70-701, 10:6

Mean 122.0)

A Bach figure 49 the computed wean of four replica

three N repines.

---Page Break---

= 136 -

?TABLE 35, TOTAL DRY MATTER YIELDS POR THREE ENERGY CANE VARIETIES

HARVESTED AT 6-AND L8-MONTH INTERVALS; PLANT CROP

Total

36.1

dais

40.2

PR 980 56.1

US 67-22-2 65.7

2 70-701 58.8

Hean OO

|/ Bach figure 4s the computed wean of four replicates and thri

Fegines.

---Page Break---

sane

{WMLE 36, ORY ATTEN pRcOUCTION YEE FRERCY CARE YARIETIES PRORAGATED WIT

VARIABLE

SUPrLty Fat chor, 18 OTIS.

SS ee

¥ surety

arieey elite te) rom

mer eee te) ee oe me tets traeh toe eft

ae ae a2 ae 2

= es 3

=e

mem es e

3 a w

& i Hi

=e eos

rem egg ne

SOR. ORR: 3

ca)

AY ecoding detached Cen

2/ Tacheting detached teeth

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TABLE 37. DAY MATTER YIELDS FOR THREE VARIETIES HARVESTED AT 12-AND

S-YONTHS INTERVALS; PLANT CROP

uv

Tot. DM ons/A), Ae =~

Variety 12 Months 18 Honths Tons Tnerease

Pn 980 36.6 Sea ror

user? 4.8 65.7 23.8

3 70-701 v2 38.8 2.6

ean 3a6 35 70.9

/ Includer detached crash

1X Increase

478

56.8

sea

3

---Page Break---

TABLE 38, TRASH YIELDS FOR THREE ENERGY CANE VARIETIES HARVESTED

AT 6-AND 18-MONTHS; PLANT CROP

Variety Total

a

PR 980 40 7.3 16.6

US 67-22-2 an 89 wt

3 70-701 37 6.2 15.7

Neon 38 73 at

AB

PR 980 23.3

Us 67~22-2 26:9

3 70-701 21.2

23.8

1/ Bach figure Se the computed mean of four replicates and three

W regines, and includes both attached and detached trash.

---Page Break---

?ABLE 39. N@AM JUICE QUALETY AD SUGAR YIELD VALUES FOR TREE SNERGY CANE VARIETIES

HARVESTED AY 12-440 10-MoNTH INTERVALS: PLANT CROP

__sulee Quality Paranecer ?

ay Mawes ?

vertery 2! "fonth) Fol bik Fiber Purity fend 7A

mx 980 bo Wt we ws Te 6

23 ea? ara as

wser2z-2 121.1 8s

2 Le De Ba we a3

3 70-701 2 56079 6 OT 36 e532

is Gh PP dee ess aoe 23

crand Mean 12 gant 778 95.4

ie 85 tos 33 eo 129

D7 teen figure to the conputed sean of 3 ostropen regime, 2/ Millable atone.

---Page Break---

?TABLE 4o, MAN BIOWASS YHHLDS FOR FIRST AND SECOND GENERATION ENERGY CANES

PLANT CHOP, 12-MONTW HARVEST

Tot, Biomass Yield (Tons/Acre Ye)

a stens/acre

Generation Green 2/ pry detached Trash tom Thousands)

Parse me 186 4s 3 55

Secone 2/ no. 38.6 82 27.5

Difference Bo ine 3 ?6 ?ee

One oa) tea * ?70

2 Fiset generation figures are the computed sean for three varletien a

?wo row spacings; plast cop only.

2/ Second generation figures are che computed mean for three varieties and

thee N repises; plant <rop only.

2 tne

stcached crash but not detached trash,

---Page Break---

~~

?TABLE 41. MEAN SUGAR YIELDS FOR FIRST-AND SECOND-CENERATION

ENERGY CANE; PLANT CROPS

Average Annual Yield, For ~

Generation TCA -Rendiment. ?TSA

Firat (12 Months) 2! 4.8 6.0 4s

Second (12 Months) 2/ 95.4 13 7.0

Second (18 Months) 2/ 322.0 6.9 6

1/ Bach figure ts the computed mean for three varieties

TER 980, NCO 310, and PR 64-1791) and two row spacings (50

?and 150'em).

2/ tach figure Le the computed mean for three varieties

?eR 980, US 67-22-2, and B 70-701) and three N levele (200,

400, and 600 Ibs elemental N/acre year).

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-in-

TABLE 42. PRODUCTION TAPUTS sD COSTS FOR ENERGY CANE; 1980 Axo 1982 1!

cous rene) 2!

First ?Second 1 cnanse

Input Generation ceneraticn Since 1960

nd Aenea 10,000 °

Seedbed preparation 3,000 0

Sater 12,000 °

Meter appiicntton 31600 na

31000 3

36%000 nt

31300 at

wa

Dey labor io

Lind tenaovation ho

Delivery he

Scout sae

13.270 B20

168,003 905,58 a

340.13 1,027.00 a

2/ Assumes 4 planted area of 200 acres, privately omeds

2/ Includes equipeent charges, equipment dapractation, and Labor

4 Labor noe included in other costs.

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=i

{ABLE 43. ANAL EHERCY INPUTS FOR FRODUCTION OF SECOND-CENERATION ENENGY

GAME; PLANT cnor, 12 HONTMS, AVE, OF THREE VARIETIES

Input Paranecers

Input Tae Unite/here??BTUe/inie?_?BYUa/acre

Peretliser

? B so 33,333 13.33

P05 B 100 6,032 0.60

ge b 200 40 on

Feretiteer Gaeoeal Toe ae ive

eat (Diesel) cat n 138,680 98s

Pesttesdes w B 43,682 0.57

ator ie 2s 2159) 0.08

Machinery - - - an

Rel = 2 Bots 2.38

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= 135

TABLE 44, ENERGY YIELDS_FROM FIRST AND SECOND-

GENERATION ENERGY CANE; PLANT CROPS

$e LAT COPS

BTUs/Acee Ye (x 108)?

Bagasse Trash Total

2a 35 286

336 uy 433

45 na 38

---Page Break---

TABLE 45. NET ENERGY BALANCES FOR PRODUCTION OF THREE SECOND-

GENERATION ENERGY CANES; PLANT CROP, 12 MONTHS

Brvs/Acre (x 10°)

Ratio

Variety ?Output Input Balance (Output/Input)

7 980 fos. 29.4 374.7 13.7

us 67-22-2 470.3 29.4 440.9 16.0

3 70-701 493.8 29.4 cond 16.5

Meas 452.5 29.8 23.1 154

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~ 7

TABLE 46. ENERGY BALANCE AS A FUXCTION

OF N SUPPLY; PLART CROP

Energy Balance 1/

Lbs N/acre (Output/Eapue)

200 19.7

400 15.4

600 2s

1/ Mean of three varieties.

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oa

?aus 67. Esra@o VALUES oR ACO-TEST YOLASES au FOE To ARE. ERGY CAE ARES

Yieta/here Yeas ua/nere ($95)

vectety ?(beere Ye) Ton cat, wo rier Teeat

mmo 200 me 2an eer ats

ioe Ba ne Yee Year see

m0 Hoe er ao

ine ea

wer i ae pany

ry as u

re so 3

ie 3 aa

ico Tie

Tere Tae ee

ae comes # Seer 2 we =

12/ Tous IH = tone Brin plus tone {ber (LncLeding tops and attached trash).

2/ Gal. RIM» (Gone Brix) (0.85 recovery) (2000 Lefton) + 9.5 Ube F.5./a

A) Ae $0.76/ 4a HH

(3) Ae $40,00/00 ton (44/00 18)

---Page Break---

{WOLE 48, FERFOMUACE EVALUATIONS FOR TAE Hc ROTARY SCYTUE OPERATING OH SORDAM TOA PLASTS OF actmcad cep Mase MOEEY Sythe Nang, At Lodeing status ?

cron age Hime eon Sepp ere tetas A enttne Seetan =

Gena" Tlhers tow als woe Rom ww ene

. woe Wao. a a oad ey

» wo ,oroa a a a a sae

? on 00 ro a Lay

7 Rieevtatiowss & (Conpleceiy Uprig) Greeny inte)

5 Gort deta} i (Severely Lode & mecced)

t ipety eee tis (every toda, tied «

We Oolereely tape) Teeratte with eis)

2 bevionns rating scales 1 = Soran performance, operating

Icey unable fo opecate a4 daigaed

astgneds 5 = taniey perforne

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oo Sis as Sa PT

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TABLE 50, DRY MATTER YIELD FROM NAPIER GRASS FIELD PLOTS MECHANTCALLY-

HARVESTED AT 6 MONTHS OF AGE; FIRST-RATOON CROP.

EE EESIEATOON CHOP

Rotary Scythe area om vied! Crom 2/

Plot No. Mowing Height (in.) (Acres) (Tons/Acte) ?-Dasage

1 10 0.69 7.98 wa

2 8-10 0.69 8.77 wa

3 12 0.69 1.67 wo

4 12 0.69 8.80 wa

ee

¥ Bectuding approximately 20% of the total DM in the form of unraked Fesidues, This material could not be windroved with the available forage rake.

2 opservations based on subsequent production of new shoots.

---Page Break---

oe

my

posses ~~ aarp Tal

?SHANK 1A GAOW S9MED HATER NI SUROTIN ONTLIO ORL EY OMTZVHRIO KANOLETaRNOO-?HLIO$ HUVION 9-N TAL WOK SMOLLVITVAR BOON NOMANT Md

---Page Break---

TAMLE 52, BRY MATTER YIELD AND WOISTUNE CONTENT VALUES FOR EXERGY CANE STUDY HATILLO:

Sow RANTES

?_ Sa

shore taoe/Acre, tor ?

Foal yy PY Detached oe

Teasteent creen te. 2/ matter "ash Dey've. tm

femeest dow ran) / 07.2 won a6 ms

conerot (ugse Corp.) 70.3, Bs a 23.0 ws

terigacad t, cane! 5.1 ws 16 ay na

reetguted 2. Cane 110.9 Bo 0 ao ae

ora? Gerianed) tot sa BE we

es erae2 Geetweed) 308 8s ne

y

YY wan of cow sites. 2 cetacned rah not included. 2 oetached rash included

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me

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TABLE 54, YOISTURE CONTENT CUACES FOR RAPLERGRASE THAT WAS SOLAR-DRIED,

BALD,

1a" SrouD ooT-or-boons

Smee

Metre Conese (yh Day =

oe 8 a mn

y Mee Re

av Be mA Sea v8

ng of to Dalen, pareiaily dry sone baled.

fatty dey ven

Y contacting of 32 bas

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TABLE 55, MOISTURE CONTENT CHANCES IN VARIABLY-DRY NAPIER CRASS BALES STORED

(OUT-OF-DOORS 1/

Baling Moisture Bale Moisture Content (X) At Storage Day ~

@o ow 4 60 Be Mean,

36.5 36.5 32.2 23.2 22.0 23.0 21.8 26.4

15.8 15.8 26.0 16.0 15.4 16.1 15.5, ara

Mean 26.2 28.1 19.6 18.7 19.6 19.6

© warvested at 6 nonths of age.

---Page Break---

TABLE 55, GREEN MATTER YIELDS BY FIRST-AND SECOND-CENERATION ENERGY

CANE: PLANT CROP, HATILLO

ae

yu

Tot. GM (Tons/A), At Month ?

Treatnent é 2 18 Mean

Controt 2/ 30.8 76.4 8.9 65.7

B. cane (ist cen.) 2/ 36.0 95.9 208.5, 80.1

Cane (2nd Gen.) ¥ 50,2 124.9 126.6 99.9

Youn 39.098. ~107-7 as

A/ Simulated PR Sugar Corporation, var. PR 980, unirrigated.

2/ nergy cane managesent, var. PR 9860, trrigat

3/ nergy cane managenent, var. US 67-22-2, irrigated.

A/ Detached trash excluded.

---Page Break---

M8 -

TABLE 57, MILLABLE CANE YIELDS BY FIRST-AND SECOND-GENFRATION ENERGY

CANE; PLANT CROP, HATTLLO

MiLlable Cane (T/A), At Month ?

?Treatnent 6 2 18 Mean

controt 2/ 19.3638 TT 53.4

E. cane (iat Gen.) 2/ 24,0 82.6 98.3, 7.8

B. Cane (2nd Gen.) 2/ 34.7960 109.0,

ean 26.6 80.8 one

42/ Similated PR Sugar Corporation, var. PR 980,untrrigated.

2/ Energy cane management, var. PR 980, irrigated.

13/ Energy cane managenent, var. US 67-22-2, irrigated.

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TABLE 58, DRY MATTER YIELDS FOR PIRST-AND SECOND-GENERATION ENERGY

CANES FLANT CROP, HATILLO

Tot. DM (Tons/A)

Treatment, 6 12 Mean

controt 2/ 5.7 29.4 30.0 28

E.cane (ist cen.) 2/ 5.9 32.8 37.0 25.2

B, Cane (2nd Gen.) / 8.8 50.5 49.6 36.3

Mean CE) 8

A/ Simulated PR Sugar Corporation, var. PR 980, unierigated

2/ Energy cane managenent, var. PR 960, irrigated.

3/ Energy cane management, var. US 67-22-2, irrigated.

4/ Detached trash included.

---Page Break---

~~

TABLE 59. CANE QUALITY 480 SUCAK YIELDS BY FIRST-AXO SECOND-CENERATION EXERGY CANE

e-voNTH HARVEST, PLANT CROP, RATILLO

(quality Paraneter ?

reestaent Month Fol trix Fiber Parity fend. eat,

coatrot 276 97 TS bt 6.83.9

oes as 3 mat es

Ho cane (lat Gen.) 120 9.5 22 aS 62

TB 103 120 ssw? as

E, cane (20d Gen.) 22 10.3 18.3 AT 16.8 %.0 7.8

1 ton Gt ie eae wo

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- an

TABLE 60. TRASH YIELOS IN| FIRST-AND SEOOND-GENERATION ENERGY CARE AT

HATILLO; FLAKY CROP

SRE STN SECOWDNSENERATION EREAGY CAE AT RATILLOS

?Teeatnent

cconeror Saas

. Cane (ast Gen.) 2! 62 37 to

tare (2nd Gen.) 2.

ean 38 as ed

2/ Simlated PR Sugar Corporation.

2/ Variety PR 580.

BY Warsety US 67-23-2

ms

14.9

ma

Bo

1s

ns

2.4

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TABLE 61. RELATIVE SIONASS AND SUCAR YIELDS BY ENENGY CANE VARIETY US 67=22-2

AP LAS 480 HATILLO SrTeS: 12 416 MONTHS, PLANT CROP

Fetal OF (E/n), ae ?

Month Lajas _Hattilo Tonnage Difference 1 Difference

2 nes 128.9 ae 2a

is Mele ies 98 a3

He ios tae ?as 2

2 a6 20.5

i Bu 2s

tea TF Tee

?ons Cane/nere

2 589 96.5 = 28 239

= et santo lah S83

eee as

Tone Susae/Acte

2 35 78 = 0.7

an? a 8

Mens 1a as re

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TABLE 62. SUGARCANE CROSSES POR BIOMASS; NOV.-DEC., 1979

Fenale Parent

B77 x

Neo 310

Nco 310 x

PR 62-195 x

PR 68-330 x

R960 x

PR 67-1070 x

PR 64-1618 x

Male Parent Objectives

ST-NC-34 Fiber only

us 67-22-2 Fiber &

Fernentable

8 ro-701 2/ Fiber &

Fernentable

S7-N0-54 Fiber &

Fermentable

4 T-NG=54 Fiber &

Fermentable

?S. spont. Wybrid Fiber &

Fernentable

S. spont. Hybrid Faber &

Fornentable

+ spont. Hybrid Fiber Only

Solide

Sol

Solids

Solids

Solide

sols

LU Field cro

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~ ase

TABLE 63. TONS CANE PER ACRE AND TONS DRY MATTER PER ACRE FOR

SIX Fy PROGENY OF THE CROSS US 67-22-2 x B 70-701 ra

Proseny tea!? Totex om}! roma 2!

mito 93.7 9.7 2.7306

mies a7 ieee Ta

mith 93 ler se sans

Moin 2 ies ans 9853

mists se ta ded Blo

Gee: Gi eo 3 yao

?2/ Data recorded at 12 months of age, plant crop.

2/ Determined for one sample consisting of 10 aillable stems.

BJ Reference clone, US 67-22-2, = 100.

---Page Break---

TUBE 64, GROWTH FEATURES OF THE TOP SIX P, PROGENY

FROM THE CROSS US 67-22-2 x 3 704701

Stem Characteristics 2/

Height Diameter

Progeny (a) (en) No. /Aere

aun 2a 43,930

270	2.0	40,936
210	Ls	51,565,
300	20	36,181
310	19	aziz
260	us	45,518
250	Xs	32,982

A/ Data recorded at 12-months of age.

2/ Reference clone.

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TABLE 65. QUALITATIVE VALUES FOR THE TOP SIX Fy PROGENY OF THE

CROSS US 67-22-2 x B 70-701

Parameter ?

Progeny	Pol	Brix	E	Fiber	Purity	Sucrose
PR 791-10	5.7	7	6		64.0	3.24
PR 791-5	49	Lo	aSAL		53.0	2.32
PR 791-21	460	30.7	AT		43.0	1.67
PR 79-1-22	6.7	10.5	15.0		52.9	4.27
PR 791-3	7:5	10.3	20.7		70.0	4.99
PR 791-11	3.09.8	16.5			49.4	2.87
Us 67-22-21	13.6	86.3	9.16			
1B 70-701	63	92	68.0	aun		

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TABLE 66. SUGARCANE CROSSES FOR BIOMASS AND SUGAR;

1978 BREEDING SEASON

cross Second

Number ros Selections

Seton

79-4 PR 67-245 x S. sp. RP 2! 5

7-12 Us 67-22-2 x PR 68-3061 2/ ag

79-5 PR 68-330 x US 67-22-2 2/

73-6 PR 67-1070 x us 67-22-22/ yg

79-3 F 160 x us 67-22-2 2f 3

79-17 68-3061 x US 67-22-2 10

79-16 Us 67-22-2 x F 160 2

A/ Being evaluated in 20" x 20° field-plot tests

for biomass; two progeny had been crossed vith

conventional breeding canes during the 1961 cane

breeding season.

2/ Being evaluated in 20' x 20 fLeld-plot teste

For both biomass and sugar.

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TABLE 67

CANE CROSSES FOR BIOMASS; 1979 BREEDING SEASON

oun

Nosbee ero

Bo-1 PR 980 x S. sp. RP rs y

Ss 2. yee

for PR GAteiB x 8 apm Sop

sos me er-iowxs.. mF Fy 8. gp

fos PR-66-255 x 5. sob. rs. eon.

80-27 PR IOI9S x PR II-DSI-137 BH Ss aps 2!

?2/ Being evaluated in 20" x 20" fleld-plot tests for

2 few progeny had been crossed with conventional,

breeding canes during the 1981 breeding season.

2/ Being evaluated in 20" x 20' fteld-plot tests for both.

Bhoaaan and sugar.

---Page Break---

ARLE 68, CANE LOSSES FOR BIOMASS; PERFORMED DURING 1980 BREEDING SEASON

cross

Wonber cross

? Neo Bio x vs 67-22-28

10 co 310 x 8 70-701

ar PR 69-3061 x

1-29 PR 70-260 PR IED

B30 Fy (PR 66-955 x 5. cob.) &

FLOR 67-1070 eS ap RP)

a137 (PR 68-355 5. 208) x

sa

Fy (PR 67-1070 « §. ap. me) x

(PR 68395 KS Fob.)

---Page Break---

= 160

?TABLE 69. SUGARCANE CROSSES FOR BIOMASS; 1981 BREEDING SEASON

cross Breeding

Number Cros Generation

y

82-2 PR 62-195 x PR 9-4-1 3c, 8. sp.

1

82-23 TAC 51/205 x PR 79-4-3 3c, 8. sp.

82-30 1 76-424 x Fy (PR 68-355 x Bc, s. rob. /

57 NC 54)

82-33 PR 67-1070 x F (PR 68-355 x BC, Ss.

357. NC 54)

A/ To be evaluated for biome and sugar.

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