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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

THIRD QUARTERLY REPORT
1978–1979

TO

THE UNITED STATES DEPARTMENT OF ENERGY

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

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Second Annual Report
1978-1979

To

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

By

The University of Puerto Rico
Center for Energy and Environment Research

Through

The Office of the President
University of Puerto Rico

CONTRACT NO.: ET-78-S-05-5912 (AES-UPR Project C-481)

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PRODUCTION OF SUGARCANE AND TROPICAL GRASSES AS A RENEWABLE ENERGY SOURCE

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ABSTRACT

Research continued on tropical grasses from *Saccharum* and related genera as sources of intensively-produced, solar-dried biomass. Categories of candidate grasses include short-, intermediate-, and long-rotation species. These categories are based on the time interval required for maximum dry matter production, and on future management requirements of energy crops for intensive co-production with food crop commodities. Year 1 studies at the greenhouse and field-plot levels were continued and broadened during Year 2. This included candidate screening, importation and quarantine of new clones, breeding, controlled nitrogen and water regimes, chemical growth control, tissue expansion and maturation control, seeding rates, harvest frequency, and variable row spacing. Second-year studies were extended to the project's field-scale and mechanized-harvest phases. These include initial economic analyses for the short-rotation category of candidate species.

1/ Contract no. ET-78-S-05-5912 (AES-UPR project C-481).

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

INTRODUCTION

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

1. Project Objectives

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

1/ Contract No. ET-78-S-05-5912 (AES-UPR Project No. C-481).

2. Scope of the Project

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

Optimized production operations require the identification of a few select clones and the conditions required for their management in an economically-realistic operation. This is being accomplished in the continued development of three project phases, including greenhouse, field-plot, and field-scale investigations (Table 1). A fourth phase, commercial-industrial operations, follows logically but lies beyond the scope of the present project. The second-years's work herein reported deals with a continuation of the greenhouse and field-plot phases begun earlier (1), [1/] and includes initial field-scale studies together with the first mechanization experiments.

The tropical grasses have never before been evaluated under conditions such that biomass energy would be the principal salable product. As a consequence it is necessary to screen a broad range of candidate cultivars if the optimal yield capacity of these genera is to be realized. Under certain circumstances existing sugar-and fiber-producing varieties may excel also in total biomass yield, but it is generally recognized that the growth attribute

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[1/] Numbers in parenthesis refer to relevant published literature. Complete citations are listed on pages 48 to 50.

has not been fully intensified in the hybridization programs that led to the present-day varieties of commerce (2,3,4). Screening studies have therefore included older hybrid varieties no longer produced commercially, "noble" or pure intraspecific clones, superior selections from wild populations, and more primitive forms bearing the germplasm from which modern genotypes have been assembled. A screening technique was adopted for this purpose in which botanical, physiological, and agronomic attributes are evaluated in a stepwise program involving greenhouse, field-plot, and field-scale trials. In certain respects this is a tropical application of the herbaceous species screening concept originally formulated by the DOE Fuels From Biomass Program (5,6).

A breeding program designed to intensify the biomass-yielding attribute of Saccharum and related species lies beyond the scope of this project. Thorough breeding studies would require and justify a separate project. This would include the screening of candidate parental types, a physiological phase to synchronize flowering periods at the intergeneric level, and basic genetic research to break some serious constraints operating to prevent the exchange of germplasm among Saccharum and allied genera (7,8). At a very modest level some limited breeding is included in the present project. This work is confined to a few obviously desirable parent clones that have suitable flowering characteristics and which can be incorporated without inconvenience into an on-going breeding program for sugarcane (9). Certain progeny originating with the AES-UPR sugarcane breeding program are also being considered as long-rotation [1/] biomass candidates. Under these circumstances some prospect is created for the emergence of superior new progeny at very little expense.

[1/] Categories of tropical-grass candidates for biomass production are discussed in detail on pages 41-43.

3. Statement on the Presentation of Second-Year Data

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

Certain of the results recorded in this report were presented in fragmentary form in earlier quarterly statements. In a few cases these findings will be reiterated here as they were originally given. However, to the maximum extent possible, prior findings will be represented in the clearer perspective of two year's experience. The project's statistical data for Year 2 will be presented both in this report and the quarterly report to follow.

TECHNICAL REPORT

A. GREENHOUSE STUDIES

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

1. Greenhouse Methods

All plants are propagated either by sand culture in glazed, 4-gallon pots, or in 1:1 or 2:1 mixtures of soil and cachaza contained in 10-gallon galvanized drums (10). Sand culture offers precise control of water and nutrient variables. Soil-cachaza mixtures are convenient media for determining relative growth rates, growth curves from germination to the young-adult stage, responses to chemical growth regulators, and tolerance to frequent recutting of candidates having superior growth potentials. Most candidates to date have been established with stem cuttings of uniform size, age, and vigor. A few candidates such as sweet sorghum varieties and the sorghum x sudan grass hybrids are established with true seed. Insects are controlled with weekly applications of Malathion. All plants receive controlled water and nutrient supplies that are not rate-limiting for growth.

Most of the second-year experiments employed the interspecific [1/] sugarcane hybrid PR 980 as a reference clone having recognized excellence as a high tonnage producer. In this capacity PR 980 has not been very satisfactory (1). Its major dry matter accumulation begins after 6 months and the project requires some cultivars that will do this as early as 2 to 3 months after planting. Also, several Saccharum imports and AES cane breeding progeny have been identified already as tonnage producers superior to PR 980. When possible, future reference clones will be selected from the specific category of candidates under scrutiny, ie, Sordan 70-A for short-rotation candidates, napier grass (var. Merker) for intermediate rotations, and a suitable S. spontaneum hybrid for the long-rotation category.

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

The principal biomass parameters measured during the second year included total green weight, dry weight (oven dried to about 6% moisture), dry matter content (% DM), and water content (% moisture). Leaf samples, including the entire blades of leaf ranks +1 and +2, [2/] are harvested for foliar mineral analyses. In some experiments leaf samples are harvested for blade-area and

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1/ Saccharum officinarum (9/16) x S. spontaneum (5/16) x S. sinense (2/16).

2/ The uppermost leaf bearing a fully-emerged dewlap is designated "+1". In sugarcane this is the youngest fully developed leaf. Progressively older leaves are designated +2, +3, etc., while progressively younger leaves, still emerging from the spindle, are 0, -1, -2, etc.

chlorophyll determination. Biomass production characteristics evaluated during Year 2 are presented in Table 2.

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

2. Candidate Screening

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

A greenhouse experiment comparing Sordan 70A with three intermediate-rotation candidates (napier grass and two napier hybrids) and sugarcane was initiated during Year 1 and completed during the first quarter of Year 2. Harvested at 6-week intervals over a time-course of 30 weeks, Sordan 70A was the superior biomass producer at 6 weeks and approached the productivity of napier grass over the entire 30-week period (Table 3) Sugarcane (var. PR 980) was not an effective biomass producer when harvested this frequently and correctly belongs in long-rotation studies allowing 6 to 12 months for both tissue expansion and maturation to be completed. The napier grass hybrid PI 30086 was superior to common napier grass at 18 weeks (1) and this relationship persisted through week 30 (Table 3) Although we have much less information about this hybrid in Puerto Rico than we have for common napier grass (var. Merker), we have increased seed of PI 30086 during Year 2 as a replacement for Merker in forthcoming biomass field experiments.

Dry matter percentages for the same five clones remained persistently low until the final six weeks of the study (Table 4). At this time each clone appreciably increased its dry matter content. Since the harvested material itself was only six weeks old, as was true of all prior material, the higher values suggest that the aged crowns produce shoots with a better fiber-yielding capability than do younger crowns. Putting this another way, the age of the shoots was not the only factor governing the shoot's maturation. This in itself would not be remarkable since maturation rates can be altered by numerous management and treatment variables; however, none of these were introduced here and the only accountable variable is the age of the crowns.

Two other NK hybrids were evaluated during the first quarter using Sordan 70A as the reference variety. These were Trudan 5, a true hybrid sudan grass, and Millex 23, a drouth-resistant Pearl Millet hybrid (11). Over a time-course of 14 weeks, Trudan 5 and Sordan 70A produced virtually identical green weight, dry weight, and % DM values (Table 5). Millex 23 was inferior to Trudan 5 and Sordan 70A (Figure 1). The similarity between Trudan 5 and Sordan 70A is encouraging in the sense that one variety or the other could be disqualified as a biomass production candidate. This situation could arise owing to disease or insect susceptibility, drouth intolerance, salinity or pH factors, etc. The principal strong point of Millex 23, its drouth tolerance, was not a factor in this experiment where water supplies were adequate for all varieties.

3. Candidate Grasses Superior to Sordan 70A

While Sordan 70A is regarded as an extremely promising candidate for biomass production, a series of screening experiments have been initiated with the objective of identifying superior or more versatile candidates. The reasons for this are as follows: (a) There is a strong likelihood that the same breeding programs for commercial forage grasses that produced Sordan 70A could also yield superior biomass-yielding varieties; (b) candidates are needed with greater tolerance to severe heat and drouth conditions; (c) greater disease resistance is needed (Sordan 70A has shown downy mildew susceptibility in Puerto Rico); (d); there is a need for somewhat longer-maturing grasses to supplement napier grass and napier hybrids in the intermediate-rotation category; and (c) there is also need for shorter-maturing grasses to accommodate extremely short-rotation situations.

One screening experiment initiated during the second quarter included seven forage grasses from the same breeding program (Northrup King Company) that produced Sordan 70A. In this instance Sordan 70A was retained as the standard or reference variety. Dry matter yield values were recorded from weeks 3 through 7 (Table 6). In essence, this covers the period of rapid tissue expansion for Sordan 70A. On an individual plant basis Sordan 70A appeared to outyield each of the other grasses by week 7; however, the difference was statistically significant only in the instance of Millex 23. At the time this experiment was terminated it was felt that the total productivity of varieties such as Sordan 77 and NK 300, when measured in terms of total dry matter/ acre year, could conceivably equal or exceed that of Sordan 70A. This potential was borne out in subsequent experiments employing variable moisture regimes.

4. Candidate Screening with Humid-to-Arid Moisture Regimes

Variable water regime studies were initiated during the second quarter (9). Treatments consisted of simulated humid, normal, and semi-arid growth regimes with a series of Northrup-King forage grasses. An additional experiment was initiated during the third quarter which included a simulated severe drouth (arid) condition together with normal and semi-arid regimes. Johnson grass was also examined for the first time as a candidate minimum-tillage species.

Seven Northrup-King grasses (Sordan 70A, Sordan 77, Trudan 5, Trudan 7, Millex 23, NK 300, and NK 326) plus Johnson grass, were seeded in a 1:2 soil/cachaza mixture and given adequate water supplies for two weeks to assure uniform germination [1/]. Variable moisture regimes were then established by varying the frequency of watering. Being under glass, with complete reliance upon irrigation, the moisture requirements of such plants are considerably intensified and variable degrees of moisture stress are easily simulated. The first harvest was performed one week after moisture variables were established (at 3 weeks of age), and harvests continued at weekly intervals until the plants were 12 weeks of age.

Although this was an "observation" experiment without replications, several important trends emerged from the yield data: (a) Sordan 77 was superior to Sordan 70A at all moisture levels but progressively more so under moisture stress (Table 7); (b) the varieties NK 300, NK 326, and Johnson grass outyielded Sordan 70A under moisture stress but not when water was adequate; and (c) highest yields under the semi-arid and arid regimes were only 61% and 46%, respectively, of maximum yields with normal water supply.

1/ In an actual field cropping situation, minimum tillage plants would receive irrigation at the time of planting to assure germination even under the most arid conditions.

Mean values for main effects (for the different moisture regimes as a whole), indicate that little more than 50 to 60% of normal productivity can be expected from the present candidate species when subjected to moisture stress (Table 8). Plotted graphically (Figure 2), dry matter yields are not seen to plateau *per se* under moisture stress, and in fact growth was continuing until the close of the experiment. However, without adequate moisture, the plants were simply unable to sustain beyond week 4 the linear flush of growth which characterized normal water regimes through week 9.

Of further interest was an inability of moisture-stress regimes to induce earlier maturation as main effects (Table 9). In other words, lack of moisture did not encourage the young plants to begin earlier their physiological maturation, as would have been evident in data for dry matter content. In sugarcane, for example, the withholding of moisture is the most effective means available to hasten maturation (14, chap. 11). However, the sugar planter deals with relatively old plants in which some level of maturation has already begun. In the present experiment the essentially immature plants deprived of moisture simply continued their tissue-expansion processes at reduced rates. As a *varietal* effect, Trudan 7 continued to display a tendency toward early maturation in direct comparisons with Sordan 70A (Figure 3). Sordan 77 showed a similar tendency (Table 8). This property was noted previously in both species (9).

As unreplicated data these trends are not yet verified statistically but they have important implications nonetheless. They suggest that a fairly large pool of short-rotation candidates exists having a productive capability at least equal to Sordan 70A under favorable growing conditions, and superior to Sordan 70A under adverse conditions. Putting this another way, a species offering the same quantity of biomass as Sordan 70A with less water is one than can be grown more cheaply, and under the kind water constraints very likely to prevail in Puerto Rico's future. The emergence of Johnson grass as a viable biomass candidate, from the role of an arid-loving "weed", is especially encouraging in this respect.

One "ratoon" crop was harvested at four weeks after the experiment's principal harvest was complete. Yield trends were very similar to those of the plant crop although total DM was lower owing to the immaturity of the ratoon plants. Combined DM yield data for the two crops and three moisture regimes were compiled to evaluate varietal performance as main effects (Table 10). From these data the varieties Sordan 77 and NK 326 are superior to Sordan 70A by an order of magnitude of 20 to 25%.

The very favorable performance of Sordan 77 is consistent with Northrup King Company claims of its greater productivity and drouth tolerance (13), and with our own earlier observations (9) in direct comparison with Sordan 70A. Together with downy mildew and insect resistance, these properties speak strongly for the replacement of Sordan 70A with Sordan 77 as the project's principal short-rotation species. However, a definite superiority of Sordan 77 must first be verified in replicated trials. Similarly, the superiority of NK 300 and NK 326 for arid environments must also be verified. The toughness of Johnson grass and the ease of its establishment and maintenance also favor its further study as a short-rotation species for arid and semi-arid conditions.

5. Candidate Screening; Multiple-Rotation Tests

The first "multiple rotation" experiment of the project was begun during the third quarter. This involves the simultaneous propagation of discrete species having variable growth habits, and the harvest of part of each species population at different intervals coinciding with short-and intermediate-rotation cropping periods. This procedure enables multiple-species and multiple-category screening to proceed continually under conditions such that not all of the seed or cuttings needed for a year's work can be made available at one time.

Candidate grasses for the on-going experiment include five Saccharum clones regarded as potential replacements, or supplements, for napier grass (Pennisetum species), the outstanding intermediate-rotation candidate studied to date. Grasses in this category would maximize dry matter at 4 to 6 months after seeding (Table 1). The five Saccharum candidates include the S. spontaneum clones SES 231 and Tainan, the domestic S. spontaneum hybrids US 67-22-2 and US 72-70, and a wild S. spontaneum hybrid collected in the Río Piedras area.

Additional test varieties for this experiment included PR 980, a confirmed long-rotation sugarcane hybrid, and the hybrid napier grass PI 30086. The latter is classified as an intermediate-rotation plant (1,15) with a biomass potential moderately superior to common napier grass (var. Merker). Also being tested is common Johnson grass (Sorghum halepense). Originally brought into Puerto Rico as a cattle forage, Johnson grass has "escaped" to the wild and is regarded as a weed by land owners along the semi-arid south coast. However, its unattended growth in the Lajas region is sufficiently impressive to warrant testing as both a short-and intermediate-rotation species. It is also a potential "low till" candidate in view of its excellent survival properties under semi-arid conditions.

All test species were propagated in the greenhouse using a 1:2 soil/cachaza mixture as the growth medium. Water supplies were adequate to sustain maximum growth for all candidates. There were three replications of each treatment arranged in a randomized block design.

A single candidate species, Johnson grass, gave a clearly outstanding performance for the first two-month growth period (Figure 4). It is the only candidate that appears suitable for further consideration as a short-rotation species. Napier grass hybrid PI 30086 also produced superior growth (Table 11), but Pennisetum species are already known to maximize their dry matter yields over a longer time course, that is, between 4 and 6 months after planting (1,15,16). All of the six Saccharum candidates gave growth performances that were roughly equal and unimpressive. Dry matter content ranged from 14.1 percent for napier grass to 20.0 percent for SES 231 (Table 11). This indicates that none of the species, including Johnson grass, had completed their maturation phase in the 2-month growth period. Johnson grass was the only candidate to begin flowering, and it was believed that this plant would have approached 30 to 35 percent dry matter given an additional 2 to 4 weeks of growth (17).

A subsequent harvest from the same experiment, at 4 months, did reveal a DM content of 38% for Johnson grass (Table 12), although at this time Johnson grass was no longer the leading candidate with regard to total DM yield/planted area (Table 13) or DM yield/individual plant (Table 14). As a multiple-rotation experiment, yield data for month 4 will reveal the most suitable species for intermediate-rotation cropping, while no longer favoring short-rotation species (2-3 months) and not yet favoring long-rotation species (12-18 months). Hence, Johnson grass, the most productive candidate at 2 months, was the least productive at 4 months and napier grass (var. PI 30086) had become the superior candidate for 4-month cropping (Tables 13 and 14).

The enormous yield potential differences of tropical grasses within a time-frame differential of only two months can hardly be overemphasized. For example, the DM content of napier grass increased some 1200% between months 2 and 4, while Johnson grass increased DM by only 162% during the same interval (Table 15). Sugarcane (var. PR 980) also made large increases in DM content by the fourth month, but as a long-rotation candidate it had not yet attained its maximum productivity and remained inferior to napier grass at this time (Tables 13-15).

6. Growth Regulator Experiments

The plant growth inhibitor Polaris (Monsanto Agricultural Products Co.) produces increased growth in sugarcane when applied in low concentrations as an aqueous foliar spray (18,1). Initial attempts to induce the same effect in Sordan 70A were made during the first quarter of Year 2. Polaris was administered to 3 weeks-old plants propagated in a soil-cachaza mixture, and whole plants were harvested for growth evaluations from weeks 2 to 8. Polaris concentrations ranged from 50 to 600 ppm. Dry weight yields were increased moderately (about 35%) by the fourth week after treatment with 200 ppm Polaris, but the effect did not persist to the sixth week (Table 16).

Dry matter was maximized in all Polaris-treated plants two weeks earlier than in control plants (Figure 5). This latter response, even when total yields are not increased, could itself be highly desirable in short-rotation crops where timing of the harvest is a critical factor. The Polaris effects on Sordan 70A require further study with special reference to the timing of application.

Efforts were made to repress growth in Sordan 70A using Polaris concentrations of 2000 and 4000 ppm. These levels will terminate all tissue expansion activity in sugarcane and drastically increase the rates of sucrose accumulation (18). Only slight repression was noted in Sordan 70A, even by 4000 ppm Polaris (Table 17). By the sixth week after treatment the high Polaris plants were moderately exceeding control plants in dry matter production. Although this was only a small observation experiment, at this point the sensitivity of Sordan 70A to Polaris appears totally different from that of Saccharum species.

7. Mineral Nutriton

(a) Sordan 70A: A nitrogen nutriton experiment established late in Year 1 was completed during the first quarter of Year 2. Variable nitrate-N levels were provided to Sordan 70A to establish the plant's N-response curve. The objective was to determine the slope of the dry matter response to progressively higher levels of N. Accordingly, N supplies were increased in a geometric progression from 1.0 to 81.0 milequivalents per liter of NO_3. The 1.0 meq/l treatment would be deficient for virtually all plants. By way of reference, an N supply of 81.0 meq/l is much more than sugarcane can utilize efficiently (14).

Growth data recorded at 4, 8 and 12 weeks after seeding are illustrated in Figure 6. Over this time course, maximum dry weights were produced by the 3, 9, and 27 meq/l treatments, respectively. This may reflect the plant's increasingly well developed root system with advancing age. There were no growth increases as NO_3 was doubled to 54 meq/l, and significant growth repression occurred as NO_3 was raised to 81 meq/l (Table 18).

It should be noted that, during the plant's rapid growth phase (from 0 to 8 weeks), there were no significant growth responses to NO_3 levels higher than 9 meq/l. Higher N levels may be needed to maximize Sordan's fiber-accumulating phase which occurs approximately between weeks 6 and 10 under field conditions (1). Optimal dry matter percentages were a function of N supply in young material (4 and 8 weeks) but there were no significant N differences for dry matter content in mature plants (Table 18).

Nutritional information obtained by the sand culture technique is not directly applicable to field conditions; however, important relationships of nutrient supply to growth potential are revealed in this way. For example, the shape of the N-response curve is a characteristic feature of the candidate variety or species whether propagated in soil in an open field or by nutrient culture under glass. The response curve for Sordan 70A appears quite favorable in that a distinct growth plateau is reached beyond which additional N supplies are wasteful (Figure 6). Moreover, NO_3 concentrations higher than 9 meq/l reduced significantly the number of plants/plot (Table 19), while 27 meq/l very severely restricted the number of regrowth stems following the final harvest (Table 20). By contrast, NO_3 levels in the order of 54 or 81 meq/l produce very profuse tillering in sugarcane (19).

Foliar mineral analyses for 12-weeks old plants suggest an inability of Sordan 70A to incorporate N from solutions containing more than 27 meq/1 of this element (Table 21). The N absorption data actually corresponded quite closely with the N-response curve for dry matter production (Figure 7). Both P and K incorporation was significantly increased at NO_3 concentrations of 27 meq/1 and higher.

(b) Napier Grass: Nitrogen-response curve studies were extended to the intermediate rotation category of tropical grasses during the second and third quarters of Year 2. The hybrid napier grass PI 30086 was used as the representative cultivar. Plants were propagated with the same sand culture technique and nutrient levels employed earlier for Sordan 70A. Samples consisting of six whole plants per replicate were harvested when the plants were 8, 12, 16 and 22 weeks of age.

Yield data for total dry matter indicate that never more than a fraction of the 81 meq/1 of nitrate were needed to sustain maximum growth (Table 22). There were no appreciable yield responses to NO_3 levels above 3 meq/1 at 8 weeks (Figure 8), possibly reflecting a root zone too poorly developed to absorb much of the higher N levels. However, a distinct growth pattern had begun to develop by week 12 showing a repressive effect of high NO_3, and this trend was accentuated through week 22. By the close of the study at 22 weeks there was no growth benefit whatever from supplying napier grass with more than 3 meq/1 of NO_3 (Table 22, Figure 8).

(c) N Requirements; Biomass vs Cattle Forage: One of the clearest examples to date of the need to distinguish between tropical grasses when propagated for conventional cattle forage on one hand, and the same species produced for biomass on the other, is presented in Figure 8 where N-response curves for napier grass are graphically illustrated. As noted above, there was no need to supply these plants with more than 3 meq/l of NO_3 to maximize total biomass in the time-frame when they were botanically most effective in producing biomass, ie, between 5 and 6 months after planting. Nor was more than 3 meq/l of NO_3 needed to maximize maturity at this period (Figure 9). Conversely, 27 times this amount of NO_3 (81 meq/l) was hardly sufficient to maximize biomass when the plants were only 8 weeks of age. Ironically, our present understanding of the growth management requirements of napier grass come from forage studies where 8-week old material is almost excessively old and where harvests are ordinarily performed at 4-to 6-week intervals (20,21,22).

In producing napier grass for cattle feed emphasis is understandably directed toward large numbers of succulent stems having a high water content, a low fiber content, and a high content of soluble protein (20). These conditions are encouraged by high nitrogen fertilization. In one Puerto Rico study with common napier grass (var. Merker), high nitrogen treatments in the order of 2000 lbs of elemental N per acre year did not fully maximize the plants' yields as a cattle forage (22). This level is perhaps three times the quantity that a Puerto Rican farmer could afford to purchase at 1979 fertilizer costs. Moreover, the ecological impacts of using such high fertilizer levels are unknown and could very possibly be detrimental if the practice were pursued for any appreciable length of time.

A vastly more favorable picture is emerging for the N requirements of napier grass grown as an energy crop. First, the harvest costs from frequent recutting (at 6-week intervals) will be lowered appreciably when the same species is harvested for energy (at 16-to 24-week intervals). Second, the more mature energy plants should have a correspondingly better root development and hence a more efficient utilization of applied nitrogen. Third, in a purely quantitative sense, the elemental N needed to produce fiber (mainly cellulose, hemicellulose, and lignin) is less than that needed to produce soluble protein. Taken together with the potential improvements in soil ecology (resulting from fewer heavy machinery operations and lower salt applications to agricultural lands) these factors suggest that energy planting will be a far simpler and less costly operation even when dealing with a species whose management needs have supposedly been known for years.

8. Variable Moisture Regimes

The first variable-moisture study of the project was performed during the first and second quarters of Year 2 using the same Northrup-King varieties discussed on pages 9 to 12. It was a non-replicated observation experiment in which humid, normal, and semi-arid conditions were simulated by varying the frequency of plant watering. All plants were propagated in the greenhouse in a 1:2 mixture of soil and cachaza, and Sordan 70A again served as the reference variety. In this instance the experiment's duration was extended to 11 weeks, thereby encompassing both the tissue-expansion and maturation phases of Sordan 70A (1).

Summary data for all varieties revealed the following trends: (a) The "humid" regime in which the propagation medium was kept constantly moist was repressive for total DM production (Table 23), while the "normal" regime was superior to both humid and semi-arid conditions; (b), mean values for dry matter content indicate that, as a group, the candidate grasses experienced a rapid maturation phase from week 6 to 10 (Figure 10); (c), individual varieties, in direct comparisons with Sordan 70A and propagated with normal water regimes, revealed a much superior maturation curve for Trudan 7 (both earlier and more extensive DM accumulation), and an inferior maturation curve for Millex 23 (Figure 11); (d), under semi-arid regimes, the varieties Trudan 7, Sordan 77, NK 300, and NK 326 gave growth performances which equaled or exceeded those of Sordan 70A (Table 24, Figure 12).

9. Importation and Quarantine of Candidate Tropical Grasses

A number of Saccharum clones and clones from both related and unrelated genera were available in Puerto Rico for screening as biomass candidates when this project was initiated on June 1, 1977. However, the vast majority of clones from these genera reside outside of Puerto Rico, both in the wild and in national and international collections. During the summer of 1978 two shipments of candidate grasses were imported into Puerto Rico and placed in quarantine at the AES-UPR Gurabo Substation. These include a group of five clones from the USDA-World collection at Beltsville, Maryland, and a group of 32 clones from the USDA-World collection at Canal Point, Florida (Table 25). The Beltsville shipment consists entirely of S. robustum clones, a species which has been notably lacking in Puerto Rico. The bulk of the Canal Point group are S. spontaneum clones. The latter group also includes germplasm from the genus Ripidium [1/], Miscanthus, and Erianthus, together with the Saccharum species S. fusca, S. narenga, and S. robustum.

These candidates were planted in soil-cachaza mixtures and all but one gave satisfactory germination. Growth has been adequate though unremarkable for most clones. Several clones produced tassels (flowers) late in November and December, 1978. Saccharum species very rarely flower under greenhouse conditions, but the late flowering trait could be a useful factor in its own

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

right since it would enable these clones to be crossed with hybrid sugarcanes which normally tassel at this time [1/]. The observed flowering could also be an artifact of the plant's greenhouse environment or their late-summer time of planting.

None of the imported species are thought to be suited for short-rotation cropping. They are regarded as candidates for long-rotation and minimum-tillage biomass crops, although certain of the Saccharum species may compare favorably with napier grass and napier hybrids as intermediate-rotation candidates. They might also expand the planting zones of intermediate-and long-rotation species into semi-arid and arid regions too dry to sustain napier grass and conventional sugarcane hybrids.

The principal objective of the clone-screening process is still to find superior producers of dry biomass (fiber) for intensive propagation as solar-dried forages. Added to this is the need for minimum-tillage candidates that will survive and produce acceptable yields under arid conditions and various types of marginal lands.

B. FIELD PLOT STUDIES

1. Saccharum Species Candidates; Gurabo Substation

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

[1/] The sugarcanes of commerce tend to flower later than the more primitive Saccharum species. This is an unfortunate trait of considerable importance to sugarcane breeders concerned with utilizing the widest possible range of Saccharum germplasm in their hybridization programs.

(a) Total Biomass Production: The final harvest completing one year of growth evaluations was taken during October of 1978 (Table 26). Cut repeatedly at 2-month intervals during the final eight months of Year 1, the plants were subjected to a reharvest syndrone comparable to that of short-rotation cropping. Under this harvest regime the *S. spontaneum* clones SES 317 and SES 327 died out, as did the one *Erianthus maximus* clones tested to date, NG 132.

Yield values (Table 26), together with tillering and maturation characteristics (Table 27), indicate that three outstanding candidates emerged in two categories. The first group is dominated by the *S. spontaneum* clone SES 231, a wiry, thin-stemmed grass having no sugar potential at all but persistently high fiber production per acre year. It tillers abundantly and has a fairly high dry matter content for 2-month old material (Table 27, Figure 19). Similar traits were evident to a lesser degree in the *S. sinense* clones Chunnee and Tainan. The second category includes thick-stemmed *S. spontaneum* clones having a sugar-yielding capability in addition to high fiber production. The outstanding clone is US 67-22-2, followed closely by US 72-70 (Table 26). Their dry matter yields slightly exceed that of SES 231 while exceeding the commercial hybrid reference clone (PR 980) by roughly 50 percent. Neither US 67-22-2 nor US 72-70 tillered as profusely as SES-231, but nonetheless they produced more than double the number of stems recorded for PR 980.

Each of the three outstanding grasses is regarded as a potential minimum tillage candidate for field plot trials on the Island's semi-arid south coast. At this point in time, SES 231 is viewed as an intermediate-rotation candidate to be harvested as a solar-dried forage at intervals of 4 to 6 months. There is some possibility also that it can serve as a dryland short-rotation crop to be harvested at 2 to 3 month intervals. The thick-stemmed grasses, US 67-22-2 and US 72-70, should probably stand a year between harvests to obtain both sugar and fiber. In any case, these varieties would require milling as a de-watering step in their processing operations for fuels. They cannot be accommodated by any existing equipment for production of solar-dried forages.

The *S. spontaneum* and *S. sinense* crowns presently established at the Gurabo Substation are being retained for one additional year. This will provide the project with data on the long-term durability of such species without accruing the added time and expense of a new experiment. During the second year these clones will also be managed as minimum tillage crops receiving low water, fertilizer, and pesticide inputs. Harvest intervals are being extended from two months to six months.

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

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

was administered by overhead sprinklers at planting and by flooding as needed thereafter.

Whole plots were harvested for green-weight determinations at 10, 20, and 30 weeks following seeding. Sub-samples consisting of ten whole plants per plot were harvested and dried in a forced-air oven for dry matter determinations. Identical sub-samples were also harvested for foliar mineral analyses. The entire blades of leaf ranks $^{+}1$ and $^{+}2$ were oven-dried, ground to pass a 40-mesh screen, and submitted to the AES Central Analytical Laboratory for total N, P, and K analyses.

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

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

Foliar N analyses were consistent with the view that Sordan 70A made little or no response to N-fertilization levels higher than 300 lbs/acre (Table 31). It should be noted that the dry matter and foliar N data are at least consistent with earlier data obtained by sand culture during Year 1 (1). At that time the N-response curve revealed an abrupt plateau for dry matter which could not be altered by large increases in nitrate-N supply.

It is now evident that the N-fertilization range established for this experiment was too high. The optimal level probably lies within the range of 100 to 300 lbs N/acre. This point can be verified rather easily with a small field plot experiment far less elaborate than the one presently described.

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

Tissue samples harvested weekly during the plants' growth and maturation phases similarly reveal little effect on maturation by the two controlled variables (Table 33). Plotted graphically (Figure 13), the maturation curves for low-N and high-N plants are seen to differ persistently from week 4 onward, with high N causing a moderate delay in maturation. However, this delay amounts only to a week or less in the maturation time-course. It is interesting to note that all plants experienced a minor increase in dry matter at about week 3 (Figure 13). This may have been caused by a temporary soil moisture stress.

(c) Plant Density, Lodging, and Downy Mildew: Increased seeding rates produced moderate increases in the number of harvestable stems (Table 34).

However, these gains did not reflect the large amounts of seed involved. Mean values for main effects indicate that plant number was increased by only 24 percent in response to a 100 percent increase in seed. Somewhat larger gains in harvestable plants resulted when seeding rates were increased within the lowest two N regimes (300 and 600 lbs/acre). These gains were negated in the higher N regimes (Table 34).

Some evidence of downy mildew was detected at about the fifth week of the study. By week 10 the disease had spread in varying degrees to all plots. The infection was not sufficiently severe to reduce yields among any of the treatments; however, the apparent severity of this disease was visually ranked on a numerical scale to determine whether it was directly related to the N-and seeding-rate variables. Some evidence of lodging was also visible in certain plots by week 10, and this was similarly rated on a numerical scale while the plots were being harvested. The numerical rankings indicate that downy mildew became moderately more severe with increasing levels of N fertilization (Table 35). Lodging was apparently unrelated to the variable N levels. In a similar vein, neither downy mildew nor lodging were related to variations in seeding rate (Table 36).

3. Sugarcane and Napier Grass Trials; Lajas Substation

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

(a) Increased Fertilization and Crown Maturity: During Year 1, sugarcane received nitrogen at the rate of 300 lbs per acre applied in three increments (1/3 at planting, 1/3 at 4 months, and 1/3 at 8 months). Napier grass received 600 lbs of nitrogen per acre applied in three increments at the same time intervals. For Year 2, these levels were increased to 600 and 1200 lbs per acre for sugarcane and napier grass, respectively, by increasing the number of incremental applications from three to six (ie, to six applications at two-month intervals).

Growth data for the plant crop had revealed major growth surges in the two months following the application of each fertilizer increment, followed by growth decline for the subsequent two months preceeding the next fertilizer increment (Figure 14). This response was more pronounced for napier grass than for sugarcane. One potential effect of applying fertilizer at two-month intervals rather than four months would be a persistent growth surge throughout the crop's second year. Added to this, the increased maturity of the plant crowns (particularly for sugarcane) might logically sustain greater yields throughout Year 2.

(b) Growth Responses; Two-and Four-Month Harvests: Biomass yields for the first two 2-month harvests and the first 4-month harvest of Year 2 were summarized and discussed in the previous quarterly report (9). Yields for the third, fourth, and fifth 2-month harvests (Tables 37, 38 and 39), and the second 4-month harvest (Table 40) are herein reported.

Yield increments for the third and fourth 2-month harvests were progressively lower (Tables 37 and 38) than those reported earlier in the ratoon crop (9). This is possibly a reflection of Puerto Rico's "winter" season (mid-December through mid-March). For varieties PR 980 and PR 64-1791, this also reflects a varietal inability to sustain crown vigor under the rather severe stress of repeated harvest at close intervals. The fourth recutting, for example, produced on the whole little more than 1/3 of the dry matter obtained from July through November. At this writing (June, 1979) many of these plots are losing their sugarcane crowns entirely; space formerly occupied by cane is being overgrown by Johnson grass. The sugarcane variety NCo 310 still retains considerable vigor. Napier grass yields also declined in the December-March period but proportionately less so than for sugarcane. In no instance was a consistent trend observed in response to narrow row centers.

The fifth 2-month harvest revealed an increase of productivity (Table 39). This growth interval, covering the period March 15 to May 15, represents Puerto Rico's spring and early summer. The renewed productivity is hence interpreted as a seasonal response.

Somewhat more favorable yields were obtained from the second 4-month harvest (TAble 40). Nontheless, dry matter production for sugarcane was only 40-50 percent of the levels obtained earlier under "summer" conditions (9). Napier grass yields also were about 40 percent lower for the second 4-month harvest. Again, no appreciable differences could be shown for the narrow-row treatments (Table 40). Hence, seasonal effects on plant yield are more evident in the first-ratoon crop than in the plant crop, since in this case yield decline cannot be attributed to lack of nitrogen.

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

Consistent differences have now emerged in the performances of individual sugarcane varieties (Table 42). Variety NCo 310 was apparently superior to PR 980 and PR 64-1791 at each harvest interval. The trend was most pronounced at the 2-month interval where NCo 310 exceeded PR 980 and PR 64-1791 by 144% and 86%, respectively. There was no consistency of performance, on a varietal basis, at the same stage of data accumulation for the plant crop (9).

At the tenth month into Year 2, ratoon-crop yields as main effects differ in several respects from the plant-crop yields (Tables 43 and 44). As already indicated above, sugarcane ratoon yields were clearly inferior at the 2-month harvests. The 4-month harvest totals are about the same for Year 1 and Year 2, while 6-month data indicate a ratoon-crop superiority of about 33% (Table 43). Napier grass yields are very comparable for the plant and ratoon crops.

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

(d) Trash Yields: Since around 1960, when mechanical harvest machines had largely replaced hand labor, Puerto Rico's sugar industry has been disposing of sugarcane trash by burning the mature cane stands as a preharvest operation (26). By this means less fiber was deliverd to the sugar factory and the machine operator's task was eased considerably. Preharvest burning has highly variable effectiveness, however, and it was still necessary to clean incoming cane by "wet" or "dry" cleaning equipment installed at the site of delivery. Moreover, the practice is both wasteful of energy (roughly 12 to 16% of the total biomass energy/crop) and is a source of air pollution. By law, Puerto Rico's cane industry will be required to cease burning trash in the open field by January 1, 1981 (26).

Hence, sugarcane trash is seen as a valid biomass source which must be credited to the total energy yield capability of future sugarcane-energy plantations in Puerto Rico (27). Project cane harvests have included the collection and weighing of trash at the 12-month harvest (15). Both cane and napier grass trash was collected at this time. Trash is also being collected and weighed for the ratoon crop, this time beginning with the 6-month harvest (Table 45). Yields of this material from both cane and napier grass amounted to less than two tons/acre. This figure should increase several-fold between months 6 and 12 (15). Total dry matter yields, ie, standard harvest material plus trash, are presented in Table 46. Taken together as main effects, sugarcane yields at six months into the ratoon crop are 33% higher than at the same period for the plant crop, and napier grass yields are 4% higher.

(e) Juice Quality Responses (Year 1 Data): Juice quality data from the sugarcane and napier grass trials of Year 1 became available during the first quarter of Year 2. Hand refractometer values (a rough estimate of soluble solids in raw juice) is presented for cane samples aged 6 months and older in Tables 47-49. Moderate increases in juice quality were recorded between months 6 and 12, although none of the values are especially high. A "sweet" or high sucrose variety ready for harvest should give hand refractometer readings in the order of 22 to 23. Nonetheless, several trends were evident, including a superiority of the variety NCo 310 (Table 48), and of the narrow row center (Table 49). The latter trend may signify considerable importance if it holds also for recoverable fermentable solids. It suggests that the increased sugarcane densities needed for total biomass production may not result in lower cane quality.

The long-term outlook for Puerto Rico's sugarcane industry holds that high-test molasses for ethanol production, together with cane fiber as a boiler fuel and feedstock for cellulose-based industries, will be the principal objective for both field and factory managers (28). This is a break from the traditional emphasis on refined sucrose for domestic and foreign sales which dominated the industry for more than a century. The change in emphasis reflects the high cost of producing sucrose in Puerto Rico today (about 28 cents/pound in 1978), but it also underscores the need to develop sugarcane as "energy cane" (29,30,31,35) while supporting the local rum industry with both qualitative and quantitative increases in fermentation feedstocks (28,32).

In an energy cane context the parameter Brix becomes the most meaningful measure of energy cane quality. Brix values, together with polarization, purity, rendiment, and fiber data from the 6-and 12-month harvests of Year 1, are presented in Table 50. Brix values are slightly lower (at 12 months) than one would ordinarily expect from conventional cane managed for sucrose (a value of 14 to 16 would be normal for PR cane). This probably reflects the higher input of water and fertilizer received by this cane in our attempt to maximize total biomass. There were no consistent effects of narrow row centers on Brix data, and only slight differences on a varietal basis. Hence, assuming an essentially constant recovery of fermentable solids (85-88% would be normal for PR cane), the highest production of total fermentable solids should mainly be a function of the highest tonnage of millable cane that can be obtained through intensive cane management.

The importance of maximizing the tonnage of millable cane for increased yields of fermentable solids cannot be overemphasized (28). An example of this is presented in Table 51, using the average yield of Puerto Rico's cane industry in 1978 (30 green tons/acre), plus the approximate mean value for first-year millable cane from the present project (80 green tons/acre). Also listed is a projected tonnage for first-and second-ratoon cane from the same project (100 green tons/acre). Immediately evident is the large increase of fermentable solids that will accrue even with low Brix (13.1%) and a conservative extraction estimate (85%). The low Brix value is normal for sugarcane continually forced toward high biomass tonnage without regard for sucrose. The relatively low extraction estimate reflects the expected sugar losses arising from higher fiber and cane residues delivered to the factory (33,34). Yet, these "losses" are quite negligible when viewed in the context of the two-to three-fold increases in tonnage of energy cane over conventional sugarcane. Again, in this scenario it is high-test molasses and fiber rather than sucrose that constitute the prime management objectives.

(f) <u>First Ratoon Trends; Main Effects for Cane and Napier Grass</u>: While the first-ratoon crop data are incomplete at this writing (June, 1979), several trends are evident for the first six months of Year 2 (Table 52). For purely botanical reasons the cane plant will normally produce more dry matter for at least two ratoon crops following the plant crop (ie, following the first year's productivity from the original seeded cane). However, as indicated by the summary data in Table 52, the first-ratoon response for sugarcane is heavily reliant on the frequency of harvest. Ratoon plants harvested at 2-month intervals were no more productive than were their first-year predecessors. Ratoon plants harvested at 4-and 6-month intervals produced about 65% and 43% more dry matter than had the first-year cane, respectively. This trend toward a lesser-difference between plant-and first-ratoon cane yields should continue throughout the second year, a first-ratoon superiority in the order of 20% being about normal for PR cane. Second-ratoon yields should equal or slightly exceed those of the first ratoon crop. For napier grass, ratoon yields were markedly higher for both the 2-and 4-month harvest intervals (Table 52).

A curious feature of the 4-and 6-month cane is the much greater increase of dry matter than green matter in the ratoon plants (Table 52). This effect, although noted previously (1), is extremely difficult to explain on a physiological basis. In essence, two sets of plants of the same species, having the same calendar age and agronomic care show widely differing physiological ages, that is, in terms of tissue expansion and maturation. The only variable factor here is the age of the crown; hence, the maturity of above-ground shoots of equal age can apparently vary as a function of the age or degree of development of the crown and root system.

4. Sordan 70A and Napier Grass Trials

A second field-plot study was established during January of 1978 for direct evaluations of Sordan 70A and napier grass (Common Merker) as short-rotation candidates. Two napier hybrids (PI 7350 and PI 30086) were also tested for the first time as possible replacements for Common Merker. PR 980 was retained as a reference clone. This experiment was conducted at the semi-arid Lajas Substation under soil and climatic conditions identical to those described earlier (1). Common Merker, the napier hybrids, and PR 980 were planted at 50 cm row centers, ie, approximately the commercial spacing for napier grass but about 1/3 the commercial distance for PR 980. Sordan 70A was seeded at 25 cm row centers, slightly farther apart than the standard seed-drill setting of 22.5 cm for this crop. Harvest intervals were at two, four, and six months. Overhead irrigation amounting to about two acre inches was

TROPICAL GRASSES EVALUATED AS SHORT-ROTATION CANDIDATES; LAJAS, 1978

Cultivar	Species	Row Center (cm)	Harvest Interval
PR 980	*Saccharum* Hybrid	50	2, 4 & 6 Months
Common Merker	*Pennisetum purpureum*	50	" " " "
PI 7350	*P. purpureum* Hybrid	50	" " " "
PI 30086	*P. purpureum* Hybrid	50	" " " "
Sordan 70-A	Sorghum x Sudan Hybrid	25	" " " "

applied at planting and at four weeks, and flood irrigation was administered at 10 weeks. Fertilizer was given in three increments; 1/3 at planting, 1/3 at two months, and 1/3 at four months.

Harvests for this experiment were only partially complete at the close of Year 1. Yields are presently reported on finalized data from three 2-month harvests, one 4-month harvest, one 4-month plus 2-month harvest, and one 6-month harvest (Table 53). Salient findings from this study include the following:

- Sordan 70A (an NK hybrid) is a very superior short-rotation candidate
- Napier grass is a superior intermediate-rotation candidate
- Napier hybrid No. 30086 is superior to common napier grass
- 6-month maximum yields are in the order of 10 and 15 dry tons/acre, for Sordan and napier grass, respectively.

These data essentially verify the incomplete results reported earlier (1). Important implications for biomass research, and for energy planting in collaboration with food planting, are discussed in detail in that report.

(a) Final Tonnages; 6-Month Harvest: The final harvest for this experiment was taken during the first quarter of Year 2. The 6-month data verified a very favorable growth potential of Sordan 70A when harvested repeatedly at 2-month intervals. This hybrid equalled or exceeded the yield capacity of the three napier grasses and vastly exceeded that of PR 980 (Table 53). When four months were allowed for plant development, napier grass emerged as the superior producer while the sugarcane control still lagged behind. Sugarcane improved its yields markedly at six months but remained inferior to napier grass. Among the three napier grass varieties tested, the Plant Introduction hybrid 30086 significantly out-produced the standard variety common Merker (Table 53).

(b) Trash Yields: Trash data were recorded for the five varieties at 6 months (Table 54). Relatively little material was expected yet roughly one ton/acre was collected for sugarcane and the napier grasses. This amounts to approximately 8 to 10 percent of the total dry matter yield over a time-course of six months. Sordan 70A produced virtually no trash. The highest yield for total dry matter (trash plus intact plants) was 15.3 tons/acre, obtained from napier hybrid PI 30086. This was significantly higher than the Common Merker yield of 12.7 tons/acre [1/].

(c) Response to Variable Crown Establishment Periods: An important but difficult question underlying the use of tropical grasses for frequently-recut biomass is the time required for crowns and root systems to be fully established, that is, to develop to the point where they can best withstand the "shock" of repeated harvests at 6-to 10-week intervals. For example, should harvests planned for 2-month intervals be initiated two months after seeding, or should four months or a year elapse before such harvests are begun? The project's limited resources have not allowed this point to be studied as a controlled variable. Some limited information was obtained from the present experiment owing to the 2-, 4-, and 6-month harvest intervals tested in a 6-month study. The plants from the 4-month harvest were recut at six months, thereby providing a "4 months plus 2 months" harvest in which 2-month old plants were cut from crowns having four previous months to become established. This contrasts with prior 2-month harvests, all of which were performed either two months after seeding or two months after a prior harvest.

Mean values for the five test varieties indicate that tonnages of 2-month old tops were increased by about 50 percent if crowns were allowed either two or four months development time before the first 2-month growth performance is measured (Table 55). Putting this another way, the two months of measured growth was significantly less productive when reckoned from the day of seeding rather than from established crowns. This in itself is not surprising since the

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1/ Some question remains as to whether or not common napier grass is actually less productive than hybrid forms, or whether there is a difference in the amount of water needed for their maximum yields to be realized (36).

germination process is a time-consuming factor. However, there was no appreciable difference between the yields from 2-month old crowns and 4-month old crowns. This suggests that the pre-establishment of crowns is important only up to a very limited point in time, possibly just enough time to compensate for the growth period lost in the initial germination process. This is substantiated by the fact that Sordan 70A, the only direct-seeded variety and the only variety noted for its rapid germination, was also the only candidate producing superior growth when measured from the day of seeding rather than from an established crown (Table 55).

With Sordan 70A it would be clearly to the planter's advantage to perform his first 2-month harvest at two months from the time of seeding—and this in fact is a principal characteristic of an authentic short-rotation species. For the three napier grasses it could very well be better to perform the first harvest at four months after seeding. With sugarcane, the question of crown establishment becomes a mute point since the plant is obviously neither a short- nor intermediate-rotation candidate. For long-rotation candidates such as sugarcane the process of crown establishment would be accommodated within the long time lapses between planting and the first harvest, and between all subsequent harvests.

5. Minimum Tillage Studies; Lajas Substation

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

The first experiment involving minimum tillage conditions was conducted during the spring and summer of 1978. Five clones were planted in 1/50 acre plots on a Fraternidad Clay soil characteristic of the AES-UPR Lajas Substation (38). These clones included three with predominantly S. spontaneum germplasm (US 67-22-2, US 72-72, and US 72-93), a wild Saccharum clone believed to a S. spontaneum hybrid, and the interspecific hybrid PR 980 serving as the reference clone. A single fertilizer application containing 100 lbs. of N/acre was given at planting together with about two acre inches of water. Two additional irrigations of approximately two acre inches each were administered during the course of the experiment. Germination was very poor for the S. spontaneum hybrid, but all other clones experienced excellent germination and vigorous early growth.

A single harvest was taken at six months. The leading biomass producer was US 67-22-2, while the S. spontaneum hybrid lagged behind owing to its very sparse stand (Table 56). Both green-and dry-matter yields for US 67-22-2 were significantly greater than those of the reference clone PR 980. Trash yields were exceptionally high for 6-months old plants (Table 57), but this was probably a result of the generally low water supplies which totalled only six acre inches above natural rainfall. Under these conditions sugarcane tends to shed its oldest leaves as a water-conserving measure. Low N supplies may also have been a factor, although no visible deficiency symptoms were observed.

At first glance the yield data for total dry matter do not appear impressive (Table 57), until one recalls that this was only a 6-month experiment with rather meager production inputs. Yields for PR 980 (9.0 tons) were consistent with those at six months from a more intensive propagation regime (Table 58 , 8.6 tons for PR 980). Moreover, this was exceeded significantly by US 67-22-2 (10.9 tons). This in fact compares very favorably with the Island's sugar industry average which is placed in the order of about 9 dry tons/year.

C. FIELD-SCALE STUDIES

1. Purpose

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

2. Species Categories

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

The first category deals with standing biomass in the order of 15 to 25 green tons/acre. Sordan 70A, a short-rotation crop, is characteristic of species having yields of this magnitude. The project's approach to such materials is to harvest them as solar-dried forages. The machinery tasks will vary with the state of the crop's maturity, ie, with plants having from 10 to 12% fiber at six weeks to 30 to 35% fiber at 12 weeks. A second category deals with standing biomass in the order of 25 to 50 green tons/acre. The representative species here is napier grass, an intermediate-rotation crop whose dry matter content is maximized between four and six months after planting (9). Again the crop's state of maturity is critical to the success or failure of harvest machinery. Harvested at two months of age (8-12% moisture) napier grass should offer no more difficulty than conventional cattle forages. At six months, offering 35% dry matter and up to 50 green tons/acre of standing biomass, the harvesting task may possibly exceed the capabilities of existing forage-making equipment (39). The project's plan is to try to handle such crops as solar-dried forages.

Biomass crops offering more than 50 green tons/acre comprise a third category of harvesting tasks. The characteristic species here are the hybrid sugarcanes of commerce. There is no possibility of dealing with these plants as forage crops. Not only is there an excessive mass of material confronting the harvest machinery, but also the thickened cane stems do not lend themselves to solar drying, unless first prepared by some process of milling and juice expression. Project plans are to use a combination of solar drying (for leaves and "trash" removed in the field) and mill dewatering for the cane stalks. Bagasse issuing from the sugar mill might also be solar dried and baled, or at least partially dried by stacking in the open air. A harvest machine capable of handling cane in excess of 50 tons/acre is the Klaus Model 1400, single row, whole cane harvester. This machine removes leaves and trash in the field with a powerful air blast, thereby preparing a clean, billeted, and physically organized whole cane for delivery to the mill.

3. Initial Machinery Trials

Most of the project's field machinery arrived on the Island during the third quarter of Year 2. Specific items include a Model 8700 Ford tractor, an M-C Model 9-E Rotary Scythe (with 9-foot mowing swath), a heavy-duty, side-delivery forage rake (New Holland Model 57), a New Holland Model 851 Round Baler, and a New Holland Model 393 Tub Grinder.

(a) Trials With Johnson Grass: Preliminary tests were performed with the rotary scythe using wild Johnson grass (*Sorghum halepense*) as the test material. This implement does not cut or mow grasses as does a conventional sickle-bar mower, but rather breaks off and "conditions" the grass with a series of steel plates rotating at high speed with extremely powerful force (Figure 15). The conditioned material is deposited in windrows of adjustable width directly behind the mower. The rotary scythe is a thoroughly rugged machine (40). Relatively few factors can inhibit its performance short of an inadequate power supply (tractors having less than about 90 hp), or the encountering of plant materials of sufficient mass to stop the blades or the tractor engine.

No difficulty of any kind was encountered in the first trial with Johnson grass. This material amounted to roughly 10 to 12 green tons/acre. The rotary scythe was moved to a second field where Johnson grass had grown wild for several years. The implement performed quite adequately, with the exception of "heavy" areas where accumulating dead Johnson grass had formed mats approximately two to three feet thick. In such areas the mats sometimes tended to push ahead of the implement rather than pass under it in contact with the rotating blades. It should be noted that the rotary scythe is designed to function most effectively on individual plant stems. The stems would preferably be upright but the rotary scythe is also designed to harvest lodged material.

All of the materials that were harvested (conditioned) with the rotary scythe were effectively solar-dried within three to four days. The drying process was assisted by turning the windrows twice with a side-delivery forage rake. The Round Baler performed quite effectively on Johnson grass with initial bales weighing in the order of 1000 to 1200 pounds.

(b) Trials With Sordan 70A: Sordan 70A was the first biomass candidate scheduled for field-scale harvesting trials. Four blocks of approximately six acres each were planted at the close of the third quarter. Seeding rate was 60 pounds/acre, drilled in 9-inch row centers in two directions on the field. The planting of these fields was delayed approximately two months owing to atypically heavy rainfall in December-January, 1978-79. Harvests for the respective blocks of Sordan 70A were performed at 6, 10, and 14 weeks after seeding.

Performance ratings for the rotary scythe are presented in Table 59. The 6-week old material presented no problems of any kind for this machine. The plants were completely upright and succulent. Initial concern that the relatively long stems (averaging 5 1/2 to 6 feet) [1/] might cause them to fall backward over the rotary scythe, rather than forward to pass under the rotating blades as intended, were unfounded. All of the upright material fell forward

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[1/] When mowing conventional cattle forages (as its manufacturer intended) the rotary scythe will rarely encounter plant materials more than about three feet high. Hence, the leading edge of the implement which strikes the upright stems will cause them to fall forward without problems. This is not necessarily true of tropical grasses which are much taller and thicker-stemmed, and which offer greater resistance to the rotary scythe.

without exception (Figure 16). Nor was there any tendency to form balls or mats in front of the mower, even when operating at "high" speed (in the fourth and fifth forward gears of the Model 8700 Ford Tractor).

A much worse set of harvest conditions was experienced for the 10-and 14-week old crops, but the rotary scythe nonetheless gave a very satisfactory performance (Table 59). Extremely heavy and unseasonal rainfall was received intermittantly from week 8 through week 13. This caused moderate to severe lodging in both the 10-week and 14-week old plants. In both instances much of the Sordan 70A was flattened to a height of 8 to 12 inches and was severely matted, that is, the stems had cris-crossed and interlaced in all directions. The plants harvested at 14 weeks had remained in this condition up to five weeks. During this interval, the matted Sordan 70A was further interlaced with herbaceous weeds (both vines and upright grasses) plus a regrowth of secondary Sordan 70A plants stimulated by the heavy rainfall. Together with the abnormally soft seedbed, these conditions offered the worst possible circumstances that one can reasonably expect in harvesting short-rotation crops. However, the rotary scythe performed quite adequately. At no time was it necessary to stop and clear the machine [1/] of balled grasses, and only occasionally was it necessary to shift into a lower operating gear.

A period of intermittant rainfall following the 10-week harvest caused considerable difficulty in drying the conditioned biomass. Good weather followed the 14-week harvest. This material was solar-dried and ready for baling within three days.

Baling operations for the solar-dried Johnson grass and Sordan 70A were performed without encountering major problems (Figures 17 and 18). Minor

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[1/] Such stops would have been an almost continuous feature if we had attempted to harvest the 14-week old material with a sickle-bar mower.

problems incident to hydraulic connections between the Baler (a New Holland product) and the project's Ford tractor were easily corrected. Because no one on the project staff was directly familiar with the baler's operation, it was necessary to practice its handling on solar-dried weeds and Johnson grass. For example, the correct amount of twine needed for a 1500 pound bale , about 150 feet, was determined by trial and error. Such factors as the baler's best operating speed, the correct size and compaction of the bale, and the amount of twine needed to secure the bale for subsequent loading and transport operations are largely a matter of judgement by the machinery operator confronted with a specific set of conditions.

D. ECONOMIC ANALYSES

The project's initial economic analyses were performed at the close of Year 2. Production cost estimates for Sordan 70A, including solar drying, baling, and delivery to a centralized combustion site, were prepared on the basis of field-plot and field-scale data obtained since Sordan 70A was identified as an authentic short-rotation species during Year 1 (1). Total costs are in the order of \$24.00/oven-dry ton, or about \$1.60/million BTU's (Table 60).

Cost estimates are based on a hypothetical 200 acre energy plantation operating in the Lajas Valley with current production input costs and dollar values for Puerto Rican agriculture. A 200 acre energy farm can be accommodated comfortably with a single set of forage-making machinery such as that being utilized for project studies. Specific figures for Sordan yields and production input parameters are derived directly from project data compiled during Years 1 and 2. Machinery purchase, maintenance, and operation costs are also based on project data. Biomass delivery cost (at \$6.00/dry ton) is the only purely estimated figure in the expenditure analysis. It is based on 1979 rental rates for a 40 ton, low-bed truck (at $125.00/8 hour day), two drivers/ truck/8 hour day (at $25.00/driver), field loading of the low-bed truck with hired equipment and equipment operator, delivery of four 25-ton loads/day/ truck, and unloading the truck at the combustion site with hired equipment and equipment operator.

The cost estimate of $6.00/ton is probably a bit high. Sugarcane, for example, was being delivered for about $4.80/ton throughout the Island during the 1979 cane harvest season. Moreover, an energy planter with a 200 acre operation would probably purchase his own truck and loading equipment, thereby reducing delivery charges by a significant amount.

It is very probable that Sordan 70A will be replaced by Sordan 77 as the principal short-rotation species during 1980. Sordan 77 should yield at least 20% more dry biomass with the same acreages and production inputs expended for Sordan 70A. If this projection is correct, and assuming a delivery cost increase of 20%, final costs for Sordan 77 would be in the order of $21.08/ ton, or about $1.41/million BTU's

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APPENDIX

Appendix Tables 1-60

Appendix Figures 1-19

TABLE 1. CATEGORIES OF CANDIDATE TROPICAL GRASSES

Cropping Category	Production Interval [1/] (Months)	DM Max. [2/] (Months)
Short Rotation	4-6	2-3
Intermediate Rotation	8-18	4-6
Long Rotation	36-60	12-18
Minimum Tillage	Indeterminate	(?)

[1/] Replanting frequency; at least one ratoon crop is anticipated.

[2/] Time required physiologically to maximize dry matter.

TABLE 2. BIOMASS PRODUCTIVITY PARAMETERS BEING EVALUATED DURING THE PROJECT'S GREENHOUSE PHASE 1/

Parameter	Performance (Relative to Reference Clone PR 980) Required For Field Plot Phase
Total Biomass	Superior
Growth Curve	Superior
Regrowth Rate	Superior
N Response	Equal Or Superior
Water Response	Equal Or Superior
Recutting Toerance	Superior
Insect Tolerance	Equal
Disease Resistance	Equal
Tillering Density	Superior

1/ Plants propagated by sand culture or in soil-cachaza mixtures.

TABLE 3. DRY MATTER YIELDS FOR NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70A PROPAGATED IN THE GREENHOUSE AND HARVESTED AT INTERVALS OF SIX WEEKS

Cultivar	Kg/Plot [1/] For Production Interval –					Total Yield	% Of PR 980
	Week 1-6	Week 7-12	Week 13-18	Week 19-24	Week 25-30		
PR 980 (Reference)	0.21	0.37	0.35	0.18	0.14	1.25	100
Napier Grass	0.75	0.60	0.50	0.27	0.36	2.48	198
Napier Hybrid 7350	0.65	0.44	0.51	0.27	0.41	2.28	182
Napier Hybrid 30086	0.78	0.60	0.65	0.34	0.67	3.04	243
Sordan 70A	0.84	0.38	0.42	0.16	0.24	2.04	163

1/ Unreplicated greenhouse trial.

TABLE 4. DRY MATTER CONTENT (%) FOR NAPIER GRASS, NAPIER HYBRIDS, AND SORDAN 70A HARVESTED AT INTERVALS OF SIX WEEKS [1/]

Cultivar	% DM For Production Interval –					Mean
	Week 1-6	Week 7-12	Week 13-18	Week 19-24	Week 25-30	
PR 930 (Reference)	16.9	17.0	21.1	16.9	24.3	19.2
Napier Grass	10.3	12.5	14.9	14.2	20.6	14.5
Napier Hybrid 7350	13.5	14.7	15.5	11.9	16.0	14.3
Napier Hybrid 30086	11.3	13.7	15.4	12.0	18.2	14.1
Sordan 70A	11.7	15.5	19.9	12.7	23.4	16.6

1/ Unreplicated greenhouse trial.

TABLE 5. GROWTH PERFORMANCE OF THREE NK HYBRID FORAGE GRASSES [1]

NK Variety	Green Wt (g/Plant) At Week – 4	6	8	10	12	14	Mean
Millex	21.5 a	41.2 a	39.8 a	30.3 a	31.7 a	26.7 b	31.9
Trudan-5	30.2 a	52.9 a	47.3 a	31.5 a	43.9 a	38.3 a	40.7
Sordan 70A	34.3 a	46.7 a	50.0 a	44.0 a	48.1 a	48.5 a	45.3
	Dry Wt (g/Plant) At Week –						
Millex 23	1.5 a	5.5 a	8.6 a	7.0 a	9.0 a	7.8 b	6.6
Trudan-5	2.6 a	8.5 a	11.8 a	12.9 a	14.3 a	13.3 a	10.6
Sordan 70A	3.0 a	7.3 a	11.1 a	12.6 a	15.5 a	15.9 a	10.9
	Dry Matter Content (%) At Week –						
Millex 23	7.4 a	13.1 a	21.0 a	22.8 b	28.3 b	29.0 b	20.3
Trudan-5	8.5 a	16.0 a	27.0 a	31.4 a	32.5 a	32.0 a	24.6
Sordan 70A	8.7 a	15.6 a	24.1 a	26.3 ab	32.2 a	31.5 a	23.1

[1] Developed by the Northrup-King Company, Minneapolis, Minn.

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

TABLE 6. DRY MATTER YIELD OF SEVEN NORTHRUP-KING GRASSES

NK Variety	Dry Matter (g/Plant), At Week –					Mean
	3	4	5	6	7	
Sordan 70A	0.9 a	2.3 a	5.3 a	6.0 ab	10.5 a	5.1
Sordan 77	0.9 a	2.3 a	4.8 a	6.7 ab	8.2 ab	4.6
Trudan 5	0.8 ab	2.2 ab	4.3 ab	5.7 b	8.1 ab	4.2
Trudan 7	0.7 ab	1.9 b	4.2 ab	5.9 ab	8.8 ab	4.3
Millex 23	0.6 b	1.8 b	3.6 b	3.6 c	5.2 b	3.0
NK 300	0.8 ab	2.2 ab	4.2 ab	7.6 a	9.4 a	4.8
NK 326	0.8 ab	2.0 ab	4.3 ab	6.6 ab	7.5 ab	4.2

1/ Mean values in the same column bearing unlike letters differ significantly ($P < .05$). Mean values bearing one or more letters in common do not differ significantly.

TABLE 7. DRY MATTER YIELDS BY EIGHT CANDIDATE TROPICAL GRASSES PROPAGATED UNDER GLASS WITH SIMULATED NORMAL, SEMI-ARID, AND ARID MOISTURE REGIMES

Simulated Water Regime	Candidate	Total DM (Kg) For Planted Area 1/	% Of Control
Normal	Sordan 70A (Control)	5.12	100
	Sordan 77	5.90	115
	Trudan 5	5.41	106
	Trudan 7	4.98	97
	Millex 23	2.94	57
	NK 300	5.31	104
	NK 326	5.23	102
	Johnson Grass	4.25	83
Semi-Arid	Sordan 70A (Control)	2.67	100
	Sordan 77	3.36	126
	Trudan 5	2.94	110
	Trudan 7	2.99	112
	Millex 23	2.70	101
	NK 300	3.37	126
	NK 326	3.61	135
	Johnson Grass	3.29	123
Arid	Sordan 70A (Control)	1.98	100
	Sordan 77	2.71	137
	Trudan 5	1.87	94
	Trudan 7	2.07	105
	Millex 23	1.44	73
	NK 300	2.38	120
	NK 326	2.46	124
	Johnson Grass	2.31	117

1/ Approximately 30 square feet.

TABLE 8. DRY MATTER YIELDS BY EIGHT TROPICAL GRASSES PROPAGATED WITH VARIABLE WATER SUPPLY OVER A TIME-COURSE OF TEN WEEKS [1/]

Simulated Moisture Regime	Variety	Dry Matter (g/Plant), At Indicated Week – 3	4	5	6	7	8	9	10	Mean
Normal	Sordan 70A	1.1	2.3	5.1	5.9	7.1	10.3	12.8	12.4	6.9
	Sordan 77	1.1	3.1	4.5	8.3	8.1	13.8	18.1	16.0	9.1
	Trudan 5	0.8	2.2	4.6	5.2	9.1	10.4	15.9	11.1	7.4
	Trudan 7	1.0	2.7	5.4	7.5	9.0	11.7	13.1	14.1	8.1
	Millex 23	0.7	2.1	4.0	4.5	4.1	5.2	5.5	5.5	4.0
	NK 300	1.0	2.4	4.0	6.8	7.1	10.3	8.5	9.6	6.2
	NK 326	1.0	2.1	4.5	5.9	8.0	9.9	15.2	11.5	7.3
	Johnson Grass	0.5	1.4	3.5	4.7	6.0	5.2	5.6	6.6	4.2
	Mean	0.9	2.3	4.5	6.1	7.3	9.6	11.6	10.9	6.7
Semi-Arid	Sordan 70A	1.5	3.4	3.9	4.1	5.0	6.6	9.6	10.2	5.5
	Sordan 77	1.5	2.9	4.0	5.1	5.0	5.7	8.5	10.1	5.4
	Trudan 5	1.6	3.4	4.7	4.3	5.1	5.5	8.8	10.6	5.5
	Trudan 7	1.1	2.4	3.5	4.6	4.1	5.0	5.4	7.4	4.2
	Millex 23	1.3	2.8	4.0	3.1	4.0	3.8	3.0	5.9	3.5
	NK 300	1.1	2.3	3.7	4.1	4.1	4.6	6.9	9.5	4.5
	NK 326	1.2	2.7	4.1	5.3	4.1	5.9	6.9	7.1	4.7
	Johnson Grass	0.5	1.4	2.5	3.1	2.1	4.0	3.6	6.8	3.0
	Mean	1.2	2.7	3.8	4.2	4.2	5.1	6.6	8.5	4.5
Arid	Sordan 70A	1.5	2.7	3.1	4.0	3.0	4.5	4.9	6.7	3.8
	Sordan 77	1.3	2.1	2.7	4.0	5.0	5.7	5.6	6.6	4.1
	Trudan 5	1.4	2.0	3.2	3.1	3.1	3.7	3.5	6.2	3.3
	Trudan 7	1.1	2.2	3.0	3.0	4.0	4.4	5.0	5.1	3.5
	Millex 23	0.9	2.2	3.7	2.1	4.0	3.9	3.4	3.6	3.0
	NK 300	0.9	2.0	2.8	3.0	3.0	3.3	3.5	4.6	2.9
	NK 326	1.0	2.1	2.2	3.0	3.0	3.6	4.0	4.7	3.0
	Johnson Grass	0.5	1.5	2.2	2.0	2.0	2.5	3.1	4.7	2.1
	Mean	1.1	2.1	2.9	3.0	3.4	4.0	4.1	5.3	3.2

1/ Unreplicated observation experiment.

TABLE 9. DRY MATTER CONTENT OF EIGHT TROPICAL GRASSES PROPAGATED WITH VARIABLE WATER SUPPLY OVER A TIME-COURSE OF TEN WEEKS [1/]

Simulated Moisture Regime	Variety	Dry Matter Content (%) At Weeks – 3	4	5	6	7	8	9	10	Mean
Normal	Sordan 70A	9.2	7.9	12.8	19.0	19.0	22.1	31.0	25.2	18.3
	Sordan 77	10.5	8.8	12.8	20.6	20.6	24.1	32.7	31.2	20.2
	Trudan 5	10.3	7.6	10.0	16.8	17.7	23.2	30.0	27.4	17.9
	Trudan 7	9.1	8.6	14.1	21.1	22.0	27.2	31.9	31.6	20.7
	Millex 23	8.2	7.3	12.7	20.0	21.3	23.7	26.1	23.7	17.9
	NK 300	10.2	9.1	13.6	21.4	20.5	25.7	31.4	28.5	20.1
	NK 326	9.5	8.1	11.0	16.1	18.5	21.5	35.3	25.3	18.2
	Johnson Grass	8.6	7.8	11.9	22.7	22.9	24.0	31.2	32.1	20.2
	Mean	9.5	8.2	12.4	19.7	20.3	23.9	31.2	28.1	19.2
Semi-Arid	Sordan 70A	10.0	10.7	13.8	20.9	16.6	19.6	24.6	26.9	17.9
	Sordan 77	11.2	12.5	16.4	25.6	20.9	22.8	29.2	33.4	21.5
	Trudan 5	9.6	9.7	14.0	23.0	16.8	22.2	33.5	29.1	19.7
	Trudan 7	10.8	11.7	15.9	26.5	20.9	25.1	32.7	34.9	22.3
	Millex 23	8.9	9.2	13.7	18.2	20.8	22.3	24.7	25.1	17.9
	NK 300	10.7	9.7	14.1	22.0	17.3	21.4	28.9	27.1	18.9
	NK 326	10.0	10.1	13.3	23.2	17.3	20.7	27.2	24.2	18.3
	Johnson Grass	12.8	7.6	14.2	25.4	16.5	24.8	31.3	40.0	21.6
	Mean	10.5	10.2	14.4	23.1	18.4	22.4	29.0	30.1	19.8
Arid	Sordan 70A	10.6	10.6	14.9	18.8	17.8	27.9	21.3	22.7	18.1
	Sordan 77	11.8	11.8	13.3	22.5	23.8	30.8	23.1	25.1	20.3
	Trudan 5	9.7	10.7	14.7	17.0	18.4	29.3	22.5	24.8	18.4
	Trudan 7	10.6	12.2	17.1	21.1	21.6	30.9	26.0	28.3	21.0
	Millex 23	8.2	9.2	14.3	15.2	21.0	29.5	24.2	23.8	18.2
	NK 300	10.0	12.2	16.7	22.0	20.5	27.9	24.6	24.5	19.8
	NK 326	9.6	11.3	16.9	20.1	18.5	27.9	21.0	23.0	18.5
	Johnson Grass	8.9	8.4	10.9	20.8	20.6	34.2	24.0	25.4	19.2
	Mean	9.9	10.8	14.9	19.7	20.3	29.8	23.4	24.7	19.2

1/ Unreplicated observation experiment.

TABLE 10. TOTAL DRY MATTER YIELD OF EIGHT CANDIDATE TROPICAL GRASSES; COMBINED YIELD OF TWO CROPS AND THREE MOISTURE REGIMES .

Candidate Grass	Total DM (Kg) For Planted Area 1/	DM Yield As % Of Control
Sordan 70A (Control)	11.60	100
Sordan 77	14.53	125
Trudan 5	12.21	105
Trudan 7	11.88	102
Millex 23	8.42	73
NK 300	13.04	112
NK 326	13.78	119
Johnson Grass	11.60	100

1/ Approximately 90 square feet.

TABLE 11. DRY MATTER PRODUCTION BY EIGHT CANDIDATE TROPICAL GRASSES HARVESTED TWO MONTHS AFTER PLANTING 1/

Cultivar	Genus & Species	Dry Matter g/Planted Area 2/	Dry Matter g/Plant	% DM
PR 980	Saccharum Hybrid	650	4.0	16.2
US 67-22-2	S. spont. Hybrid	1,055	3.4	17.2
US 72-70	S. spont. Hybrid	710	2.9	18.4
SES 231	S. spontaneum	1,090	2.1	20.0
Tainan	S. spont. Hybrid	1,370	2.9	16.4
Wild	S. spont. Hybrid	1,341	2.9	19.9
PI 30086	Pennisetum purpureum	3,032	8.0	14.1
Johnson Grass	Sorghum halepense	4,061	4.2	19.7

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

2/ Approximately 30 square feet.

TABLE 12. DRY MATTER CONTENT OF EIGHT CANDIDATE TROPICAL GRASSES HARVESTED AT 2, 4 AND 8 MONTHS AFTER PLANTING 1/

		DM (%) At Month —		
Cultivar	Genus & Species	2	4	6
PR 980	Saccharum Hybrid	16.2	25.6	
US 67-22-2	S. spont. Hybrid	17.2	25.5	
US 72-70	S. spont. Hybrid	18.4	27.2	(Incomplete Data)
SES 231	S. spontaneum	20.0	32.0	
Tainan	S. spont. Hybrid	16.4	34.7	
Wild	S. spont. Hybrid	19.9	32.3	
PI 30086	Pennisetum purpureum	14.1	35.4	
Johnson Grass	Sorghum halepense	19.7	38.2	

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

TABLE 13. DRY MATTER PRODUCTION BY EIGHT CANDIDATE TROPICAL GRASSES HARVESTED 2, 4 AND 6 MONTHS AFTER PLANTING 1/

Cultivar	Genus & Species	DM (Kg/Planted Area) 2/ At Month — 2	4	6
PR 980	_Saccharum_ Hybrid	0.65	8.26	(Incomplete Data)
US 67-22-2	_S. spont._ Hybrid	1.06	7.91	
US 72-70	_S. spont._ Hybrid	0.71	6.61	
SES 231	_S. spontaneum_	1.09	8.43	
Tainan	_S. spont._ Hybrid	1.37	9.05	
Wild	_S. spont._ Hybrid	1.34	7.87	
PI 30086	_Pennisetum purpureum_	3.03	19.31	
Johnson Grass	_Sorghum halepense_	4.06	6.67	

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

2/ Approximately 30 square feet.

TABLE 14. DRY MATTER PRODUCTION, INDIVIDUAL PLANT BASIS, BY EIGHT TROPICAL GRASSES HARVESTED 2, 4 AND 6 MONTHS AFTER PLANTING 1/

Cultivar	Genus & Species	DM (g/Plant) At Month — 2	4	6
PR 980	Saccharum Hybrid	4.0	42.4	
US 67-22-2	S. spont. Hybrid	3.4	26.5	
US 72-70	S. spont. Hybrid	2.9	20.4	(Incomplete Data)
SES 231	S. spontaneum	2.1	14.0	
Tainan	S. spont. Hybrid	2.9	18.1	
Wild	S. spont. Hybrid	2.9	17.8	
PI 30086	Pennisetum purpureum	8.0	95.8	
Johnson Grass	Sorghum halepense	4.2	6.8	

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

TABLE 15. DRY MATTER INCREASE, ON AN INDIVIDUAL PLANT BASIS, FOR EIGHT TROPICAL GRASSES AGING FROM THE SECOND TO FOURTH MONTH AFTER SEEDING 1/

Cultivar	Genus & Species	DM Increase (%), Month 2 to 4
PR 980	*Saccharum* Hybrid	1,060
US 67-22-2	*S. spont.* hybrid	779
US 72-70	*S. spont.* Hybrid	703
SES 231	*S. spontaneum*	667
Tainan	*S. spont.* Hybrid	624
Wild	*S. spont.* Hybrid	614
PI 30086	*Pennisetum purpureum*	1,198
Johnson Grass	*Sorghum halepense*	162

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

TABLE 16. GROWTH RESPONSES OF SORDAN 70A PLANTS GIVEN VARIABLE POLARIS TREATMENTS AT THREE WEEKS OF AGE

Polaris 1/ (ppm)	Green Wt (g/Plant) At Week — 0	2	4	6	8	Dry Wt (g/Plant) At Week — 0	2	4	6	8
0 (Control)	5.9 a 2/	37 a	50 d	67 a	49 a	0.5 a	4.4 a	9.5 b	15.4 a	15.6 a
50	6.2 a	39 a	52 cd	59 ab	44 a	0.5 a	4.7 a	10.0 ab	15.1 ab	14.8 a
100	6.3 a	41 a	65 ab	62 ab	47 a	0.5 a	4.8 a	11.3 a	14.6 ab	14.3 a
200	6.2 a	44 a	69 a	55 b	47 a	0.5 a	5.1 a	12.8 a	12.8 b	14.0 a
400	6.1 a	42 a	63 abc	60 ab	50 a	0.5 a	4.8 a	11.5 a	14.1 ab	15.3 a
600	5.9 a	40 a	56 bcd	56 b	46 a	0.5 a	4.8 a	10.6 ab	13.6 ab	14.1 a
	Moisture Content (%)					**Dry Matter Content (%) At Week —**				
0 (Control)	91.5 a	88.2 a	81.0 a	77.1 a	70.3 a	8.5 a	11.8 a	19.0 a	22.9 a	29.7 a
50	91.4 a	88.0 a	80.8 a	67.5 a	68.7 a	8.6 a	12.0 a	19.2 a	32.5 a	31.3 a
100	91.4 a	88.3 a	82.7 a	71.5 a	69.6 a	8.6 a	11.7 a	18.3 a	28.5 a	30.4 a
200	91.1 a	88.5 a	81.5 a	66.4 a	70.3 a	8.9 a	11.5 a	18.5 a	33.6 a	29.7 a
400	91.3 a	88.6 a	81.8 a	69.7 a	69.4 a	8.7 a	11.4 a	18.2 a	30.3 a	30.6 a
600	91.5 a	88.0 a	81.1 a	66.3 a	69.4 a	8.5 a	12.0 a	18.9 a	33.7 a	30.6 a

1/ Administered as aqueous foliar sprays containing Tween 20 as wetting agent.

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

TABLE 17. RESPONSES OF SORDAN 70A PLANTS TO GROWTH-INHIBITORY LEVELS OF POLARIS APPLIED AS AQUEOUS FOLIAR SPRAYS 1/

ppm Polaris	Plant Weights (g/Plant) Green Wt, At Week --				Dry Wt, At Week --			
	0	2	4	6	0	2	4	6
0 (Control)	30.1	48.3	55.0	50.1	3.8	11.1	14.3	16.2
1000	30.2	47.0	55.7	53.0	3.9	10.2	15.3	17.5
2000	25.7	45.3	48.7	50.7	3.4	9.6	12.1	16.1
4000	25.8	44.7	49.7	55.8	3.3	10.6	13.9	19.9
	% Dry Matter				% Moisture			
0 (Control)	12.3	22.8	26.0	32.3	87.7	77.2	74.0	67.7
1000	12.8	21.7	27.4	33.0	87.2	78.3	72.6	67.0
2000	13.2	21.1	24.9	31.8	86.8	78.9	75.1	68.2
4000	12.7	23.7	27.9	35.7	87.3	76.3	72.1	64.3

1/ Unreplicated observation experiment.

TABLE 18. DRY MATTER AND MOISTURE VALUES FOR SORDAN 70A PLANTS PROPAGATED WITH VARIABLE NITROGEN SUPPLIES IN SAND CULTURE

NO_3 (meq/1)	Dry Wt (g/Plant) At Week --				Dry Matter (%) At Week --				Moisture Content (%) --			
	4	8	12	Mean	4	8	12	Mean	4	8	12	Mean
1	.24 c [1/]	1.5 c	2.3 c	1.3	14.2 a	18.7 a	36.1 a	23.0	85.8 b	81.3 c	63.9 a	77.0
3	.37 a	3.3 b	4.2 b	2.6	12.9 b	17.5 a	33.6 a	21.3	87.1 ab	82.5 c	65.4 a	78.3
9	.56 a	4.5 a	5.9 b	3.7	12.0 c	16.5 ab	34.6 a	21.0	88.0 a	83.5 bc	67.7 a	79.7
27	.58 a	3.5 b	9.2 a	4.4	11.4 c	12.5 c	33.6 a	19.2	88.6 a	87.5 a	66.4 a	80.8
54	.56 a	3.9 ab	9.1 a	4.5	12.7 b	14.6 bc	39.5 a	22.3	87.3 ab	85.4 ab	60.5 a	77.7
81	.48 b	3.3 b	6.5 b	3.4	13.5 ab	15.7 ab	33.7 a	21.0	86.5 ab	84.3 abc	66.3 a	79.0
Mean	.45	3.3	6.2		12.8	15.9	35.1		87.2	84.1	65.0	

[1/] Mean values in the same column bearing unlike letters differ significantly ($P < .05$). Mean values in the same row (weeks 4-12) bearing unlike letters also differ significantly. Numerical values having at least one letter in common are not significantly different.

TABLE 19. PLANT DENSITY VALUES FOR SORDAN 70A PROPAGATED WITH VARIABLE NITRATE N IN SAND CULTURE

NO_3 (meq/l)	Stems/Plot 1/
1	249 ab 2/
2	234 ab
9	270 a
27	189 b
54	182 b
81	183 b

1/ Greenhouse bench space = approximately 1/250 acre. Data were recorded at 12 weeks after seeding.

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

TABLE 20. POST-HARVEST SHOOT PRODUCTION BY SORDAN 70A CROWNS GIVEN VARIABLE NITRATE N IN SAND CULTURE 1/

NO_3 (meq/1)	Shoots/Plot 2/	Dry Wt. (g/Plant)	Moisture (%)	DM (%)
1	660	4.0	79.0	21.0
3	664	8.2	75.0	25.0
9	830	8.0	82.0	17.5
27	1010	5.8	81.7	18.3
54	81	3.6	87.1	12.9
81	30	3.0	87.7	12.3

1/ Recut four weeks after termination of the variable NO_3 study.

2/ Each figure is the computed mean of three replications.

TABLE 21. FOLIAR N, P, AND K CONTENTS OF SORDAN 70A PLANTS PROPAGATED IN SAND CULTURE WITH VARIABLE NITRATE SUPPLY

NO_3 Level (meq/l)	Leaf Content (% Dry Wt) For —		
	N	P	K
1.0	1.10 d [1/]	0.24 d	1.69 b
3.0	1.35 c	0.28 cd	1.42 b
9.0	2.14 b	0.23 d	1.50 b
27.0	2.51 a	0.33 bc	2.04 ab
54.0	2.65 a	0.38 ab	2.23 a
81.0	2.69 a	0.40 a	2.27 a

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

TABLE 22. GREEN-AND DRY-MATTER YIELDS FOR NAPIER GRASS (Var. PI 30086) PROPAGATED BY SAND CULTURE WITH VARIABLE NITROGEN SUPPLY

Plant Age (weeks)	N Level (meq/l NO_3)	Yield (g/Plant)		
		Green	Oven-Dry	% DM
8	1	29	4.1	14.1
	3	54	7.1	13.1
	9	60	7.1	12.8
	27	77	9.2	11.9
	54	81	9.5	11.7
	81	81	9.4	11.6
12	1	60	10	16.7
	3	95	16	16.5
	9	153	31	20.2
	27	145	29	20.0
	54	125	24	19.2
	81	136	23	16.9
16	1	114	22	19.5
	3	217	44	20.3
	9	251	58	22.8
	27	200	49	24.5
	54	196	43	24.6
	81	188	47	24.7
22	1	154	36	23.0
	3	312	83	26.5
	9	359	86	23.8
	27	262	61	23.2
	54	204	53	25.9
	81	265	55	24.7

TABLE 23. DRY MATTER PRODUCTION BY SEVEN NORTHRUP-KING GRASSES PROPAGATED WITH VARIABLE WATER SUPPLY OVER A TIME-COURSE OF ELEVEN WEEKS 1/

Simulated Moisture Regime	Variety	Dry Matter (g/Plant), At Indicated Week – 2	3	4	5	6	7	8	9	10	11	Mean
Humid	Sordan 70A	.06	0.3	1.2	2.6	4.1	6.2	9.0	12.5	16.9	17.9	7.1
	Sordan 77	.07	0.4	1.4	3.1	4.5	4.9	5.4	8.2	14.0	15.3	5.8
	Trudan 5	.04	0.2	1.0	2.9	4.2	6.9	9.1	9.9	10.4	10.5	5.6
	Trudan 7	.04	0.3	1.3	2.6	4.0	5.1	5.8	8.0	11.1	11.3	5.0
	Millex 23	.03	0.2	0.7	1.5	3.9	3.9	4.4	4.7	5.2	5.0	3.0
	NK 300	.06	0.3	1.0	2.1	3.2	5.6	8.1	8.8	8.4	8.8	4.7
	NK 326	.06	0.4	1.0	3.1	5.9	6.4	9.6	9.7	9.4	11.7	5.8
	Mean	.05	0.3	1.1	2.6	4.3	5.6	7.3	8.8	10.8	11.5	5.3
Normal	Sordan 70A	.08	0.4	1.9	3.9	6.9	12.3	12.7	13.5	13.0	14.8	8.0
	Sordan 77	.07	0.4	1.4	4.2	5.0	9.4	11.6	11.4	16.0	21.7	8.2
	Trudan 5	.05	0.4	1.4	3.4	5.0	4.4	7.3	7.2	12.5	20.7	6.3
	Trudan 7	.06	0.3	1.4	4.0	7.5	10.2	11.3	12.3	13.6	13.2	7.4
	Millex 23	.04	0.3	1.4	3.1	4.3	5.3	6.1	6.2	7.0	6.9	4.1
	NK 300	.06	0.4	1.1	3.3	5.1	9.1	9.5	10.6	13.6	11.5	6.5
	NK 326	.06	0.4	1.5	4.4	7.5	10.1	10.4	12.9	14.3	13.5	7.6
	Mean	.06	0.4	1.4	3.8	5.9	8.7	9.8	10.7	12.9	14.8	6.9
Semi-arid	Sordan 70A	.07	0.4	1.4	3.4	4.9	8.4	9.8	10.3	13.0	11.0	6.3
	Sordan 77	.06	0.4	1.3	4.1	5.3	6.1	6.8	8.8	12.4	20.5	6.6
	Trudan 5	.05	0.3	1.1	3.4	5.9	6.1	6.8	8.3	10.7	15.4	5.9
	Trudan 7	.05	0.3	1.5	4.0	6.5	9.1	9.9	12.9	12.2	15.0	7.2
	Millex 23	.03	0.3	1.3	3.7	4.5	6.6	6.7	5.0	7.5	8.6	4.5
	NK 300	.07	0.3	1.0	3.8	5.9	5.0	7.9	15.5	9.4	12.8	6.2
	NK 326	.06	0.4	1.6	3.8	5.5	12.3	12.7	14.7	13.1	10.3	7.5
	Mean	.05	0.3	1.3	3.7	5.5	7.7	8.7	11.1	10.9	13.4	6.3

1/ Unreplicated observation experiment.

TABLE 24. DRY MATTER CONTENT OF SEVEN NORTHRUP-KING GRASSES PROPAGATED WITH VARIABLE WATER SUPPLY OVER A TIME-COURSE OF ELEVEN WEEKS 1/

Simulated Moisture Regime	Variety	Dry Matter Content (%), At Indicated Week Number — 2	3	4	5	6	7	8	9	10	11	Mean
Humid	Sordan 70A	12.9	8.4	6.8	8.4	10.5	14.7	18.1	25.2	25.8	26.3	15.7
	Sordan 77	12.6	8.8	7.9	9.6	12.3	16.7	21.6	27.9	30.9	31.6	17.9
	Trudan 5	13.2	9.5	7.6	8.2	11.0	15.8	16.9	20.7	23.6	26.6	15.3
	Trudan 7	11.7	8.8	8.2	10.5	14.9	18.8	19.3	23.8	29.0	29.5	17.5
	Millex 23	11.3	7.5	7.2	8.7	14.3	17.7	18.8	21.2	22.1	22.3	15.1
	NK 300	12.7	9.6	9.0	9.9	12.6	18.0	18.0	27.3	27.0	28.8	17.3
	NK 326	11.8	9.0	7.4	8.9	12.2	14.3	16.7	21.1	22.0	24.2	14.8
	Mean	12.3	8.8	7.7	9.2	12.5	16.6	17.7	24.5	25.5	27.0	16.2
Normal	Sordan 70A	12.5	8.4	7.1	7.5	8.8	12.6	16.1	25.7	24.5	24.7	14.8
	Sordan 77	13.0	9.3	6.9	8.4	12.8	16.7	21.5	25.8	32.1	31.9	17.8
	Trudan 5	13.0	9.2	7.6	8.0	11.9	14.4	16.1	20.3	23.3	25.7	15.0
	Trudan 7	14.4	9.6	7.7	10.0	13.6	19.6	24.3	34.5	34.8	35.6	20.4
	Millex 23	10.0	7.0	5.8	6.9	8.6	13.7	14.6	14.8	16.7	17.3	11.5
	NK 300	12.6	8.9	7.4	8.6	11.1	16.1	19.1	28.1	28.7	27.5	16.8
	NK 326	11.6	8.7	7.4	7.9	9.5	13.2	14.9	13.7	23.0	22.5	13.2
	Mean	12.4	8.7	7.1	8.2	10.9	15.2	17.9	24.0	25.8	26.2	17.1
Semi-Arid	Sordan 70A	12.3	9.1	7.3	7.9	12.0	13.8	15.9	17.9	22.4	23.7	14.2
	Sordan 77	12.5	9.7	8.2	9.1	12.3	18.4	18.1	24.7	28.1	31.5	17.3
	Trudan 5	13.0	10.4	7.7	8.3	11.0	15.2	15.2	32.3	25.1	27.2	16.5
	Trudan 7	13.0	10.6	8.4	8.9	12.6	18.9	23.8	30.7	28.2	31.8	18.7
	Millex 23	9.7	8.0	6.2	8.0	12.0	16.5	17.5	18.8	20.2	22.2	13.9
	NK 300	12.0	9.7	8.6	8.9	12.0	14.6	16.6	27.7	24.4	26.7	16.1
	NK 326	11.5	9.0	7.5	7.9	9.8	13.6	15.3	27.7	20.7	21.8	14.5
	Mean	12.0	9.5	7.7	8.4	10.0	15.9	17.1	26.1	24.2	26.4	15.9

1/ Unreplicated observation experiment.

TABLE 25. TROPICAL GRASSES IMPORTED INTO PUERTO RICO FOR EVALUATION AS BIOMASS SOURCES FOR INTENSIVE AND EXTENSIVE PRODUCTION

Clone	Species	Planting Date	Remarks
28 NG 251	*S. robustum*	July 20, 1978	PI, From Beltsville
US 57-89-8	"	"	
51 NG 140	"	"	
SS 58-6	"	"	
Teboc Salak	"	"	No Germination
US 63-51	*S. spontaneum*	Sept. 30, 1978	PI, Canal Point
US 71-10-1	"	"	
US 71-10-2	"	"	
Elegans	"	"	
US 56-12-2	"	"	
SES 300	"	"	
US 57-2-2	"	"	
US 57-2-4	"	"	
SES 293-43	"	"	
SES 270	"	"	
SES 274	"	"	
SES 294	"	"	
SES 343	"	"	
SES 306	"	"	
Tabongo	"	"	
Taiwan	"	"	
UM 69-012	"	"	
SES 189	"	"	
SES 197 A	"	"	
SES 84-85	"	"	
SES 69	"	"	
India	"	"	
US 61-66-6	US 59-66-1 x *S. spontaneum*	"	
US 68-40-1	CP 52-68 x US 56-5-5	"	
US 55-1-9	? x Ripidium	"	
US 61-37-7	*R. kanashiroc* x *R. bengalense*	"	
US 64-37	*S. fusca* x *S. narenga*	"	
US 60-58	US 59-106-2 x US 57-182-2	"	
US 67-37-1	L 60-25 x *S. sinense*	"	
US 64-35	US 56-5-5 x *S. narenga*	"	
US 66-163-2	US 56-5-5 x US 65-106-1	"	
	(*S. fusca*) (*E. contortus*)	"	
US 66-157	US 56-5-5 x Mol. 4826	"	
	(*S. robustum*)	"	

TABLE 26. DRY MATTER PRODUCTION BY CANDIDATE S. SPONTANEUM AND S. SINENSE CLONES IN SMALL FIELD PLOTS 1/

Species	Clone	Dry Matter Yields (Kg/Plot) At Month —					Total Yields	
		4	6	8	10	12	Kg	% Of PR 980
Saccharum Hybrid	PR 980	17.1	2.5	2.2	1.1	0.8	23.7	100
S. sinense	Saretha	11.3	2.7	3.3	1.4	0.8	19.5	82.2
	Chunnee	11.7	2.4	3.1	3.1	3.0	23.3	98.3
	Natal Uba	9.5	1.9	2.4	1.1	0.9	15.8	66.6
	Tainan	13.3	4.1	5.0	2.8	1.7	26.9	114.0
S. spontaneum	SES 231	8.8	5.2	7.2	5.8	6.7	33.7	142.1
	SES 317	10.9	- 2/	-	-	-	-	-
	SES 327	10.9	3.1	3.0	0.9	- 3/	17.9	78.1
	US 67-22-2	18.5	4.7	5.2	3.6	4.0	36.0	151.8
	US 67-34-24	12.4	3.2	2.9	1.5	1.6	21.6	91.1
	US 72-97	12.5	4.4	5.3	2.9	3.6	28.7	122.1
	US 72-70	19.9	4.6	5.1	2.8	2.7	35.1	148.1
	US 72-72	12.4	4.0	4.0	2.6	2.8	25.8	108.8
	US 72-144	15.8	4.5	4.7	2.3	2.9	30.2	127.4
Erianthus maximus	NG 132	7.5	- 2/	-	-	-	-	-

1/ Plot size = 1/200 acre.

2/ Clones not harvested at months 6, 8, and 10.

3/ No plant growth following the 10-month harvest.

TABLE 27. TILLERING AND DRY MATTER CHARACTERISTICS OF CANDIDATE *S. SPONTANEUM* AND *S. SINENSE* CLONES IN SMALL FIELD PLOTS

Species	12 Month Harvest		Five Harvests Combined	
	No. Of Tillers	% DM	Total Tillers	Ave. % DM
Saccharum Hybrid				
PR 980	162	21.2	1,560	20.5
S. Sinense				
Saretha	242	20.6	2,415	19.4
Chunnee	603	17.9	3,414	18.9
Natal Uba	172	16.6	1,455	16.5
Tainan	651	18.0	4,257	20.6
S. spontaneum				
SES 231	1,551	20.3	7,104	20.0
SES 327	0	-	-	-
US 67-22-2	661	16.9	3,006	17.5
US 67-34-24	319	17.4	1,866	19.2
US 72-97	731	19.1	4,429	20.2
US 72-70	670	19.5	3,882	21.6
US 72-72	634	23.5	3,174	22.9
US 72-144	583	19.3	3,288	20.6

TABLE 28. QUALITATIVE ANALYSES OF CANDIDATE <u>SACCHARUM</u> CLONES FOR BIOMASS PRODUCTION [1/]

Clone	Species	Mean Values For Parameter –				
		Pol	Brix	Fiber	Purity	Rendiment
PR 980	Commercial Hybrid	11.90	13.86	14.88	84.98	10.05
Chunnee	*Saccharum sinense*	8.00	11.17	27.58	68.72	4.90
Tainan	*S. sinense*	2.70	5.00	42.93	50.01	-0.40
US 67-22-2	*S. spontaneum*	13.50	16.19	14.49	82.44	11.28
US 72-72	*S. spontaneum*	6.30	9.34	26.33	65.07	3.48
US 72-144	*S. spontaneum*	5.30	8.11	31.24	62.28	2.35
US 72-70	*S. spontaneum*	8.60	10.94	22.90	76.45	6.15
SES-231	*S. spontaneum*	0.50	4.00	36.52	11.80	-2.55
B 70-701	*S. spontaneum*	4.40	7.62	18.86	56.92	2.08
Unknown	*S. spont.* hybrid [2/]	1.20	4.68	40.09	23.95	-2.08

[1/] Data provided by Mr. T. L. Chu, Director, AES-UPR sugarcane breeding program.

[2/] Obtained from the wild near Río Piedras.

TABLE 29. DRY MATTER YIELDS BY SORDAN 70A PROPAGATED WITH VARIABLE N-FERTILIZATION AND SEEDING RATES OVER A TIME-COURSE OF TEN WEEKS

N Supply (Lbs/A)	Tons/Acre, At Seeding Rate (Lbs/A) —				
	60	80	100	120	Mean
100	5.4	4.1	5.0	4.8	4.8
200	4.2	4.9	5.6	5.3	5.0
300	4.6	4.8	5.7	4.6	4.9
400	5.0	4.2	4.9	5.5	4.9
Mean	4.8	4.5	5.3	5.1	

TABLE 30. GREEN MATTER YIELDS BY SORDAN 70A PROPAGATED WITH VARIABLE N-FERTILIZATION AND SEEDING RATES OVER A TIME-COURSE OF TEN WEEKS

N Supply (Lbs/A)	Tons/A, At Seeding Rate (Lbs/A) — 60	80	100	120	Mean
100	17.0	15.7	18.9	17.9	17.4
200	16.2	18.9	19.7	18.8	18.4
300	17.4	19.3	20.0	18.8	18.9
400	18.6	18.2	19.7	19.9	19.1
Mean	17.3	18.0	19.6	18.9	

TABLE 31. FOLIAR NITROGEN CONTENT OF SORDAN 70A PLANTS PROPAGATED WITH VARIABLE N FERTILIZATION AND SEEDING RATES 1/

N Supply (Lbs/Acre)	% N, At Seeding Rate (Lbs/Acre) — 60	90	100	120	Mean
100	2.89	2.67	2.88	2.77	2.80
200	2.71	2.84	2.73	2.83	2.78
300	2.87	2.90	2.89	2.84	2.88
400	2.91	2.79	2.79	2.94	2.86
Mean	2.85	2.80	2.82	2.85	

1/ Leaf ranks $^{+}1$ and $^{+}2$, harvested 10 weeks after seeding.

TABLE 32. DRY MATTER CONTENT OF SORDAN 70A PROPAGATED WITH VARIABLE N-FERTILIZATION AND SEEDING RATES OVER A TIME-COURSE OF TEN WEEKS

N Supply (Lbs/acre)	DM (%), At Seeding Rate (kg/ha) — 67	90	112	135	Mean
100	31.5	26.2	27.5	26.6	28.0
200	26.2	25.9	24.6	23.4	25.0
300	26.2	28.3	28.2	24.6	26.8
400	27.0	28.6	25.2	27.4	27.1
Mean	27.7	27.3	26.4	25.5	

TABLE 33. DRY MATTER CONTENT OF SORDAN 70A PLANTS PROPAGATED WITH VARIABLE N-FERTILIZATION AND SEEDING RATES OVER A TIME-COURSE OF TEN WEEKS

Nitrogen (lbs/acre	% Dry Matter, At Week –									
	2	3	4	5	6	7	8	9	10	Mean
100	12.6	14.4	13.0	11.1	13.3	15.7	18.5	24.6	27.7	16.8
200	9.2	13.1	11.8	10.6	13.2	14.6	17.3	20.5	27.3	15.3
300	13.1	15.0	12.7	10.5	11.1	14.0	16.3	20.5	26.4	15.5
400	13.2	14.8	12.3	9.6	11.8	12.3	15.8	20.8	25.5	15.1
Mean	12.0	14.3	12.5	10.5	12.4	14.2	17.0	21.7	26.8	
Seed (lbs/acre)										
60	12.0	13.6	12.7	10.6	12.1	13.8	17.0	25.7	28.3	16.2
80	13.2	14.3	12.4	9.9	12.2	14.3	16.9	20.3	25.0	15.4
100	10.5	14.4	12.4	11.7	13.2	15.3	17.1	20.2	26.8	15.7
120	12.5	15.0	12.4	9.6	11.8	13.8	17.0	20.4	27.0	15.5
Mean	12.1	14.3	12.5	10.5	12.3	14.3	17.0	21.7	26.8	

TABLE 34. EFFECTS OF VARIABLE N-FERTILIZATION AND SEEDING RATES ON THE NUMBER OF HARVESTABLE STEMS FOR SORDAN 70A TEN WEEKS AFTER PLANTING

N Supply (Lbs/Acre)	Stems/Acre (Thousands), At Seeding Rate (Lbs/Acre) — 60	80	100	120	Mean
100	118.0	96.8	157.2	161.6	133.4
200	95.2	114.0	120.0	148.8	119.5
300	91.6	88.0	110.4	116.8	101.7
400	123.2	102.4	110.0	101.6	109.3
Mean	107.0	100.3	124.4	132.2	

TABLE 35. EFFECTS OF VARIABLE NITROGEN SUPPLY ON THE INCIDENCE OF DOWNY MILDEW AND LODGING IN SORDAN 70A 1/

N Supply (Lbs/Acre)	Numerical Ranking For –	
	Downy Mildew	Lodging
100	3.04	2.25
200	3.75	2.46
300	4.75	3.04
400	5.08	2.83

1/ Disease and lodging incidence was ranked by visual inspection on a numerical scale of 1 to 10 (1 = no symptoms, 10 = severe symptoms). Each tabulated number is the arithmetic mean of 24 ranked plots. Data were recorded 10 weeks after seeding.

TABLE 36. EFFECTS OF VARIABLE PLANT DENSITY ON THE INCIDENCE OF DOWNY MILDEW AND LODGING IN SORDAN 70A 1/

Seeding Rate (Lbs/Acre)	Numerical Ranking For –	
	Downy Milew	Lodging
60	4.29	2.38
80	4.42	2.38
100	4.13	2.71
120	4.21	3.17

1/ Disease and lodging incidnece was ranked by visual inspection on a numerical scale of 1 to 10 (1 = no symptoms, 10 = severe symptoms). Each tabulated number is the arithmetic mean of 24 ranked plots. Data were recorded 10 weeks after seeding.

TABLE 37. BIOMASS PRODUCTION BY THE FIRST-RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; THIRD 2-MONTHS HARVEST

Cultivar	Green Matter (Tons/A), At Row Center —		
	150 cm	50 cm	% Change
PR 980	1.85	1.59	-14.0
NCo 310	4.74	3.91	-17.5
PR 64-1791	2.41	1.77	-26.5
	50 cm	25 cm	
Napier Grass	12.67	12.84	1.3
	Dry Matter (Tons/A)		
PR 980	0.33	0.28	-15.1
NCo 310	0.95	1.06	11.5
PR 64-1791	0.45	0.34	-24.4
Napier Grass	1.89	1.86	- 1.5
	Dry Matter Content (%)		
PR 980	17.1	17.6	2.9
NCo 310	20.0	20.6	3.0
PR 64-1791	19.1	18.9	- 1.0
Napier Grass	15.0	14.5	- 3.3

TABLE 38. BIOMASS PRODUCTION BY THE FIRST RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; FOURTH 2-MONTH HARVEST

	Green Matter (Tons/A), At Row Center -		
Cultivar	150 cm	50 cm	% Change
PR 980	0.60	0.75	25.0
NCo 310	1.65	2.01	21.8
PR 64-1791	0.88	0.98	11.3
	50 cm	25 cm	
Napier Grass	5.24	5.07	-3.2
	Dry Matter (Tons/A)		
PR 980	0.10	0.20	100
NCo 310	0.41	0.41	0
PR 64-1791	0.16	0.19	18.7
Napier Grass	0.82	0.87	6.0
	Dry Matter Content (%)		
PR 980	19.0	25.7	35.2
NCo 310	25.1	20.6	-17.9
PR 64-1791	18.8	20.2	7.4
Napier Grass	15.6	16.9	8,3

TABLE 39. BIOMASS PRODUCTION BY THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY; FIRST RATOON CROP, FIFTH 2-MONTH HARVEST

Cultivar	Dry Matter (Tons/Acre) At Row Center –		
	150 cm	50 cm	% Change
PR 980	0.39	0.54	38.4
NCo 310	0.99	1.17	18.1
PR 64-1791	0.41	0.54	31.7
	50 cm	25 cm	
Napier Grass	2.77	2.40	-13.3
	Green Matter (Tons/Acre) –		
PR 980	2.06	2.99	45.1
NCo 310	5.21	5.98	14.7
PR 64-1791	2.27	2.73	20.2
Napier Grass	17.9	17.2	- 3.9
	Dry Matter Content (%)		
PR 980	18.8	18.2	- 3.1
NCo 310	19.5	19.4	- 1.0
PR 64-1791	18.4	20.2	9.7
Napier Grass	15.5	14.0	- 9.6

TABLE 40. BIOMASS PRODUCTION BY THE FIRST RATOON CROP OF THREE SUGARCANE VARIETIES AND ONE NAPIER GRASS VARIETY PROPAGATED WITH VARIABLE ROW CENTERS; SECOND 4-MONTH HARVEST, YEAR 2

	Green Matter (Tons/Acre), At Row Center —		
Cultivar	150 cm	50 cm	% Change
PR 980	7.34	7.37	0.4
NCo 310	8.57	9.57	11.6
PR 64-1791	6.46	6.80	5.2
	50 cm	25 cm	
Napier Grass	22.8	21.6	-5.2
	Dry Matter (Tons/Acre)		
PR 980	1.49	1.63	9.3
NCo 310	2.00	2.08	4.0
PR 64-1791	1.39	1.43	2.8
Napier Grass	5.69	5.32	-5.2
	Dry Matter Content (%)		
PR 980	20.3	22.0	8.3
NCo 310	23.3	21.7	6.8
PR 64-1791	21.6	20.7	-4.1
Napier Grass	25.1	24.6	-1.9

TABLE 41. DRY MATTER YIELD FOR SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS OVER A TIME COURSE OF 12 MONTHS; FIRST RATOON CROP 1/

		Dry Matter Yield (Tons/Acre) At Indicated Month 1/						
Interval	Species	2	4	6	8	10	12	Total Yield
2 Months	Sugarcane 2/	1.0	0.7	0.6	0.2	0.5	4/	3.0
	Napier Grass 3/	2.4	2.6	1.9	0.9	2.6		10.4
4 Months	Sugarcane		5.6		1.7		4/	7.3
	Napier Grass		9.7		5.5			15.2
6 Months	Sugarcane			11.4			4/	11.4 5/
	Napier Grass			13.6				13.6 5/
12 Months	Sugarcane						4/	
	Napier Grass							

1/ Based on mean values from replicated, 1/50 acre plots.

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

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

4/ Incomplete data.

5/ Trash included.

TABLE 42. DRY MATTER YIELDS FOR THREE SUGARCANE VARIETIES HARVESTED AT VARIABLE INTERVALS OVER A TIME-COURSE OF 12 MONTHS; FIRST RATOON CROP 1/

Harvest Interval	Variety	Dry Matter Yield (Tons/Acre At Indicated Month 1/						Total Yield
		2	4	6	8	10	12	
2 Months	PR 980	0.7	0.4	0.3	0.2	0.5	2/	2.1
	NCo 310	1.4	1.1	0.0	0.4	1.1		5.0
	PR 64-1791	0.9	0.6	0.4	0.2	0.5		2.6
4 Months	PR 980	5.4			1.6		2/	7.0
	NCo 310	6.2			2.1			8.3
	PR 64-1791	5.4			1.4			6.8
6 Months	PR 980			11.3				11.3 3/
	NCo 310			12.6			2/	12.6 3/
	PR 64-1791			10.5				10.5 3/
12 Months	PR 980						2/	
	NCo 310							
	PR 64-1791							

1/ Based on mean values from replicated 1/50 acre plots.

2/ Incomplete data.

3/ Trash excluded.

TABLE 43. PLANT CROP AND FIRST-RATOON CROP YIELDS FOR SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS OVER A TIME-COURSE OF 12-MONTHS (INCOMPLETE DATA)

Harvest Interval	Species	Crop	Dry Matter Yield (Tons/Acre) At Indicated Month 1/						Total Yield
			2	4	6	8	10	12	
2 Months	Sugarcane 2/	Plant	0.4	1.2	1.2	0.8	1.7	4/	5.3
		First Ratoon	1.0	0.7	0.6	0.2	0.5		3.0
	Napier Grass 3/	Plant	2.1	1.4	3.0	0.9	4.0		11.4
		First Ratoon	2.4	2.6	1.9	0.9	2.6		10.4
4 Months	Sugarcane	Plant		3.4		3.6		4/	7.0
		First Ratoon		5.6		1.7			7.3
	Napier Grass	Plant		5.7		8.4			14.1
		First Ratoon		9.7		5.5			15.2
6 Months	Sugarcane	Plant		8.6				4/	8.6 5/
		First Ratoon		11.4					11.4 5/
	Napier Grass	Plant		13.1					13.1 5/
		First Ratoon		13.6					13.6 5/
12 Months	Sugarcane	Plant						4/	
		First Ratoon							
	Napier Grass	Plant							
		First Ratoon							

1/ Based on mean values from replicated 1/50 acre plots.

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

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

4/ Incomplete data.

5/ Trash included.

TABLE 44. PLANT CROP AND FIRST-RATOON CROP YIELDS FOR THREE SUGARCANE VARIETIES HARVESTED AT VARIABLE INTERVALS OVER A TIME-COURSE OF 12-MONTHS (INCOMPLETE DATA)

Harvest Interval	Variety	Crop	Dry Matter Yield (Tons/Acre) At Indicated Month 1/						Total Yield
			2	4	6	8	10	12	
2 Months	PR 980	Plant	0.5	1.4	1.2	0.7	1.5	2/	5.3
		First Ratoon	0.7	0.4	0.3	0.2	0.5		2.1
	NCo 310	Plant	0.4	1.2	1.4	0.8	2.1		5.9
		First Ratoon	1.4	1.1	1.0	0.4	1.1		5.0
	PR 64-1791	Plant	0.4	1.1	1.2	0.8	1.6		5.1
		First Ratoon	0.9	0.6	0.4	0.2	0.5		2.6
4 Months	PR 980	Plant	4.0			3.8		2/	7.8
		First Ratoon	5.4			1.6			7.0
	NCo 310	Plant	3.2			3.6			6.8
		First Ratoon	6.2			2.1			8.[illegible]
	PR 64-1791	Plant	3.0			3.5			6.5
		First Ratoon	5.4			1.4			6.8
6 Months	PR 980	Plant			9.2			2/	9.2 3/
		First Ratoon			11.3				11.3 3/
	NCo 310	Plant			8.4				8.4 3/
		First Ratoon			12.6				12.6 3/
	PR 64-1791	Plant			8.3				8.3 3/
		First Ratoon			10.5				10.5 3/
12 Months	PR 980	Plant						2/	
		First Ratoon							
	NCo 310	Plant							
		First Ratoon							
	PR 64-1791	Plant							
		First Ratoon							

1/ Based on mean values from replicated 1/50 acre plots.

2/ Incomplete data.

3/ Trash excluded.

TABLE 45. TRASH YIELDS FOR SUGARCANE AND NAPIER GRASS PROPAGATED AT VARIABLE ROW CENTERS; FIRST 6-MONTHS HARVEST, YEAR 2

Cultivar	Trash Yield (Tons/Acre) At Row Center — 150 cm	50 cm	% Change
PR 980	1.44	1.62	12.5
NCo 310	1.43	1.65	15.3
PR 64-1791	1.08	1.71	58.3
	50 cm	25 cm	
Napier Grass	0.94	1.17	24.4

TABLE 46. TOTAL DRY MATTER YIELDS, INCLUDING TRASH, FOR SUGARCANE AND NAPIER GRASS PROPAGATED AT VARIEABLE ROW CENTERS; FIRST 6-MONTHS HARVEST, YEAR 2

Cultivar	Total DM (Tons/Acre) At Row Center — 150 cm	50 cm	% Change
PR 980	12.2	10.5	13.9
NCo 310	12.8	12.3	-3.9
PR 64-1791	9.7	11.0	13.4
	50 cm	25 cm	
Napier Grass	13.9	13.3	-4.3

TABLE 47. HAND REFRACTOMETER VALUES FOR THREE SUGARCANE VARIETIES PROPAGATED AT STANDARD AND NARROW ROW CENTERS

	Refractometer Readings At Indicated Period And Row Center —					
	6 Months			8 Months		
Clone	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	14.2 b [1/]	14.9 a	4.9	17.4 c	19.2 a	10.3
NCo 310	14.8 a	14.9 a	0.6	19.1 ab	18.9 ab	-1.0
PR 64-1791	13.5 b	14.2 b	5.1	17.9 bc	18.1 abc	1.1
	10 Months			12 Months		
PR 980	17.9 b	18.0 b	0.5	18.5 c	19.5 abc	5.4
NCo 310	19.6 a	20.3 a	3.5	19.7 ab	20.5 a	4.0
PR 64-1791	18.5 b	18.6 b	0.5	19.1 bc	19.6 abc	2.6

1/ Mean values in the same column and sampling period bearing unlike letters differ significantly (P<.05). Values in the same row and sampling period bearing unlike letters also vary significatnly. Means having at least one letter in common are not significantly different.

TABLE 48. HAND REFRACTOMETER VALUES FOR THREE SUGARCANE VARIETIES AT FOUR SAMPLING INTERVALS 1/

Variety	HF Values At Month — 6	8	10	12	Mean
PR 980	14.6	18.3	18.0	19.0	17.5
NCo 310	14.9	19.0	20.0	20.1	18.5
PR 64-1791	13.9	18.0	18.6	19.4	17.5

1/ Each figure is the computed mean of two row centers.

TABLE 49. MEAN HAND REFRACTOMETER VALUES FOR SUGARCANE PROPAGATED AT STANDARD AND NARROW ROW CENTERS 1/

Row Spacing (cm)	HF Values At Month –				Mean
	6	8	10	12	
150 (std)	14.2	18.1	18.7	19.1	17.5
50	14.7	18.7	19.0	19.9	18.1

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

TABLE 50. CANE QUALITY VALUES FOR THREE SUGARCANE VARIETIES PROPAGATED AT VARIABLE ROW CENTERS AND HARVESTED AT 6-AND 12-MONTH INTERVALS

	6-Months Harvest			12-Months Harvest		
	Polarization, At Row Center —			Polarization, At Row Center —		
Variety	150 cm	50 cm	% Change	150 cm	50 cm	% Change
PR 980	5.2	4.8	-7.6	10.1	8.9	-11.8
NCo 310	5.2	5.0	-3.8	9.9	10.0	1.0
PR 64-1791	5.7	5.3	-7.0	10.4	9.9	- 4.8
	Brix			Brix		
PR 980	9.1	9.1	0	13.3	12.5	- 6.0
NCo 310	9.5	9.6	1.0	13.4	13.4	0
PR 64-1791	9.6	8.6	-10.4	12.7	12.2	- 3.9
	Fiber			Fiber		
PR 980	14.8	15.7	6.0	17.2	15.8	- 8.1
NCo 310	14.6	14.6	0	17.8	19.3	8.4
PR 64-1791	15.2	16.2	6.5	16.6	19.1	15.0
	Purity			Purity		
PR 980	56.6	52.7	- 6.8	75.0	70.6	- 5.8
NCo 310	53.1	49.3	- 7.1	72.7	72.8	0
PR 64-1791	58.1	50.9	-12.3	81.4	79.7	- 2.0
	Rendiment			Rendiment		
PR 980	2.8	2.2	-21.4	7.6	6.4	-15.7
NCo 310	2.8	2.3	-17.8	7.3	7.2	- 1.0
PR 64-1791	3.2	3.0	- 6.2	8.4	7.6	- 9.5

TABLE 51. ESTIMATED YIELDS AND VALUE OF FERMENTABLE SOLIDS AND HIGH-TEST MOLASSES FROM INTENSIVELY-PROPAGATED SUGARCANE 1/

	Estimated Values For –		
Millable Cane (Tons/Acre Yr)	Fermentable Solids (Tons/Acre Yr)	High-Test Molasses (Gal./Acre Yr)	Molasses Value ($/Acre)
30	3.34	655	491
80 2/	8.91	1747	1310
100 3/	11.14	2183	1638

1/ Assuming a mean Brix value of 13.1% and an average extraction of 85%. Molasses value is computed at 75 cents/gallon.

2/ Approximate mean value for three varieties and two row centers; plant-crop sugarcane

3/ Projected mean value for three varieties and two row centes; first-and second-ratoon sugarcane.

TABLE 54. TRASH [1] AND TOTAL DRY MATTER YIELDS OF FIVE CANDIDATE TROPICAL GRASSES HARVESTED SIX MONTHS AFTER PLANTING

Cultivar	Dry Tons/Acre For — Trash	Intact Plants	Total DM
PR 980 (Reference)	0.95 b	8.02 d	8.97 c
Common Napier	0.92 b	11.82 bc	12.74 b
Napier Hybrid 7350	1.32 a	13.55 ab	14.87 a
Napier Hybrid 30086	0.77 b	14.55 a	15.32 a
Sordan 70A	Trace c	3.61 c	3.61 d

1/ The term "trash" includes leaf blades and leaf sheaths that have died, desiccated, and detached from the stem in accordance with natural maturation processes. This material may contain slightly more moisture than oven-dry tissues.

TABLE 55. DRY MATTER YIELDS OF FIVE CANDIDATE TROPICAL GRASSES DURING AN 8-WEEK INTERVAL FOLLOWING VARIABLE PERIODS FOR ESTABLISHMENT OF CROWNS 1/

Cultivar	Tons/A Following Indicated Establishment Time (Months) — 0	2	4
PR 980 (Reference)	0.41 e 2/	1.34 c	0.76 c
Common Napier Grass	1.22 d	3.35 b	2.89 b
Napier Hybrid 7350	1.88 c	4.14 a	4.10 a
Napier Hybrid 30086	2.37 b	3.97 a	3.92 a
Sordan 70A	3.92 a	2.94 b	3.13 b
Mean	1.96	3.19	2.96

1/ Based on mean values from replicated 1/50 acre plots.

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

TABLE 56. DRY MATTER YIELDS FOR FIVE SACCHARUM CANDIDATES FOR MINIMUM TILLAGE PRODUCTION

Clone	Estimated Tons/Acre/6 Months 1/ Green	Oven Dry
US 67-22-2	16.5 a 3/	6.4 a
US 72-72	15.9 ab	6.0 ab
US 72-93	14.7 ab	5.5 ab
S. spont. Hybrid 2/	6.0 c	2.6 c
PR 980 (Reference)	13.3 b	4.3 b

1/ Based on data from replicated 1/50 acre plots.

2/ Plots of the *S. spontaneum* hybrid experienced less than 40% germination.

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

TABLE 57. TRASH AND TOTAL DRY MATTER YIELDS FOR FIVE MINIMUM TILLAGE CANDIDATES

Clone	Projected Dry Tons/Acre/6 Months, 1/ For — Trash	Intact Plants	Total DM	% Of PR 980
US 67-22-2	4.5 a 3/	6.4 a	10.9	121.1
US 72-72	3.3 ab	6.0 ab	9.3	103.3
US 72-93	3.5 ab	5.5 ab	9.0	100.0
S. spont. Hybrid 2/	1.9 c	2.6 c	4.5	50.0
PR 980 (Reference)	4.7 b	4.3 b	9.0	100.0

1/ Based on data from replicated 1/50 acre plots.

2/ The S. spontaneum hybrid experienced less tahn 40% germination.

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

TABLE 58. DRY MATTER YIELDS FOR SUGARCANE AND NAPIER GRASS HARVESTED AT VARIABLE INTERVALS OVER A TIME-COURSE OF 12 MONTHS (FIRST-YEAR DATA).

Harvest Interval	Cultivar	Estimated Tons/Acre At Indicated Month 1/						Total Yield
		2	4	6	8	10	12	
2 Months	Sugarcane 2/	0.4	1.2	1.2	0.8	1.7	1.2	6.5
	Napier Grass 3/	2.1	1.4	3.0	0.9	4.0	1.3	12.7
4 Months	Sugarcane		3.4		3.6		4.1	11.1
	Napier Grass		5.7		8.4		8.5	22.6
6 Months	Sugarcane			8.6			8.0	16.6 4/
	Napier Grass			13.1			12.4	25.6 4/
12 Months	Sugarcane						25.5	25.5 4/
	Napier Grass						19.3	19.3 4/

1/ Based on mean values from replicated, 1/50 acre plots.

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

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

4/ Includes trash.

TABLE 59. PERFORMANCE EVALUATIONS FOR THE M-C ROTARY SCYTHE OPERATING ON SORDAN 70A PLANTS OF VARYING MATURITY AND DEGREE OF LODGING

Crop Age (Weeks)	Estimated Crop Mass Tons/Acre	Estimated Crop Mass % DM	Rotary Scythe Rating, At Lodging Status: CU [1]	NS	LL	ML	SL	LM	LMW	Mean
6	8-10	10	1 [2]	1	1	1	1	1	1	1.00
10	16-20	24	1	1	1	1	1	1	2	1.14
14	20-24	30	1	1	1	1	1	2	2	1.29

1/ Abbreviations: CU (Completely Upright), NS (Normal Stand), LL (Lightly Lodged), ML (Moderately Lodged), SL (Severely Lodged), LM (Severely Lodged & Matted), LMW (Severely Lodged, Matted, & Intermixed With Weeds)

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

TABLE 60. PRELIMINARY COST ANALYSIS FOR SORDAN 70A PRODUCTION

LAND AREA: 200 Acres

PRODUCTION INTERVAL: 6 Months

SORDAN 70A YIELD: 15 Tons/Acre; Total 3,000 Tons of Oven-Dry Material

Preliminary Cost Analysis

Item		Cost ($)
1.	Land Rental, at $50/Acre Year	5,000
2.	Water (Overhead Irrigation), 360 Acre ft	2,160
3.	Seed, at 60 Lbs/Acre	4,800
4.	Fertilizer	10,000
5.	Pesticides	4,000
6.	Equipment Depreciation (6 mo.)	2,650
7.	Equipment Maintenance (75% of Depreciation)	1,988
8.	Equipment Operation (75% of Depreciation)	1,988
9.	Diesel Fuel	2,200
10.	Day Labor (90.00/Day for 140 Days)	12,600
11.	Delivery, at 6.00/Ton	18,000
	Subtotal:	65,386
	Plus 10% Error:	6,538
	Total Cost:	71,924

Total Cost/Ton: (71,924 ÷ 3,000): 23.97

Total Cost/Million BTUs (23.97 ÷ 15): 1.59

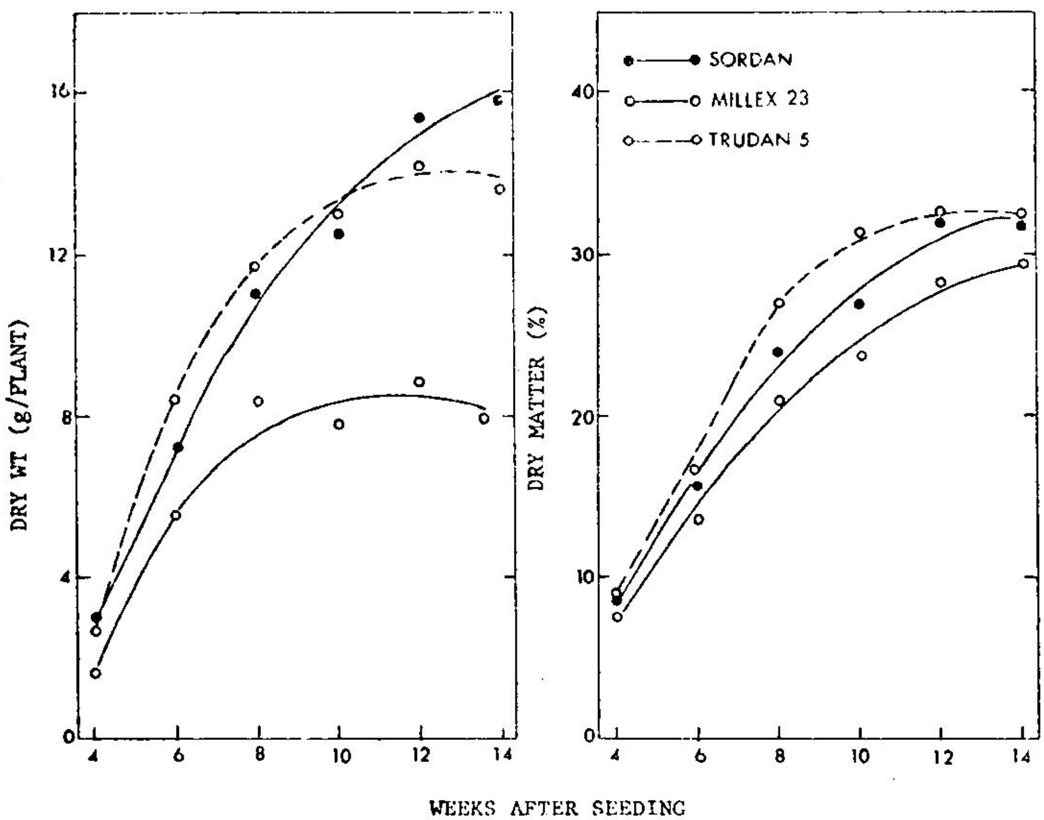

Figure 1. Dry matter yields for the NK hybrids Sordan 70-A, Millex 23, and Trudan 5 over a time-course of 10 weeks.

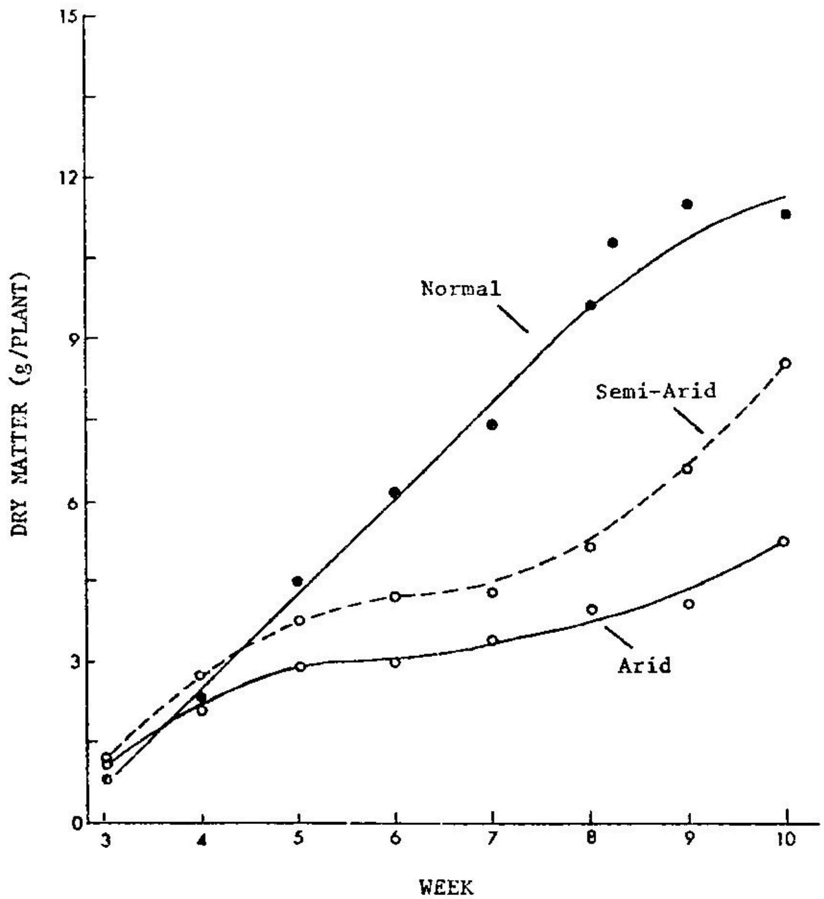

Figure 2. Dry matter yields for eight tropical grasses under simulated normal, semi-arid, and arid moisture regimes. Each curve is derived from the computed means of seven Saccharum and one Sorghum species.

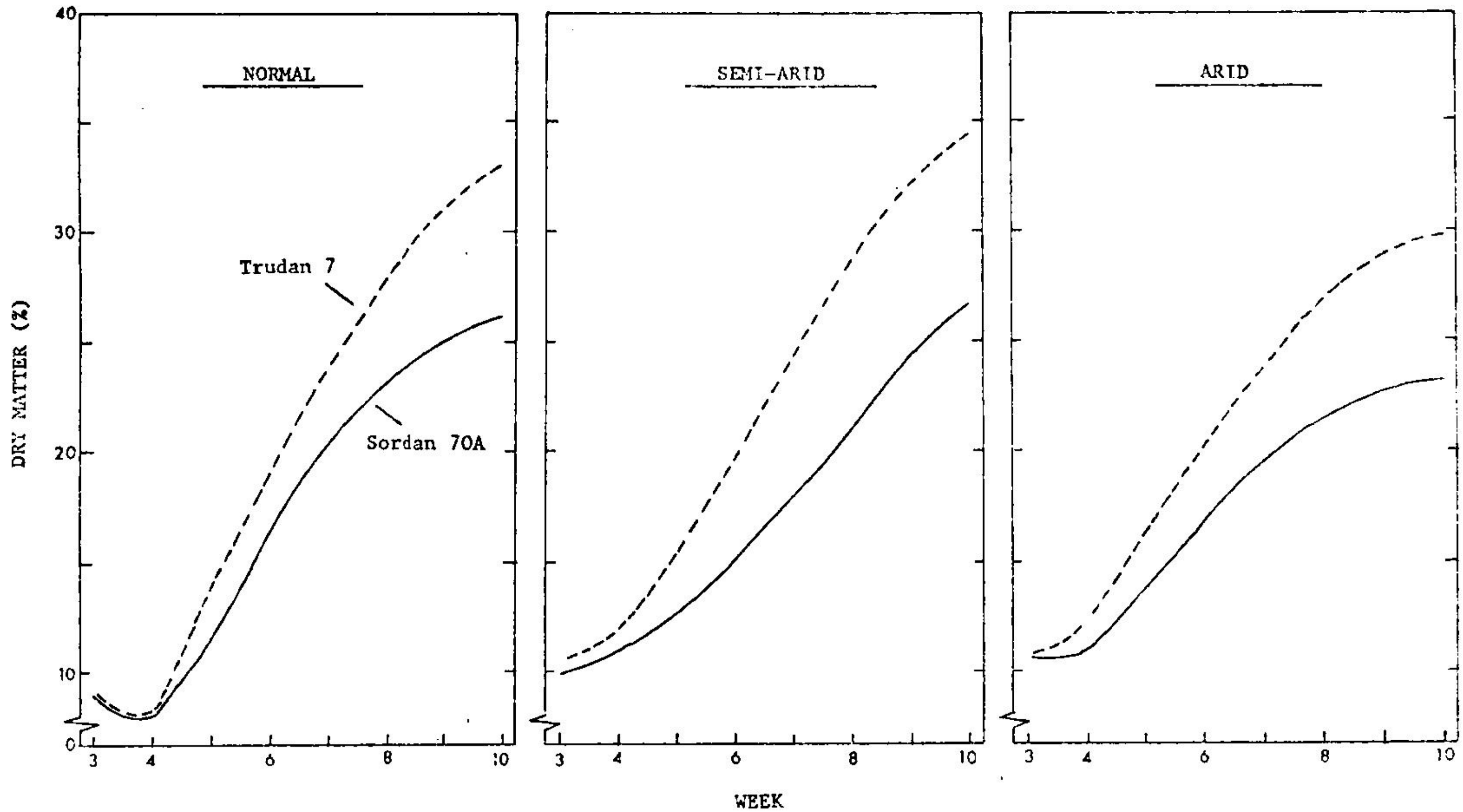

Figure 3. Dry matter accumulation in the Northrup-King hybrids Sordan 70A and Trudan 7. The plants were propagated with variable moisture regimes simulating normal, semi-arid, and arid conditions.

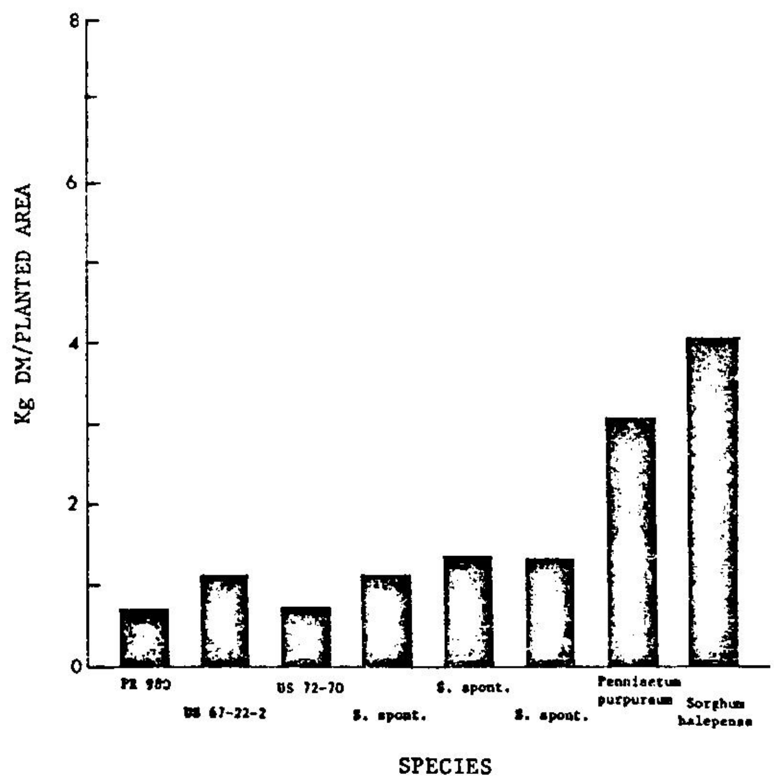

Figure 4. Dry matter production by eight candidate tropical grasses harvested 2 months after planting. This growth interval is characteristic of short-rotation cropping regimes for herbaceous biomass species.

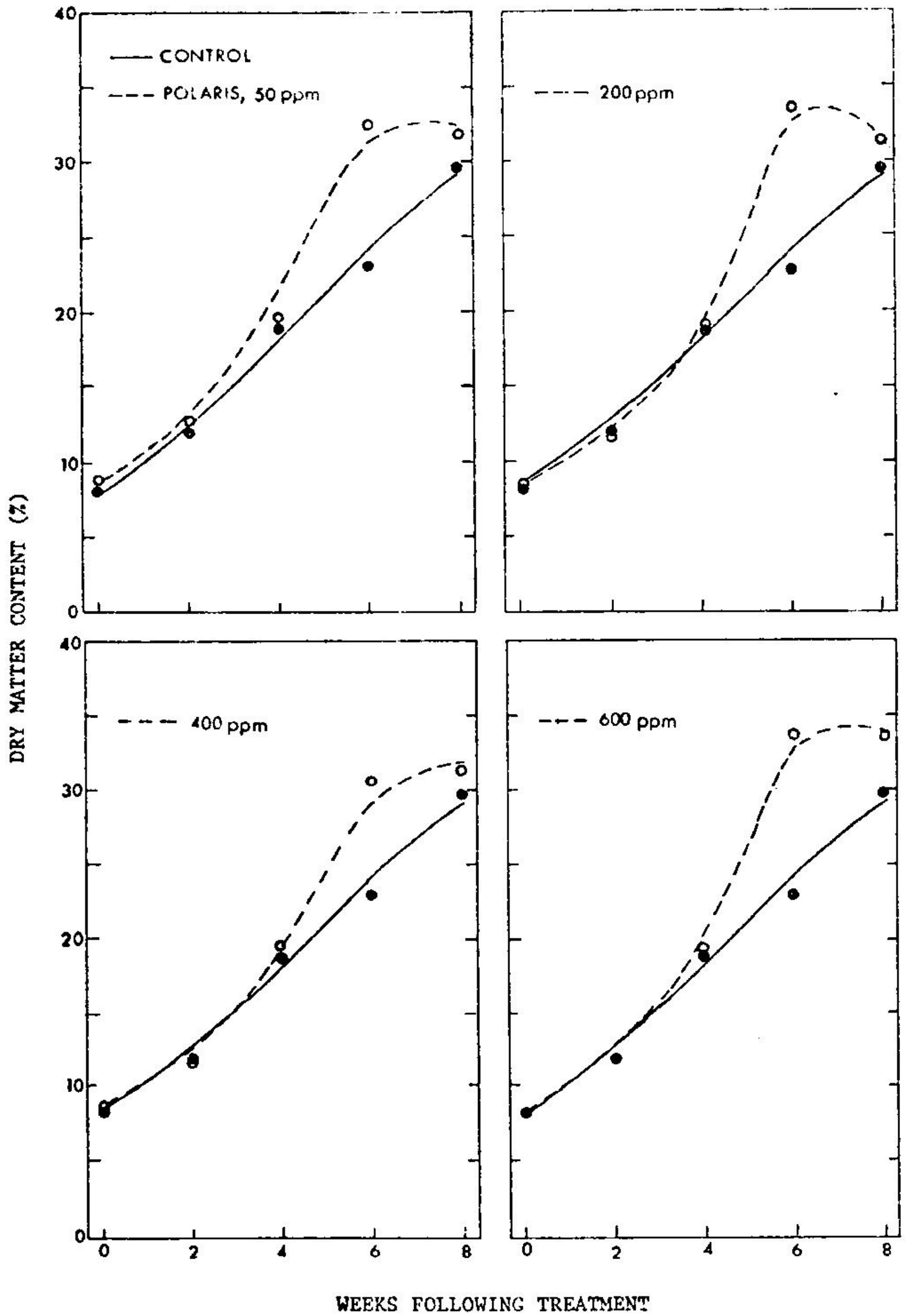

Figure 5. Dry matter content of Sordan 70-A plants treated with variable levels of Polaris at 3 weeks of age. Polaris was administered as aqueous foliar sprays. Week "0" denotes the time of spray application.

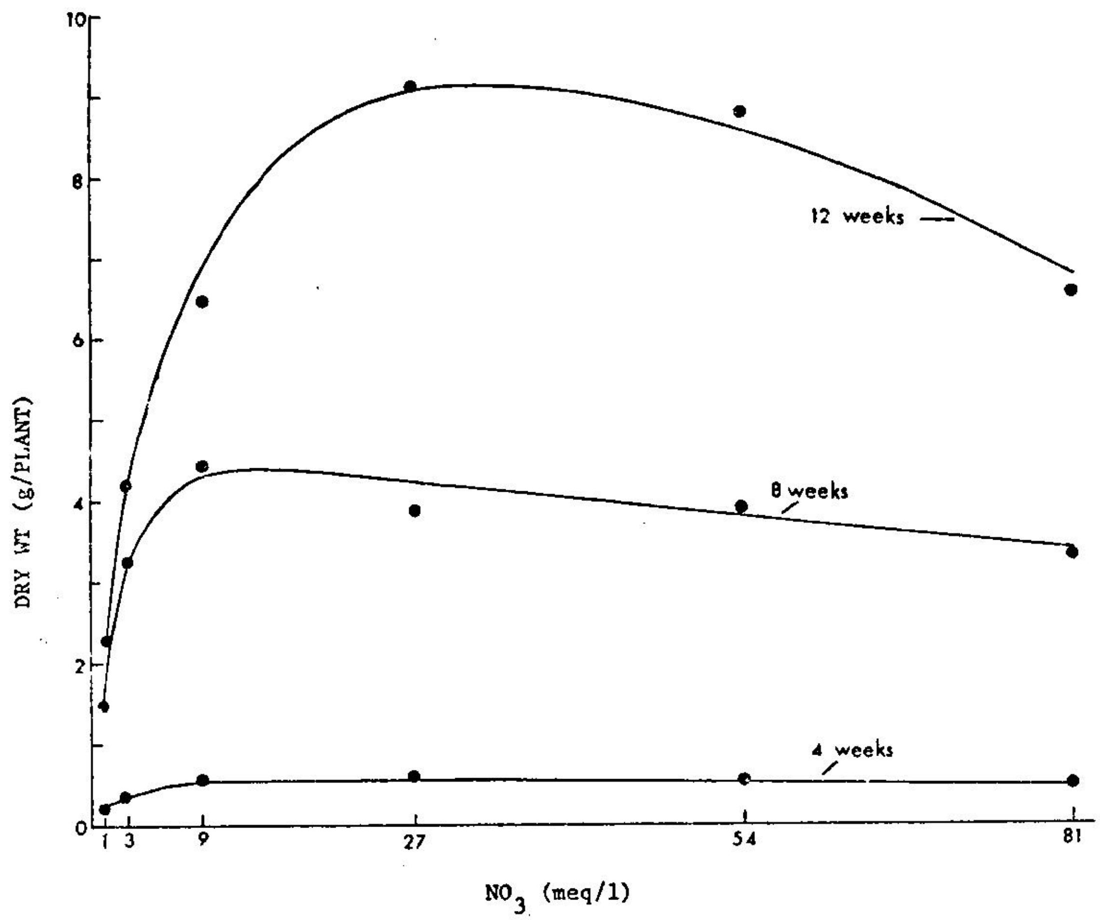

Figure 6. Dry matter production by Sordan 70-A plants given variable nitrate levels in sand culture over a time-course of 12 weeks.

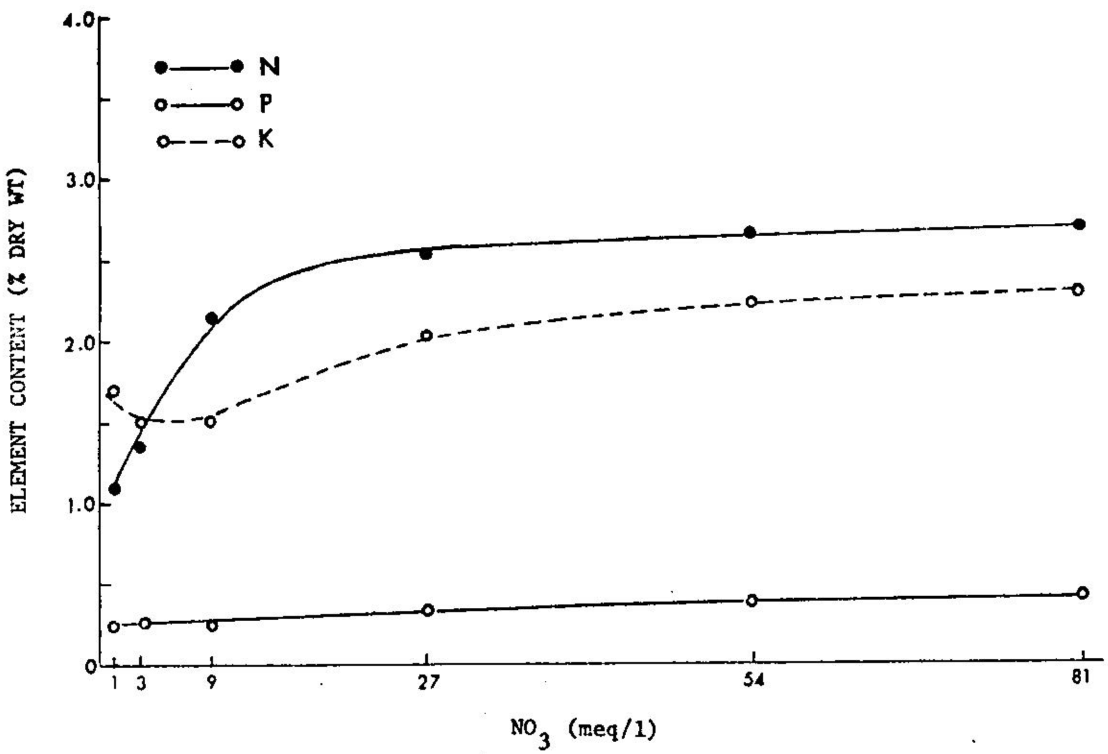

Figure 7. Foliar N, P, and K contents of Sordan 70-A plants given variable nitrate levels in sand culture over a time-course of 12 weeks. Leaf samples were harvested at week 12.

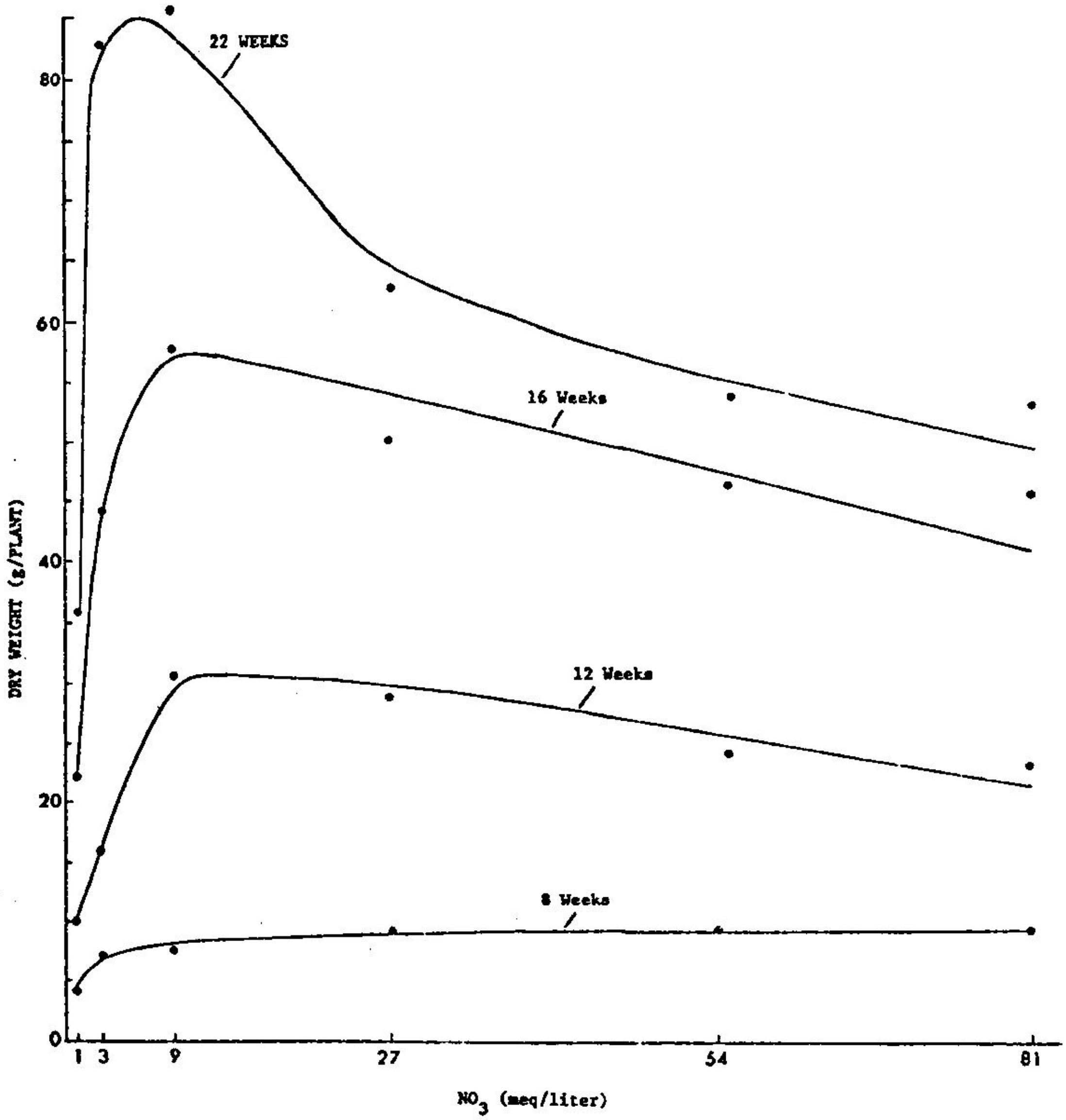

Figure 8. Dry matter production by napier grass (var. PI 30086) supplied with variable nitrate in sand culture.

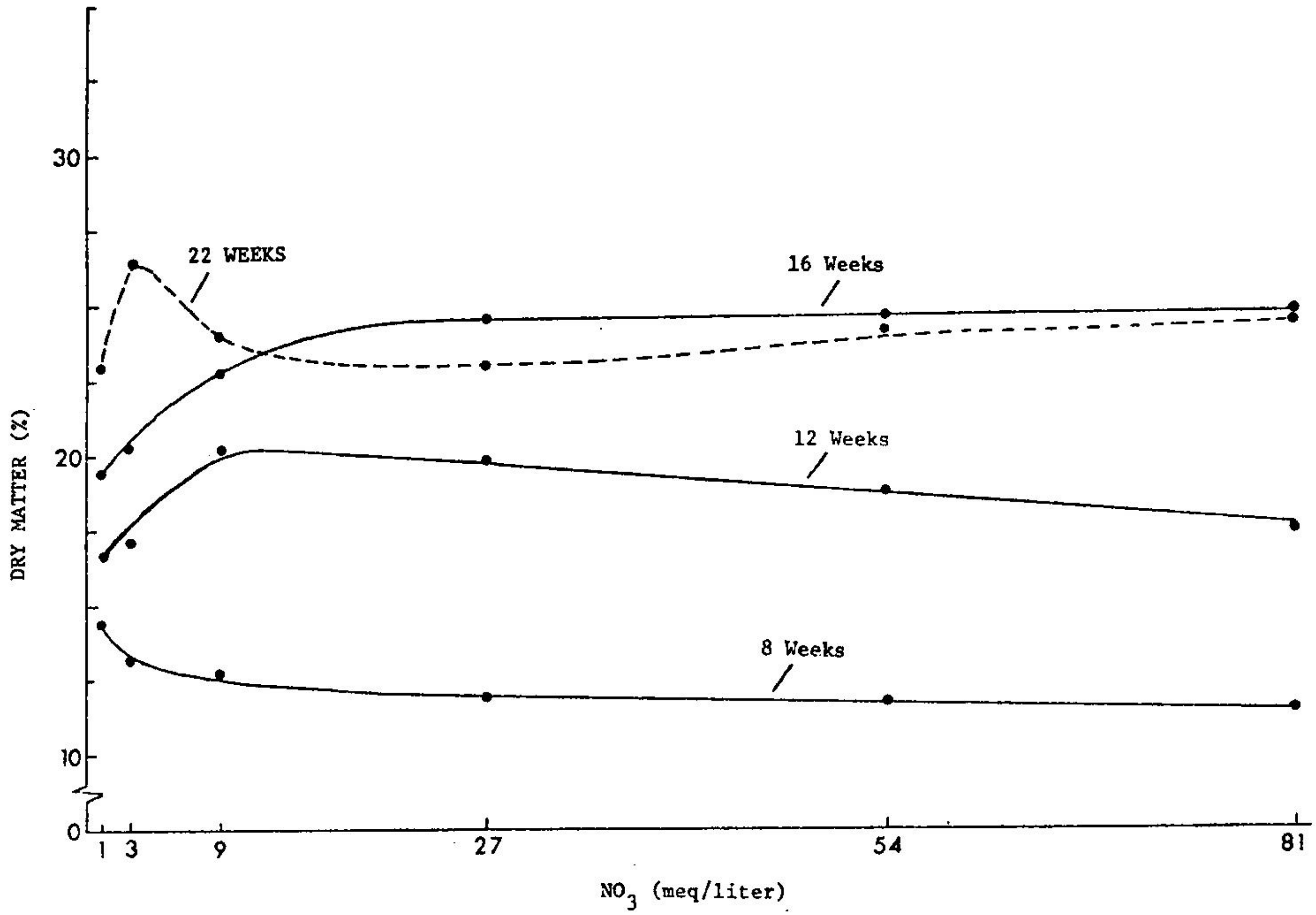

Figure 9. Dry matter content of napier grass (var. PI 30086) supplied with variable nitrate in sand culture.

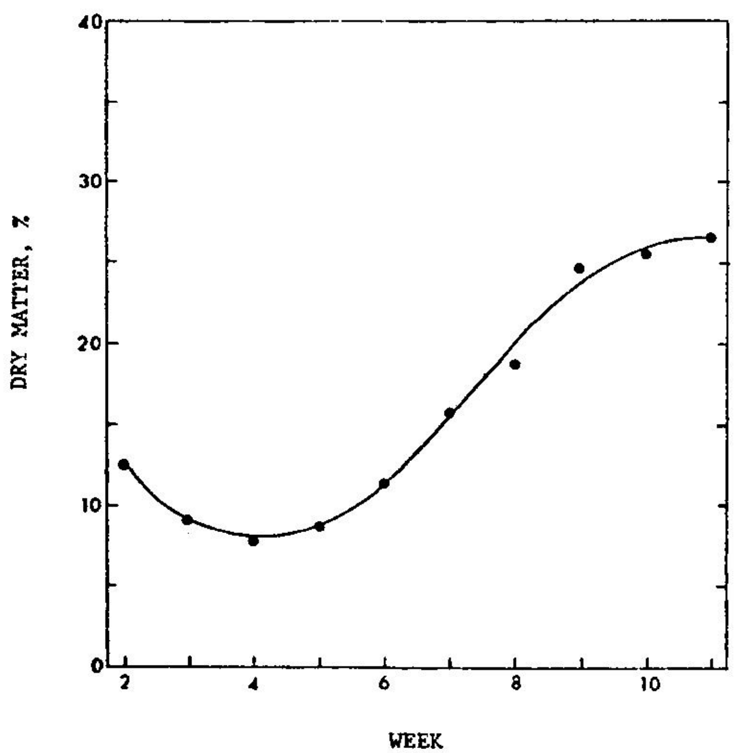

Figure 10. The mean maturation curve (dry matter accumulation) for seven Northrup-King grasses propagated over a time-course of eleven weeks. Each plotted value is the computed mean of seven varieties and three moisture regimes.

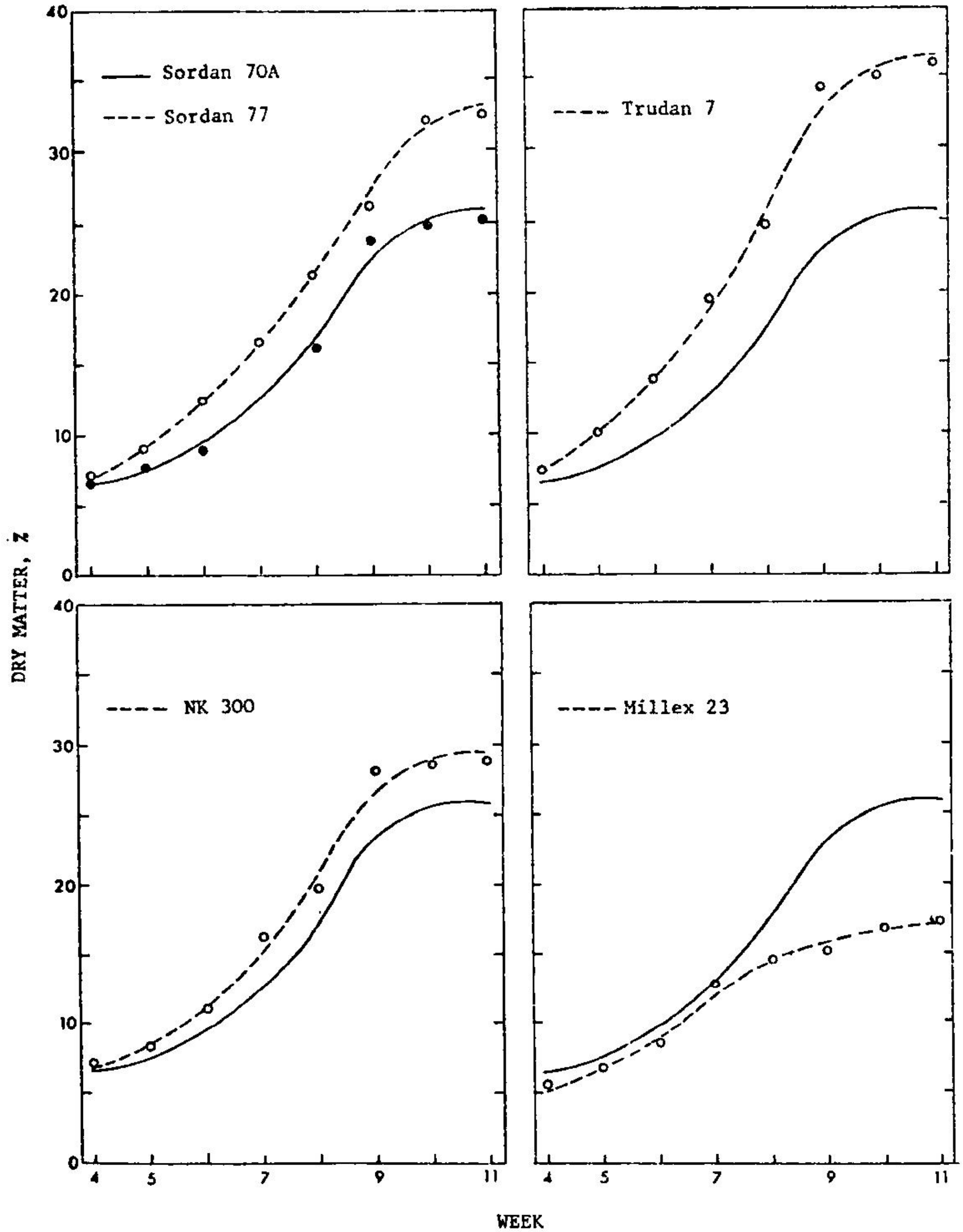

Figure 11. Dry matter accumulation in five Northrup-King grasses propagated with a "normal" water regime over a time-course of eleven weeks.

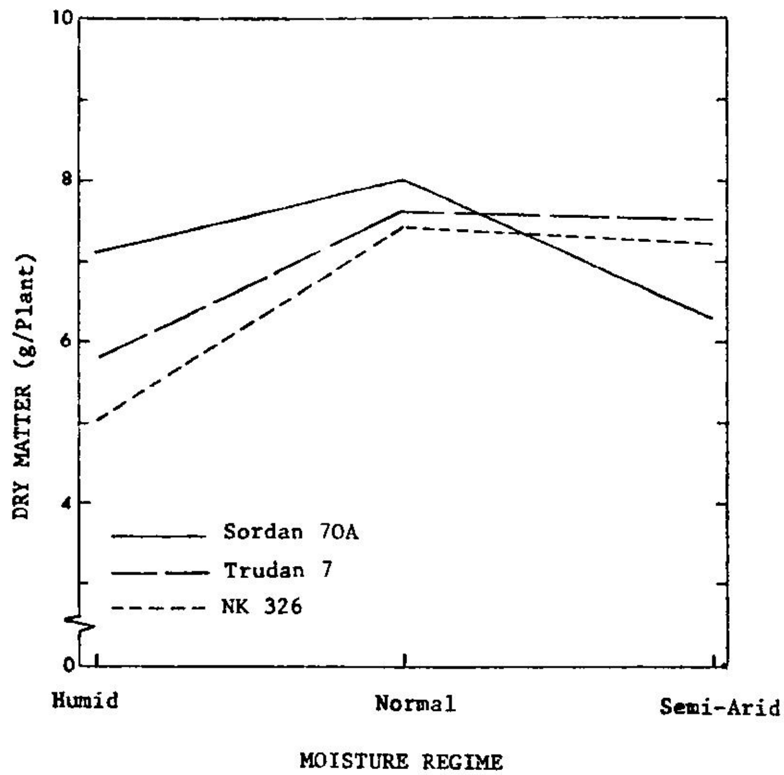

Figure 12. Dry matter production by Sordan 70A, Trudan 7, and NK 326 propagated with variable moisture supplies simulating humid, normal, and semi-arid rainfall regimes. Each plotted value is the computed mean of ten plant samples harvested over a time-course of ten weeks.

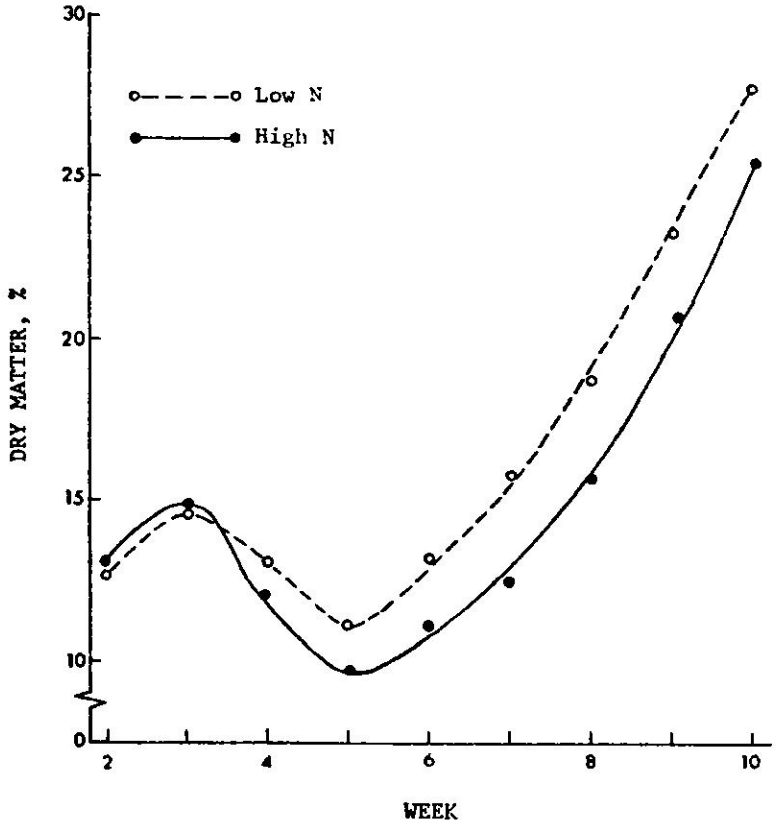

Figure 13. Effects of variable nitrogen supply on dry matter accumulation in Sordan 70A. Low N = 100 lbs/acre; high N = 400 lbs/acre, applied in a single increment at the time of planting.

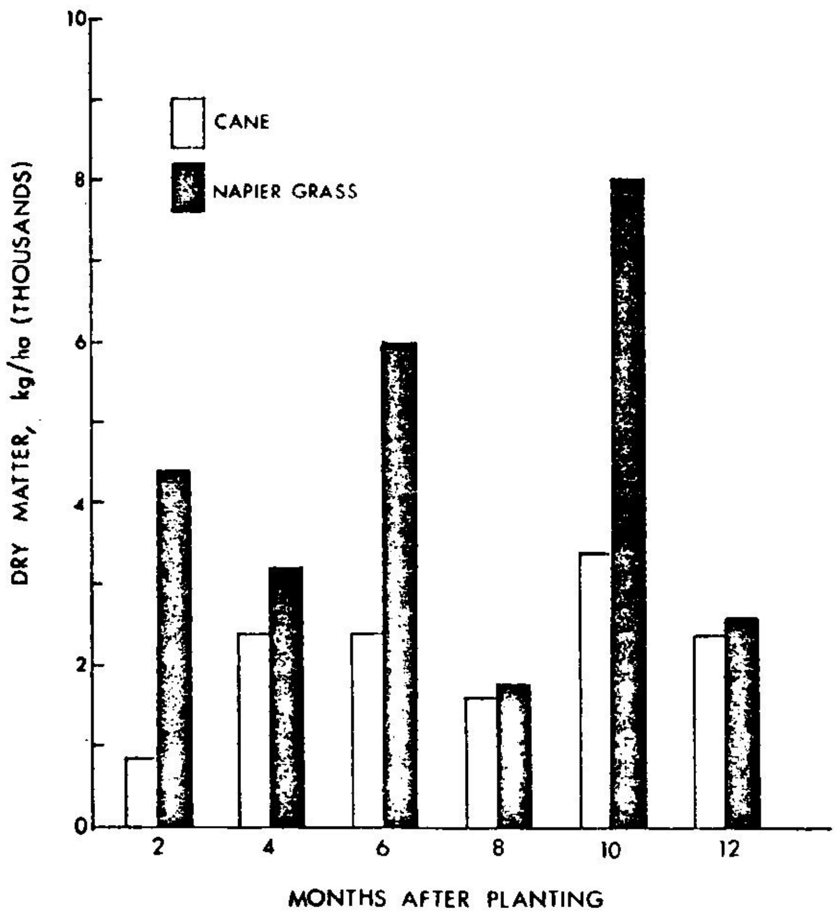

FIGURE 14. Variable dry matter production by sugarcane and napier grass as a function of incremental fertilizer supply. Both species received 1/3 of their annual fertilizer compliment at planting, 1/3 following the 4-month harvest, and 1/3 following the 8-month harvest.

FIGURE 15. The M-C model 9-E rotary scythe, with 9-foot mowing swath, being tested as a harvest implement for short-and intermediate-rotation tropical grasses. Unlike a sickle-bar mower, the rotary scythe "conditions" herbaceous materials by striking the stems with a series of metal plates rotating at high speed with extreme force. The blades can be seen suspended below the implement's leading edge.

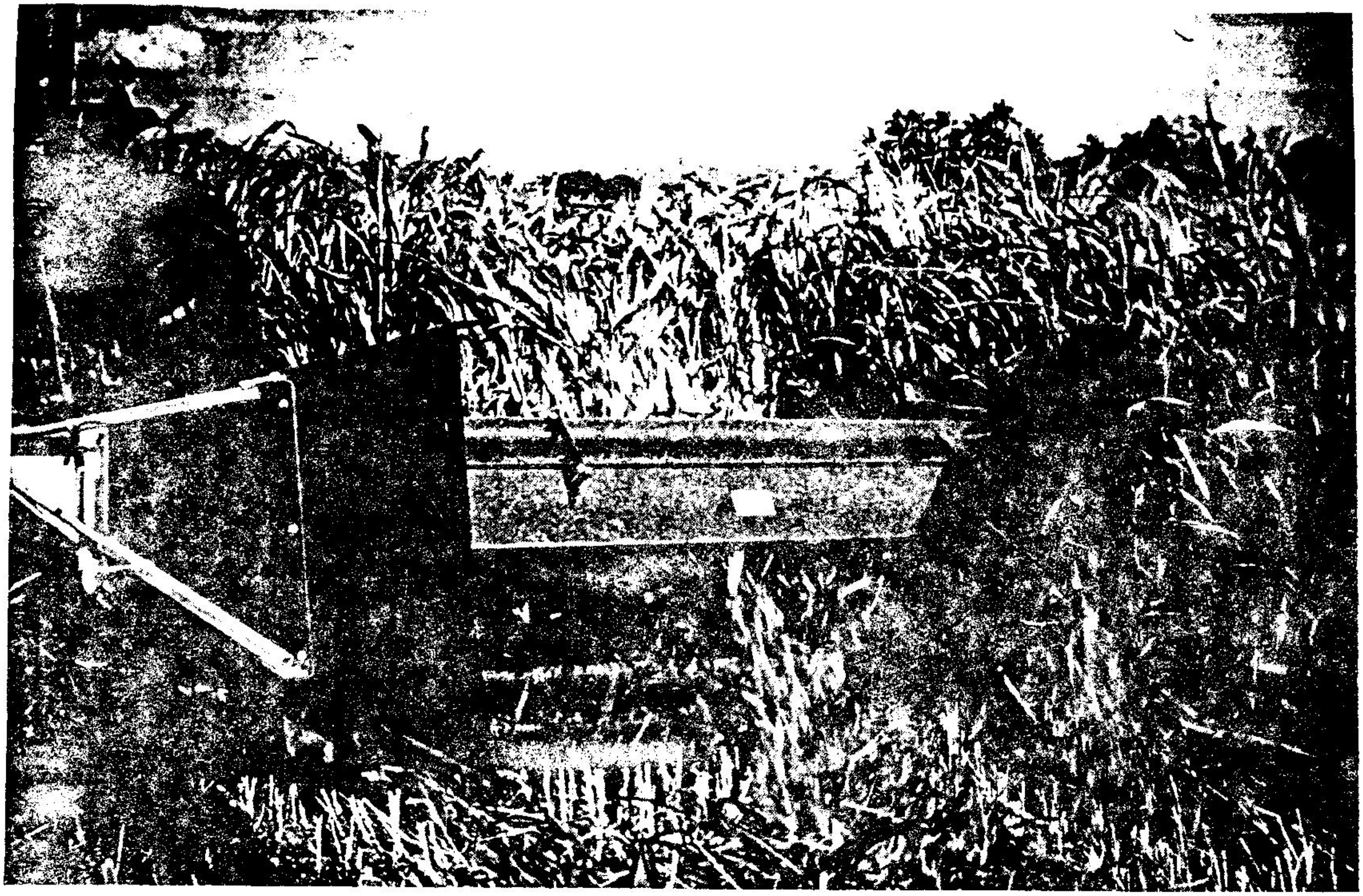

FIGURE 16. The M-C rotary scythe operating in 6-weeks old Sordan 70A, a short-rotation candidate. Sordan 70A produces about 10 green tons/acre at this age with a moisture content of 88-90%. Such material offers no problems for the rotary scythe. The most difficult material to be tested with this implement will be 6-months old napier grass, representing approximately 40 green tons/acre with a moisture content of 60-65%.

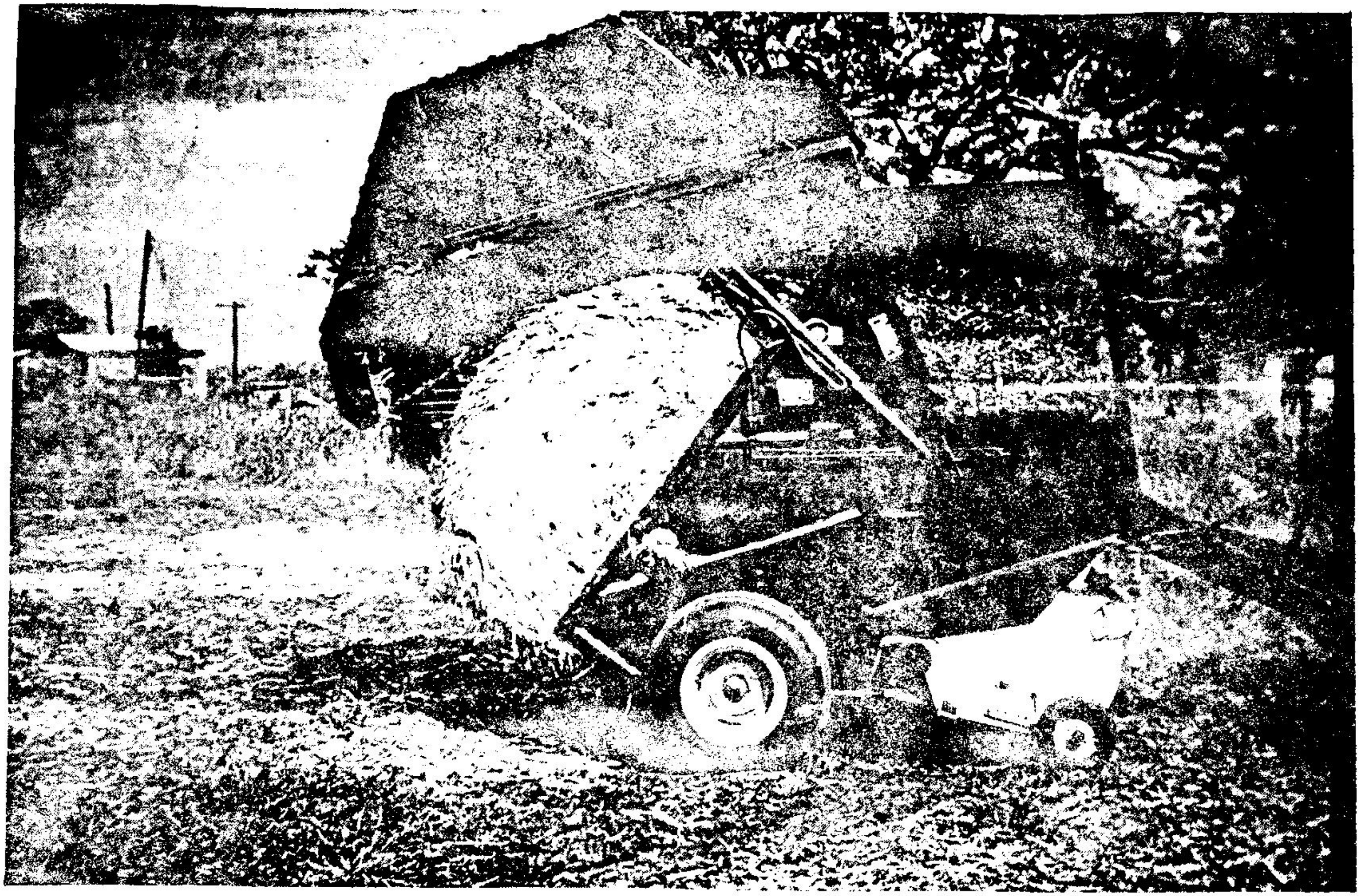

FIGURE 17. The New Holland model 851 round baler being tested on solar-dried Sordan 70A, a short-rotation candidate. This baler will be tested on solar-dried materials from the short-and intermediate-rotation grasses, and on desiccated "trash" from long-rotation grasses such as sugarcane.

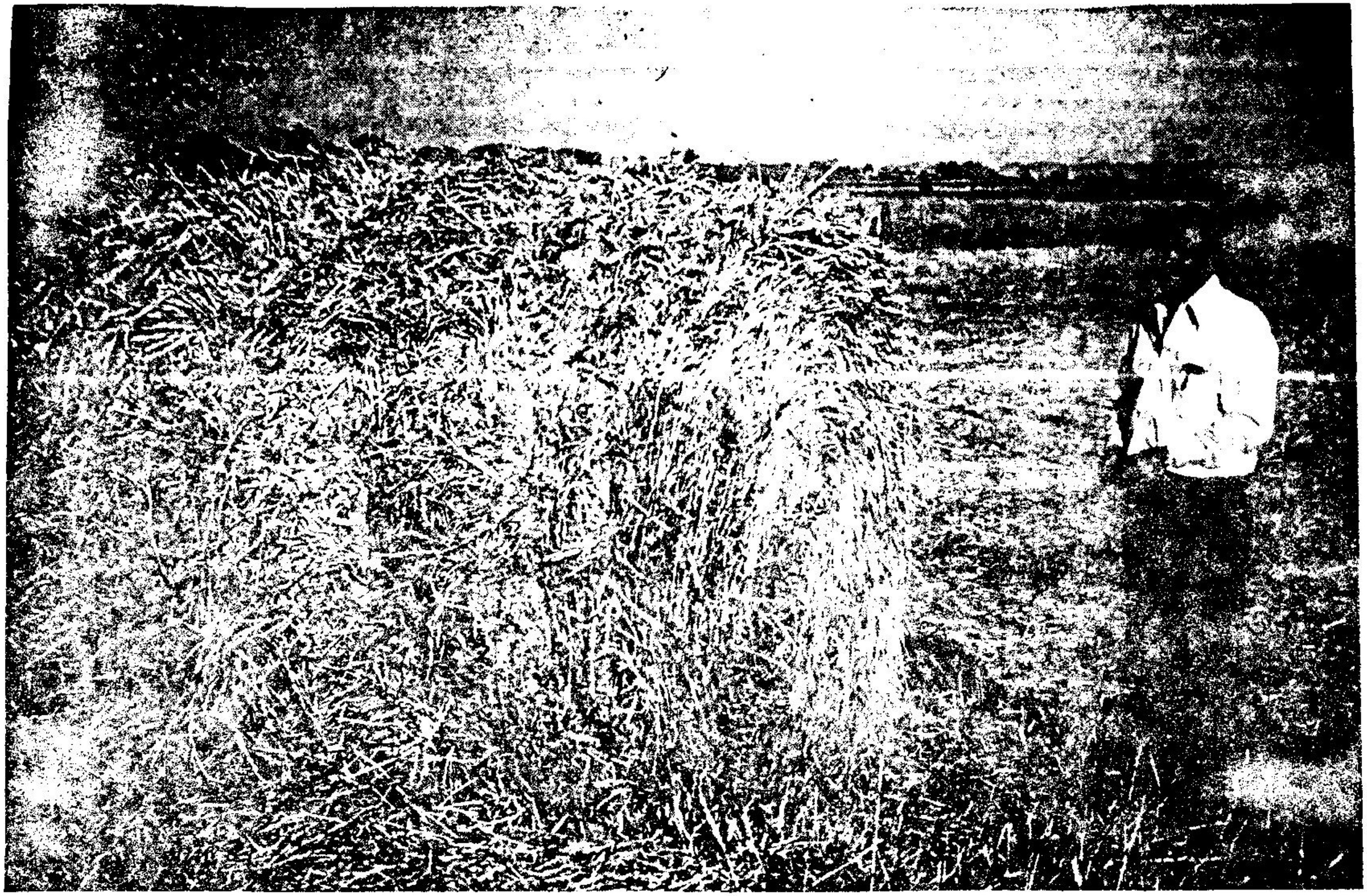

FIGURE 18. A round (bulk) bale of solar-dried Johnson grass produced by the New Holland model 851 roung baler in preliminary tests with the implement. Such bales weigh in the order of 1200 to 1500 pounds. Approximately 80 feet of standard baler twine was used on this bale, whereas 150 feet was subsequently found to be optimal.

FIGURE 19. A "wild" sugarcane clone, SES-231, being tested both as a minimum tillage and intermediate rotation candidate. Producing virtually no sugar, the plant has thin, fibrous, upright stems ideally suited for mechanical harvest. The growth illustrated above is about 10 weeks old.