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THE PRODUCTION OF BIOMASS BY SUGARCANE

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Abstract

Experiments conducted between 1962 and 1970 in South Africa permit a study to be made of biomass production by sugarcane. It is possible to estimate the proportions of trash (dead leaves + foliage) and cane stalk produced by different varieties. The accumulation of biomass in the crop, maximum rates of biomass production, and the effects of varieties, espacement, nitrogen fertilizer, water availability and season are all given consideration.

Introduction

The world-wide depletion of fossil fuels during the twentieth century has not yet precipitated the impending crisis, but there is much to be said for the development of alternative energy sources well before oil and coal reserves run out. To this end, the information already available on the production of biomass by sugarcane should be of interest. Biomass here is defined as the total above-ground dry matter produced by the crop, and is considered exclusively in terms of its energy equivalent and the photosynthetic efficiency with which it is produced, and not in the traditional terms of its food value.

Materials and Methods

During the period from 1962 to 1970, six experiments were conducted by the S.A.S.A. Experiment Station in such a way that estimates of biomass production became available. Concurrently, total incoming shortwave radiation (R_I) was measured, usually by means of a Kipp solarimeter.

Experiment 1

This experiment was planted on 1 October, 1962, at Shakaskraal (Gosnell[7]). Variety NCo 376 was used for the main part of the experiment which comprised six replications of plots to be harvested as plant cane weekly over a period of 88 weeks, starting from 6 February, 1963, when the crop was 18 weeks old. The size of each net (harvested) plot was 11,3m^2. The rows were 1,37m apart and the experiment was rainfed. All plots received 224 kg N, 73 kg P and 185 kg K per hectare. The results used in this paper are monthly means.

In addition to the main part of the experiment, a number of additional plots were planted in order to study the effects of different treatments. These included plots which received no nitrogen fertilizer, plots in which the rows were 0,46m apart, plots which were irrigated so that the crop never suffered stress, and plots which were the same as those in the main experiment but were planted on 1 March, 1963. These treatments were unreplicated, only one plot being harvested each week. Additionally, two replications were planted with variety NCo 310 and two with variety NCo 382.

At each time of harvest the above-ground parts of the crop were separated into three components. These were (i) the dead leaves (ii) the green foliage (including the apical meristem above the point of attachment of the sheath associated with the sixth unfurled leaf, counting from the top of the spindle), and (iii) the stalks. Subsamples were taken from each component and moisture contents were determined by oven-drying. In this paper the components of the crop are identified in most instances as trash (dead leaves and green foliage as described in i and ii above), and stalks (iii above).

Experiment 2

The results of Experiment 1 led to the conclusion that more valuable data would be obtained from an irrigated experiment in which the crop was planted at intervals throughout the year. Such an experiment was planted at Pongola with variety NCo 376, starting on 8 November 1967, and at seven-weekly intervals thereafter until 16 October 1968. For each time of planting there were six replications of main plots. Successive plantings were harvested when the crop was one week older than that harvested previously, the first planting being 58 weeks old when harvested. In this way it was then possible to harvest six sub-plots from each main plot in the first ratoon crop at 8-weekly intervals from 32 to 72 weeks of age. Data were obtained for first ratoon crops of each age harvested at different times of year, and for crops of different ages harvested at one time of year. Each main plot covered 404 m^2, of which 42 m^2 was used to estimate plant crop yields. First ratoon sub-plots comprised three rows, each 5,5 m long and 1,5 m apart (25 m^2). The plant crop received 224 kg N, 93 kg P and 56 kg K per hectare, and the first ratoon crop 224 kg N per hectare (Rostron[13, 14]).

Only harvestable stalk yields were recorded at each time of harvest for the whole experiment, except for the first ratoon crop from the last planting. From the plots representing this treatment, the entire crops on 5,5m of cane row were harvested intact when 32, 40, 48, 56 and 64 weeks old, and separated into the same components as described above for Experiment 1. When the plots were 72 weeks old, the same procedure was followed for the crop harvested from the whole sub-plot (25m^2). Sub-samples in each instance were oven-dried in order to determine moisture contents, and it was then possible to calculate the total biomass produced at each time of harvest.

Experiment 3

Single-budded setts of varieties NCo 376, NCo 310 and CB 36/14 were planted on 16 September, 1970, at Mt. Edgecombe in small plots containing fumigated soil. After six weeks plants of each variety were selected for uniformity of growth and planted 25 cm apart in rows 1,4 m apart in an artificially constructed, uniform soil profile 1,6m deep. There were three rows of each variety, 12,5 m long, and yields were estimated by harvesting the centre 7,2m of the middle row. The plant crop was harvested when 393 days old and the first ratoon when 362 days old. For comparative purposes, yields were "adjusted" to a common age of 365 days. In order to ensure optimum possible conditions for crop growth, successive 25 cm strata of the artificially established soil profile were sterilized with methyl bromide, 55 tons of chicken manure compost being incorporated in the surface 25 cm of soil before sterilization. The plant crop received 152 kg N, 77 kg P and 165 kg K per hectare and the first ratoon received 135 kg N, 34 kg P and 203 kg K per hectare. The crops were always adequately irrigated (Rostron[14]).

The harvested crops were separated into the same three components as described for Experiment 1. After weighing each component, the moisture contents of subsamples were determined and the amounts of biomass produced were calculated.

Experiment 4

The productivity of two sugarcane varieties (NCo 376 and CB 36/14) was determined under irrigated conditions at Pongola in an experiment in which pre-germinated single-budded setts were planted on 26 October, 1967, in square spacings which covered the range from 0,23 m to 3,66 m (see Table 6). In addition, pre-germinated 3-budded setts of NCo 376 were planted in rows 1,44 m apart, the setts spaced so that the total number of buds per hectare was the same as that in the 0,36 m square spacing. There were three replications of each spacing for each variety, and the net plot sizes ranged from 15,9 m^2 to 53,6 m^2 according to the stool spacing. The plant crop received 224 kg N, 336 kg P and 112 kg K per hectare (Boyce [6]).

The plant crop, harvested after 294 days, was separated into three components as described for Experiment 1, except that the stalks were topped at the point of attachment of the sheath associated with the *fifth* unfurled leaf. The components were weighed, the moisture contents of subsamples were determined, and the yields of biomass were calculated.

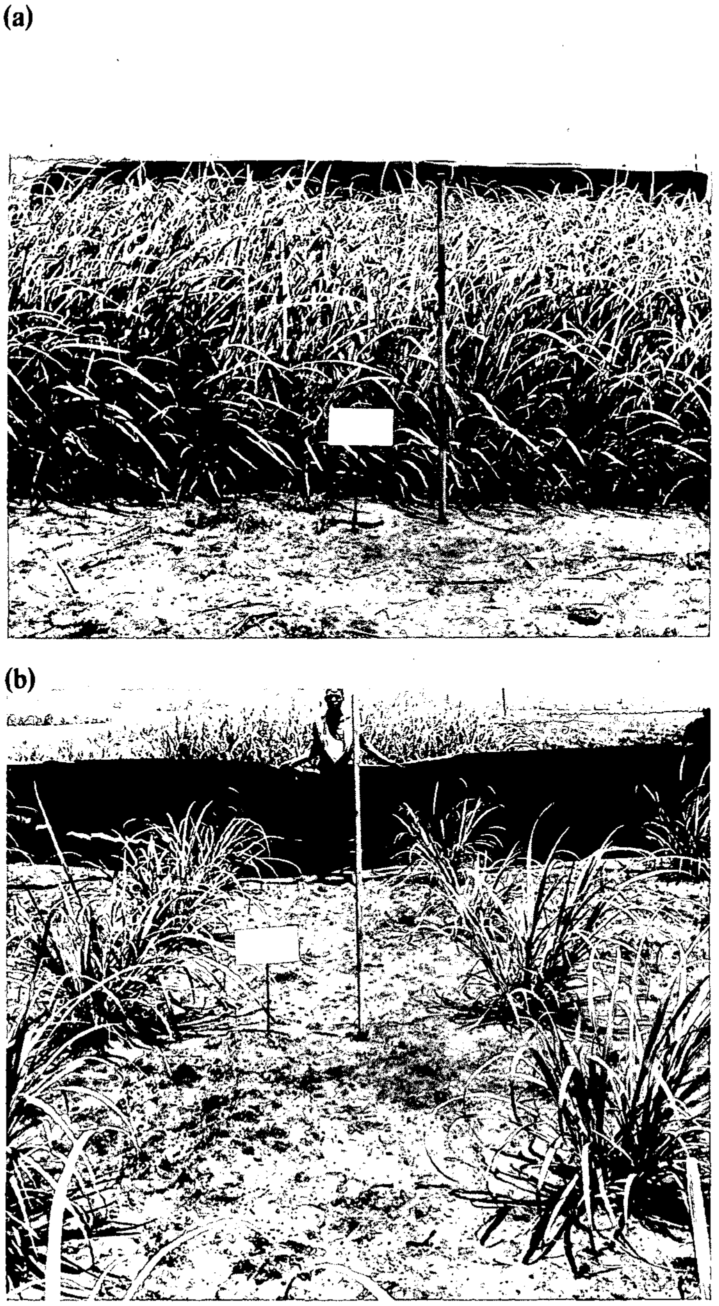

Fig. 1. Irrigated NCo 376 in Experiment 4 at 11 weeks of age (a) 0,23 m square spacing (b) 2,29 m square spacing.

Experiment 5

It was observed during the development of the crops in Experiment 4 that the closely planted material accumulated biomass per unit area at a much higher rate than the more widely spaced material during the early stages of the crop (Figures 1a and 1b), but that this advantage dissipated gradually as the crops became older. In order to assess any possible commercial advantage that might be gained due to this phenomenon, a further experiment was planted at Pongola under irrigation, and plots were harvested at 8, 10 and 12 months of age. The treatments comprised the following planting procedures, all carried out in rows 0,84 m apart with varieties NCo 376 and NCo 310:

(i) pre-germinated single-budded setts spaced 0,91m apart in the row (13 000 plants per hectare)
(ii) transplanted seedlings spaced 0,91m apart in the row (13 000 plants per hectare)
(iii) pre-germinated single-budded setts spaced 0,46 m apart in the row (26 000 plants per hectare)
(iv) pre-germinated single-budded setts spaced 0,15 m apart in the row (78 000 plants per hectare).

Planting took place on 23 May, 1969, and all plots received 168 kg N and 93 kg P per hectare. At each time of harvest, the total above-ground parts of the plants were separated into components as was done in Experiment 4. Sub-samples of each component were oven-dried to determine moisture contents, and the yields of biomass were calculated.

Experiment 6

Evapotranspiration (E_t) from a sugarcane crop was measured in a lysimeter experiment at Pongola, planted on 12 November, 1967 (Thompson and Boyce[15]). There were three direct-weighing lysimeters (each 3,7m^2 in surface area) which provided data for daily amounts of E_t. A block of land, 0,404 ha in extent, located next to the lysimeter experiment, was planted at the same time in plots so that biomass production could be estimated by harvesting four replications at approximately monthly intervals during both the plant and first ratoon crops. The net (harvested) plot size was 16,7m^2.

The plant crop was fertilized with 224 kg N, 93 kg P and 56 kg K per hectare, and the first ratoon crop received 224 kg N, 29 kg P and 56 kg K per hectare. The final harvesting of the growth plots in the plant crop was carried out on 8 August, 1968, but the lysimeter experiment was not harvested until 9 October, 1968. The plant stage of the first ratoon part of the experiment was harvested at the same time as the lysimeter experiment, and the first ratoon crop was harvested at intervals until 5 November, 1969, when it was 392 days old.

For the plant crop, the biomass accumulated on the lysimeters was estimated directly from the mean yields obtained from the four replications of harvested growth plots. In the first ratoon crop, however, the stalks from each growth plot at each time of harvest were segregated into categories according to length, and the mean amount of biomass per stalk for each category was determined. The heights of the stalks in each lysimeter were measured on the same day, and yields of biomass were calculated according to the number of stalks which occurred in each lysimeter in each length category. This was known as the "matching sample" technique.

Results

Components of biomass

The biomass harvested during the first five months in Experiment 1 comprised foliage only. As can be seen in Fig. 2, the proportions of dead leaves and stalks increased rapidly during the ensuing seven months. Thereafter, the proportion of dead leaves remained remarkably constant at about 26%, and the proportion of stalk predictably increased gradually at the expense of the foliage. Vigorous vegetative growth during the second summer period (16-20 months) did cause a temporary increase in foliage percentage, with a concomitant decrease in stalk percentage.

The accumulation of trash (dead leaves + foliage) showed a consistent trend in Experiment 1 for a number of treatments (see Fig. 3), and in several experiments for NCo 376 planted in spring. The effect of season on the production of stalk mass, however, is clearly shown in Fig. 3 for the crop planted in autumn.

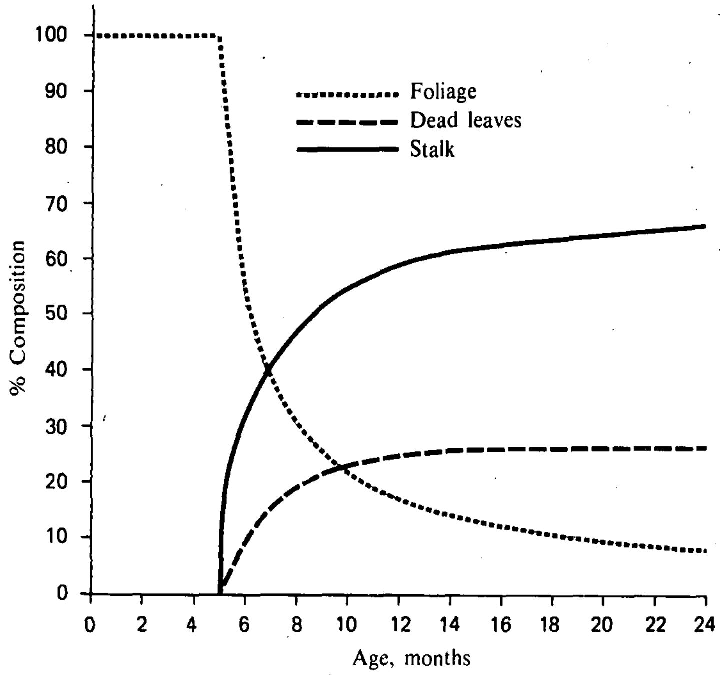

Fig. 2: The partitioning of rainfed NCo 376 dry matter between foliage, dead leaves and stalk from 0-24 months of age

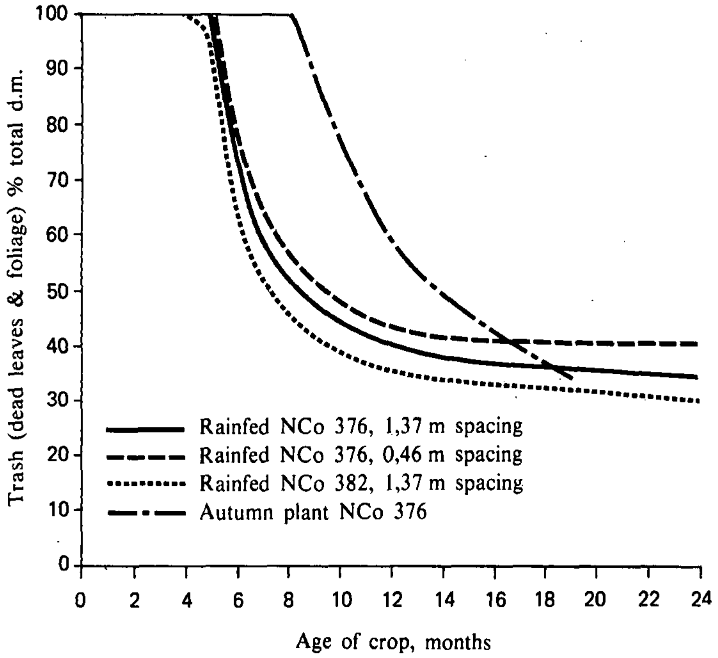

Fig. 3: The proportions of trash (dead leaves and foliage) with increasing age from 0-24 months in Experiment 1

Amounts of biomass

The production of biomass varies according to treatments and conditions in much the same way as does the production of sugarcane stalks alone. To illustrate the general levels of productivity which can be obtained, the available data for 19 crops have been summarized in Table 1. All but four of the crops were irrigated. Under rainfed conditions, crop growth is limited mainly by water availability, and is therefore much more a function of the amount and distribution of rainfall than it is of the radiant energy available.

Crop growth rate (C) can be expressed conveniently in terms of grams per square metre per day, but this characteristic will vary according to the age of the crop and the season. A more independent assessment of growth can be made by expressing it in terms of the efficiency with which radiant energy is stored in biomass. Although this efficiency is often related to photosynthetically active radiation (PAR), it is shown in Table 1 as a percentage of solar irradiance or total incoming shortwave radiation (R_1), because PAR varies as a percentage of R_1 according to cloudiness and a number of other factors (Ross[12]). The factor used to convert grams of dry matter to equivalent megajoules was $1{,}76 \times 10^{-2}$.

In Table 1 it can be seen that productivity for the four rainfed crops of NCo 376 varied from about 5 to 9 g m^{-2} day^{-1}, and photosynthetic efficiency from 0,5 to 1,0%. In contrast the data for irrigated crops were more consistent and the average photosynthetic efficiency was 1,7% and 1,6% for the plant and first ratoon crops respectively. Included in this table are data calculated from the results published by Borden [2,3,4] in Hawaii for variety H32-8560. Because solar irradiance is greater in Hawaii than in South Africa, values of C are expectedly higher in Hawaii, but the values for photosynthetic efficiency are similar for the two locations.

Maximum productivity

Sugarcane, like other crops, reaches a maximum level of productivity only after it has become fully canopied and intercepts as much solar irradiance as possible. Data obtained from four South African experiments and the three Hawaiian trials of Borden [2,3,4] were such that productivity during successive two to three month periods could be estimated. The periods during which the productivity of irrigated sugarcane reached an apparent maximum in each crop are shown in Table 2. (In assessing the data in this table it should be borne in mind that yield increments represent the differences between the mean yields from replicated plots at two separate times of harvest, and are therefore susceptible to exceptionally large amounts of experimental error).

Although the figures for the first Hawaiian experiment appear to be unusually high, there is a consistent indication that maximum productivity from H32-8560 is greater than that of NCo 376 in terms of photosynthetic efficiency. Of most interest, however, is the fact that in all eight instances the recorded maximum productivity occurred during late summer and autumn, even though the age of the crops varied from about three to 18 months at the time of observation.

Crop development

The data obtained from Experiments 1 and 2 were used to calculate the productivity of NCo 376 during the first six to eight months of crop growth, and for two or three monthly periods thereafter. The results for both rainfed and irrigated crops in Experiment 1 are shown in Table 3. There was an apparent tendency for productivity (C) at Shakaskraal to be low from June to December, although a severe autumn drought caused the rainfed crop to suffer badly between 532 and 722 days of age. The todate results show that both rainfed and irrigated crops reached a maximum level of accumulated production after only 259 days. Photosynthetic efficiency of the rainfed crop did not decline appreciably with increasing age thereafter, and even in the irrigated crop the loss of efficiency incurred by prolonging the crop to 20 months was not pronounced. It was a feature of the experiment that a net loss of biomass occurred in all treatments after 623 days.

In Experiment 2 at Pongola a net loss of production in irrigated NCo 376 occurred after 448 days, but as can be seen in Table 4 the todate level of photosynthetic efficiency reached a maximum at 448 days.

Varietal differences

It has been shown in Tables 1 and 2 that when the crops were about one year old, varieties NCo 376 and H32-8560 could both convert about 1,7% of solar irradiance into chemical energy contained in the biomass, but that the maximum efficiency of conversion over an identifiable period was apparently greater for H32-8560 than for NCo 376.

In four of the experiments being considered here, comparisons between variety NCo 376 on the one hand, and varieties NCo 310, NCo 382 and CB 36/14 on the other, have been possible. The results are shown in Table 5, and differences between varieties are neither sufficiently large nor consistent to suggest that any one of these four released varieties might be preferred over the others for biomass production.

The proportions of trash and stalk at time of harvest in varieties NCo 376, NCo 310 and CB 36/14 did not differ significantly (see Table 5), but in Experiment 1 variety NCo 382 developed stalk sooner than did NCo 376, and continued to have a higher proportion of stalk throughout 24 months of growth, as shown in Fig. 3.

TABLE 1

Estimates of biomass production and photosynthetic efficiency for harvested sugarcane crops

Site No.	Site Location	Ref. No.	Crop	Variety	Replications	Treatment	Age days	C g m^{-2} day^{-1}	P efficiency %
1	Shakaskraal	7	P	NCo 376	5	Rainfed	350	9.2	1,0
			P	NCo 376	1	Irrigated	350	11,2	1,4
2	Pongola	13	IR	NCo 376	6	Irrigated	336	15,8	1,5
3	Mt. Edgecombe	14	P	NCo 376	1	Irrigated	365	15,8	1,8
			IR	NCo 376	1	Irrigated	365	15,3	1,7
4	Pongola	6	P	NCo 376	3	Irrigated	294	13,5	1,3
5	Pongola	–	P	NCo 376	4	Irrigated	270	15,6	1,6
			IR	NCo 376	3	Irrigated	350	20,1	2,0
6	Pongola	–	P	NCo 376	2	Irrigated	362	18,3	1,8
7	Cornubia	16	IR	NCo 376	4	Rainfed	532	5,4	0,5
			IR	NCo 376	4	Irrigated	532	14,2	1,4
8	Ottawa	16	2R	NCo 376	3	Rainfed	456	6,0	0,6
			2R	NCo 376	3	Irrigated	456	16,2	1,6
9	Ottawa	16	2R	NCo 376	4	Rainfed	426	6,6	0,7
			2R	NCo 376	4	Irrigated	426	16,5	1,6
10	Mt. Edgecombe (C.F.S.)	14	P	NCo 376	1	Irrigated	365	14,9	1,7
11	Hawaii	2	P	H32-8560	6	Irrigated	348	18,3	1,6
12	Hawaii	3	P	H32-8560	15	Irrigated	366	21,0	1,7
13	Hawaii	4	P	H32-8560	15	Irrigated	366	22,3	1,8
	Mean results*		P	–	48	Irrigated	350	19,6	1,7
			R	–	21	Irrigated	411	16,3	1,6

*Weighted according to replications.

TABLE 2

Maximum rates of biomass production and photosynthetic efficiency during limited periods of irrigated sugarcane crop growth

Site No.	Site Location	Ref. No.	Crop	Variety	Replications	Period From	Period To	Age, days From	Age, days To	Age, days Total	C g m^{-2} day^{-1}	P efficiency %
1	Shakaskraal ...	7	P	NCo 376	1	Mar	June	169	259	91	19,9	2,5
2	Pongola	13	1R	NCo 376	6	Feb	Apr	393	448	55	28,8	2,4
3	Pongola	–	P	NCo 376	4	Mar	May	120	179	59	23,2	2,5
			1R	NCo 376	4	Jan	Mar	97	153	56	40,6	3,1
4	Pongola	–	P	NCo 376	2	Mar	May	305	362	57	30,7	2,2
5	Hawaii	2	P	H32-8560	6	Oct	Jan	439	530	91	47,9	5,1
6	Hawaii	3	P	H32-8560	15	Sept	Nov	93	184	91	29,1	3,2
7	Hawaii	4	P	H32-8560	15	May	Sept	183	275	92	44,0	3,0
Averages*/totals				NCo 376	17	–	–	–	–	58	30,0	2,6
				H32-8560	36	–	–	–	–	90	38,4	3,4

*Weighted according to replications

TABLE 3

Total biomass production by NCo 376 during successive periods in Experiment 1, and efficiencies of conversion of solar irradiance

Period	No. of days period	No. of days total	C g m^{-2} day^{-1} Period Rainfed	C g m^{-2} day^{-1} Period Irrigated	C g m^{-2} day^{-1} To date Rainfed	C g m^{-2} day^{-1} To date Irrigated	P efficiency % Period Rainfed	P efficiency % Period Irrigated	P efficiency % To date Rainfed	P efficiency % To date Irrigated
Oct–Mar	168	168	8,6	11,6	8,6	11,6	0,8	1,1	0,8	1,1
Mar–Jun	91	259	12,1	19,9	9,8	14,6	1,5	2,5	1,0	1,5
Jun–Sep	91	350	8,4	6,3	9,2	11,2	1,2	0,9	1,1	1,3
Sep–Dec	94	444	9,7	11,3	9,3	11,9	0,9	1,1	1,0	1,3
Dec–Mar	88	532	10,7	15,8	9,3	12,5	0,8	1,3	1,0	1,3
Mar–Jun	91	623	5,4	15,8	8,8	13,0	0,7	1,9	0,9	1,4
Jun–Sep	91	722	-1,1	-20,6	7,5	8,8	- 0,1	-2,7	0,8	1,0

TABLE 4

Total biomass production by irrigated NCo 376 during successive periods in Experiment 2, and efficiencies of conversion of solar irradiance.

Period	No. of days period	No. of days total	C g m^{-2} day $^{-1}$		P efficiency %	
			Period	To date	Period	To date
Jan–Aug	224	224	13,7	13,7	1,4	1,4
Aug–Oct	56	280	14,8	14,0	1,4	1,4
Oct–Dec	56	336	25,7	15,8	2,1	1,5
Dec–Feb	56	392	16,2	15,9	1,4	1,5
Feb–Apr	56	448	28,8	17,5	2,4	1,6
Apr–May	56	504	-7,5	14,8	-0,9	1,4

Espacement effects

Experiment 4 was harvested when it was 294 days old, and as can be seen in Table 6, spacings closer than 0,57 m square did not increase productivity in either variety. Rows of NCo 376 planted 1,44 m apart in fact provided the highest yields. The proportion of trash and stalk from NCo 376 did not vary widely or consistently over the full range of spacings, but for CB 36/14 there was an apparently consistent increase in the proportion of trash as the spacings decreased (see Table 6).

Under rainfed conditions in Experiment 1 at Shakaskraal, the proportion of trash from NCo 376 appeared to be greater at all stages of growth when the rows were 0,46 m apart than when they were 1,37 m apart, as shown in Fig. 3.

In Experiment 5 at Pongola, productivity apparently increased with increasing numbers of buds planted in rows 0,84 m apart, and planting seedlings instead of pre-germinated setts was also consistently advantageous.

Effects of nitrogen

Of the nutrients required for crop growth, only nitrogen has been studied in terms of biomass production (see Table 7). In Experiment 1, the application of 224 kg N per hectare increased biomass production of rainfed cane by 33% when the crop was one and two years old. Under irrigated conditions in Hawaii, maximum responses to nitrogen treatment were 78%, 78% and 172% in the three successive experiments conducted. Although the nitrogen-treated plots at Shakaskraal produced a higher proportion of trash when the crop was one year old, this effect had disappeared after two years of growth.

Effects of water

The results of Experiment 6 shown in Table 8 illustrate that the production of biomass per unit of water used in evapotranspiration was predictably low during the period of incomplete canopy at the beginning of each crop, and again at the end of each crop when lodging affected yield. During the interim period of erect growth of fully canopied NCo 376, productivity was reasonably consistent at about 5,2 tons dm per hectare per 100 mm E_t in the plant crop, and at about 6,0 tons in the first

TABLE 5

Comparative composition and productivity of four sugarcane varieties

Expt. No.	Treatment	Crop(s)	Age days	Variety	dm composition		C g m^{-2} day $^{-1}$	P efficiency %
					% Trash	% Stalk		
1	Rainfed	P	359	NCo 376	41	59	9,2	1,0
				NCo 382	37	63	10,0	1,2
				NCo 310	45	55	9,3	1,1
			722	NCo 376	33	67	7,5	0,8
				NCo 382	29	71	8,6	1,0
				NCo 310	29	71	8,7	1,0
3	Irrigated	P	365	NCo 376	31	69	15,8	1,8
				CB36/14	33	67	16,4	1,9
				NCo 310	37	63	12,1	1,4
		1R	365	NCo 376	36	64	15,3	1,7
				CB36/14	37	63	17,5	2,0
				NCo 310	38	62	15,7	1,8
4	Irrigated	P	294	NCo 376	36	64	13,3	1,3
				CB36/14	38	62	12,7	1,2
5	Irrigated	P	362	NCo 376	37	63	18,3	1,8
				NCo 310	35	65	15,8	1,5
Means	Irrigated	(3)	364	NCo 376	35	65	16,5	1,8
				NCo 310	37	63	14,5	1,6
Means	Irrigated	(3)	341	NCo 376	34	66	14,8	1,6
				CB36/14	36	64	15,5	1,7

TABLE 6

Composition and productivity of two sugarcane varieties planted at various square spacings

Treatment	Square spacing m	Plants ha^{-1}	dm composition				C g m^{-2} day $^{-1}$		P efficiency %	
			NCo 376		CB 36/14					
			% Trash	% Stalk	% Trash	% Stalk	NCo 376	CB 36/14	NCo 376	CB 36/14
S1	3,66	764	38	62	34	66	3,3	4,9	0,3	0,5
S2	2,29	1912	42	58	34	66	6,8	7,8	0,7	0,8
S3	1,44	4787	39	61	38	62	9,9	10,0	1,0	1,0
S4	0,91	12034	43	57	39	61	11,2	11,4	1,1	1,1
S5	0,57	30480	36	64	38	62	13,3	12,7	1,3	1,2
S6	0,36	75770	43	57	42	58	12,9	12,7	1,2	1,2
S7	0,23	192131	39	61	43	57	12,7	12,4	1,2	1,2
S8	-*	75770	38	62	—	—	13,5	—	1,3	—

* NCo 376 only planted in conventional rows 1,44 m apart

ratoon crop. Of particular interest is the observation that productivity per unit of water used in this climate did not appear to decrease during autumn and winter when air temperatures were low.

Effects of season

Of the experiments conducted by the Experiment Station, only Experiment 2 was designed to take the effects of season extensively into account, and only stalk yields were recorded regularly. Using all available data for the percentage of trash in the biomass of irrigated NCo 376 harvested at approximately 12 months of age at different times of year, there is no evidence that the proportion varies consistently. A mean value of 34% has therefore been used to calculate total biomass in Experiment 2 for the eight successive times of harvest when the crops were all 52 weeks old. The results were used to produce Fig. 4, from which it can be seen that crops started in late summer and autumn when photosynthetic efficiency is apparently at its highest (Table 2), tend to yield the least biomass per annum.

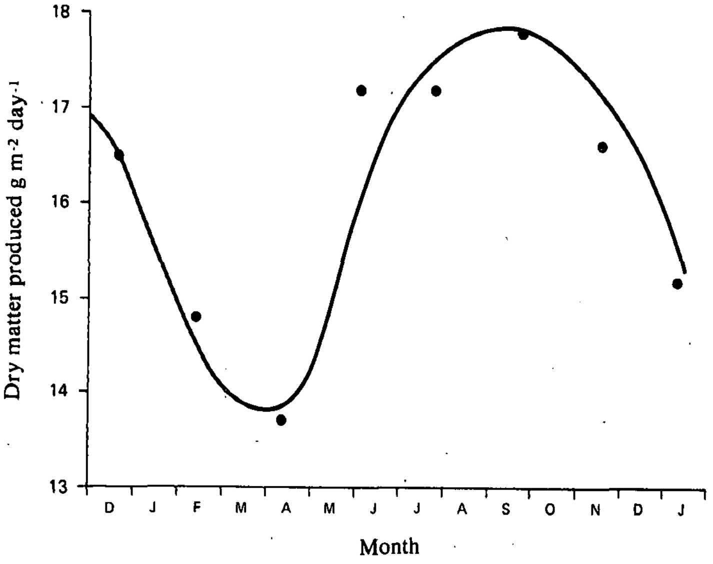

Fig. 4: Relationship between season and biomass produced by year-old irrigated NCo 376 at Pongola

Discussion

There is a large amount of data available in the literature concerning the yields of sugarcane under many different sets of conditions. The conversion of these data from stalk yields to yields of biomass, it would appear, cannot be done accurately unless the proportions of trash (dead leaves + tops) and stalks have been determined for the variety concerned, the age of the crop at harvest, the time of the year, and several other factors. This is illustrated in Figs. 1 and 2. The data of Moir [10] show that variety H109 accumulates a proportion of dead leaves much more slowly than does NCo 376, and that it comprises about 30% of trash at one and two years of age. (The proportions of dead leaves in the biomass of H109 at different ages of the crop were used to estimate the biomass of variety H32-8560, for which Borden[2,3,4] provided yields of stalks and foliage only).

For crops of current South African varieties planted in spring, however, approximate conversions may be obtained by assum-

TABLE 7

Effects of nitrogen on the composition and productivity of sugarcane

Site		Age days	kg N/ha^{-1}	Water regime	dm produced		C g m^{-2} day^{-1}	P efficiency %
No.	Location				%trash	% stalk		
1	Shakaskraal	359	0	Rainfed	34	66	6,9	0,8
			224	Rainfed	41	59	9,2	1,0
		722	0	Rainfed	35	65	5,6	0,6
			224	Rainfed	33	67	7,5	0,8
2	Hawaii (1942)	348	0	Irrigated	—	—	10,8	0,9
			336	Irrigated	—	—	18,6	1,6
			470	Irrigated	—	—	19,2	1,6
3	Hawaii (1945)	366	0	Irrigated	—	—	11,8	0,9
			246	Irrigated	—	—	21,0	1,7
4	Hawaii (1948)	366	0	Irrigated	—	—	8,2	0,6
			246	Irrigated	—	—	22,3	1,8

TABLE 8

Production of biomass in terms of water use and radiation conversion during successive periods of sugarcane crop growth in Experiment 6

Crop	Period		No. of days		Tons dm ha^{-1} (100mm E_t)$^{-1}$		g m^{-2} day^{-1}		P efficiency %	
	From	To	Period	To date	Period	To date	Period	To date	Period	To date
P	12.11.67	9.1.68	58	58	1,06	1,06	3,3	3,3	0,3	0,3
	10.1.68	11.3.68	62	120	3,55	2,73	20,8	12,3	1,8	1,0
	12.3.68	9.5.68	59	179	5,21	3,54	23,2	16,0	2,5	1,4
	10.5.68	10.7.68	62	241	5,15	3,84	15,5	15,8	2,1	1,5
	11.7.68	8.8.68	29	270	3,91	3,85	13,3	15,6	1,9	1,6
1R	10.10.68	14.1.69	97	97	3,42	3,42	11,6	11,6	1,0	1,0
	15.1.69	11.3.69	56	153	5,82	4,73	40,6	22,2	3,1	1,8
	12.3.69	6.5.69	56	209	5,27	4,85	19,4	21,5	2,2	1,9
	7.5.69	2.7.69	57	266	7,37	5,17	17,1	20,6	2,2	1,9
	3.7.69	26.8.69	55	321	5,48	5,22	17,4	20,0	2,0	1,9
	27.8.69	5.11.69	71	392	3,61	4,87	17,4	19,5	1,7	1,9

ing that trash comprises 40% of biomass after one year for rainfed cane, 34% for irrigated cane of the same age, and 33% for rainfed cane when it is two years old. The production of biomass under rainfed conditions will depend primarily on the amount of distribution of rainfall. Its prediction is therefore no easier than that of the cane crop itself. Taking an approximate average yield for the South African sugar industry of 60 tons cane per hectare per annum, and knowing that stalks of NCo 376 usually comprise 29% of dry matter, the rainfed biomass production should average about 7,5 g m^{-2} day^{-1}. This represents a photosynthetic efficiency of 0,8%.

Under irrigated conditions the potential productivity of NCo 376 has averaged approximately 16 g m^{-2} day^{-1}, with a P efficiency of 1,6%. If average commercial productivity is about 70% of experimental yields, then irrigating growers producing annual crops could expect 11 g m^{-2} day^{-1}, representing a photosynthetic efficiency of 1,1%.

Sugarcane has been an attractive crop to produce in areas to which it is suited climatically because of its sucrose content alone. It is therefore somewhat fortuitous that it appears also to be one of the most efficient crops in converting solar irradiance into stored chemical energy. Estimated biomass production by sugarcane (Table 2) over two or three month periods has reached 48 g m^{-2} day^{-1} in Hawaii and 41 g m^{-2} day^{-1} in South Africa. Superior figures for maize of 51 g m^{-2} day^{-1} (Loomis and Williams[8]) and for sorghum of 52 g m^{-2} day^{-1} (Williams, Loomis and Lepley[18]) in California, and 54 g m^{-2} day^{-1} for bulrush millet in Australia (Begg[1]), were all measured over appreciably shorter periods of time. Average maximum efficiencies of radiant energy conversion were 3,4% in Hawaii and 2,6% in South Africa.

It is significant that a loss of biomass occurred in Experiments 1 and 2, and in the second and third experiments conducted by Borden [3,4] in Hawaii, after the crop had reached a certain age. For both rainfed and irrigated cane in Experiment 1 a negative growth rate occurred after 623 days, in Experiment 2 after 448 days, and in Hawaii after 639 and 640 days in the two experiments concerned.

The mean results for the four varieties NCo 376, NCo 310, CB 36/14 and H32-8560 indicate that photosynthetic efficiencies of energy conversion do not differ materially between commercially acceptable clones after one year's growth. The data in Table 5 show that a P efficiency of approximately 1,7% is common to all four varieties. It is almost certain, nevertheless, that higher efficiencies could be obtained if variety selection were based on biomass production rather than sucrose accumulation.

The data shown in Tables 3 and 4 have indicated that the productivity of sugarcane during the early stages of crop development is limited due to incomplete leaf canopy. It is reasonable therefore to suppose that the performance of the crop might be improved by planting more closely and thereby achieving earlier canopy. In terms of sugarcane stalk and sucrose production this has been shown to be generally true (Boyce[5]; Matherne [9], Thompson and du Toit [17]). In Experiment 4 at Pongola the same effect was illustrated dramatically for biomass production when the crops were 11 weeks old (Fig 1a and 1b), but by the time of harvest after 294 days, the early advantages of the closest spacings had largely been lost. There can be little doubt that the maximum production of biomass can be achieved at very close spacings if the crop is to be harvested before sucrose accumulation becomes a criterion of any consequence, but once the manufacture of sugar is important, it would appear that an optimum square espacement exists and is cearly short of the closest possible spacing (Table 6). The highest yield of biomass from irrigated NCo 376 planted on the square was apparently matched by that from a crop planted in rows 1,44 m apart. The average results of the plant and first ratoon crops of a further experiment conducted at Pongola indicate that still higher yields might be obtained from cane grown in rows closer than 1,44 m to one another:

Row spacing m	Estimated biomass g m^{-2} day^{-1}
2,18	15,4
1,70	16,7
1,37	17,7
1,17	17,2
1,02	17,5
0,89	18,1

The energy required to place 1 kg of bagged N on the farm in the form of urea or ammonium sulphate has been estimated to be 83 MJ. The total energy required for N fertilizer and the gross energy return in terms of yield response to treatment with N, when the crops listed in Table 7 were about one year old, are as follows:

Site	N increment kg ha^{-1}	Equiv. energy MJ ha^{-1}	Gross biomass response MJ ha^{-1}
Shakaskraal	0 - 224	19 000	145 000
Hawaii (1942)	0 - 336	28 000	477 000
	336 - 470	11 000	37 000
Hawaii (1945)	0 - 246	20 000	593 000
Hawaii (1948)	0 - 246	20 000	908 000

It is clear that, in energy terms alone, all treatments were warranted if the gross energy value of the yield increase due to N treatment were all recoverable. It is possible, however, if the trash were all burnt in the field, and the efficiency of energy recovery from bagasse in the factory were low, then the extra 134 kg N per hectare applied in Hawaii (1942) might have constituted a net loss of energy.

The data provided in Table 8 do not indicate that the water requirements of sugarcane per unit increase of mass vary appreciably during the period of fully canopy. This has also been show by Mongelard and Mimura[11] for single sugarcane plants which were subjected to various air and root temperatures. Of more interest from an energy budget point of view, however, would be the energy required for irrigation in relation to the biomass produced. Except where water can gravitate to the field for surface irrigation to be practised, rainfed crops are likely to provide a significantly higher energy return than will irrigated crops.

If, for some reason, the photosynthetic efficiency of sugarcane is highest during late summer and autumn as suggested by the data in Table 2, then the implications of the data used in Fig. 4 are not surprising. Annual crops starting in March/April will have an incomplete canopy during part of this period when growth is apparently most efficient, and may well have lodged before the end of the following summer.

Conclusions

The commercial production of biomass from sugarcane may be estimated roughly on the basis of photosynthetic efficiency of 0,8% under rainfed conditions, and 1,1% under irrigated conditions. In South Africa these levels represent growth rates of approximately 7,5 and 11 g m^{-2} day^{-1} respectively. Released varieties are predictably similar in their abilities to produce biomass, but closer row spacings are likely to increase the yield potential of the crop. Attention needs to be given to the energy demands of items such as irrigation and fertilization, and to the means by which the energy value of the crop may be exploited efficiently.

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