Proc S Afr Sug Technol Ass (2008) 81: 517 - 527

SEASON EFFECTS ON PRODUCTIVITY OF SOME COMMERCIAL SOUTH AFRICAN SUGARCANE CULTIVARS,
I: BIOMASS AND RADIATION USE EFFICIENCY

DONALDSON RA[1,2], REDSHAW KA[2], RHODES R[2] and VAN ANTWERPEN R[2]

[1]*PO Box 505, Gillitts,3603, South Africa*
[2]*South African Sugarcane Research Institute, Private Bag X02, Mount Edgecombe, 4300, South Africa*
rob.a.donaldson@gmail.com *kerry.redshaw@sugar.org.za*
ruth.rhodes@sugar.org.za *rianto.van.antwerpen@sugar.org.za*

Abstract

There is renewed interest in ethanol production, and sugarcane promises to be a sustainable ethanol source. Few studies have been done on the effect of season on biomass production, and no studies have quantified yields of a range of cultivars in terms of intercepted radiation. The objective of this study was therefore to assess how season affects the biomass yields of a number of commercial cultivars. The above-ground biomass was measured in two experiments at Pongola and Mount Edgecombe. The treatments consisted of nine cultivars in each experiment and two or five crop starting dates. Season had a large influence on biomass yield production for all cultivars, with some cultivars being more adversely affected than others. Biomass yields of December crops were substantially lower than autumn/winter crops, particularly for cultivars N22 and CP66/1043. Cultivars N14, N16 and N21 were least affected by the conditions that have an adverse effect on December yields and could possibly be more stable cultivars to consider for ethanol production than some of the other cultivars assessed in this study.

Keywords: sugarcane, biomass, season, radiation use efficiencies, cultivars, varieties

Introduction

There is renewed interest in producing ethanol from sugarcane in South Africa. This is due to the rising cost of fossil fuels and their dwindling reserves. The cost of crude oil breeched US$120 per barrel for the first time in May 2008, and is predicted to rise above $150 per barrel before the end of 2008. Sugarcane is a high biomass producer and is an excellent renewable source for ethanol production. In addition to ethanol production, byproducts from sugarcane cultivation have been used in generating electricity, supplementing animal feed, producing paper and in formulations of many other high value products. Productivity of sugarcane is most often measured in terms of cane yields and sucrose content, and these parameters form the basis of cultivar selection. The total above-ground dry matter produced by sugarcane is not routinely measured in field experiments. Few studies have investigated the seasonal effects on biomass production, and no more than one or two cultivars have been included in these studies (Thompson, 1978; Singels *et al.*, 2005a; McDonald, 2006). There is therefore a need to consider the effects on a wider range of cultivars, particularly in relation to season, as was done by Gilbert and his co-workers (Gilbert *et al.*, 2006). The review by Thompson (1978) of the season effects on the production of biomass by the South African sugarcane cultivar NCo376 was based on stalk dry mass data reported by Rostron (1974). Biomass was calculated by assuming that the fraction of trash in biomass was constant at 0.34. The study also expressed productivity in terms of the efficiencies in which incident radiant is stored in biomass. A better measure of the efficiency of productivity is based on intercepted radiation rather than incident radiant energy. The fraction of light intercepted by crop canopies is affected by season (Inman-Bamber, 1994; Singels *et al*., 2005a), and the efficiency by which intercepted radiant energy is converted into biomass determines the productivity of the crop. Radiation use efficiency (RUE) is defined here as the above-ground biomass (g/m²) produced per unit short wave radiation intercepted (MJ/m²) and values between 1.25 g/MJ (Singels and Smit, 2002) and 1.96 g/MJ (Muchow *et al*., 1997) are quoted for sugarcane in the literature.

The objective of this study is to report the results of two studies in which biomass and intercepted radiation were measured and RUE calculated for a range of commercial cultivars grown in different seasons in South Africa. RUE is a predictor of biomass production, and the biomass of sugarcane is largely composed of lignocellulose and brix from which ethanol can be produced. The biomass yields of nine cultivars were measured in two experiments conducted at Pongola and Mount Edgecombe. The experiments were well irrigated and free of pests and weeds. A companion paper in these proceedings deals with the production of trash (Donaldson *et al.,* 2008).

Materials and Methods

Sites and crop husbandry

Growth and development of well-irrigated sugarcane crops were measured in one experiment at Pongola (Experiment 1, 27°25'S, 31º36'E, elevation 308 m), and one at Mount Edgecombe (Experiment 2, 29º42'S, 31º02'E, elevation 105 m). Irrigation events were scheduled to avoid stress by estimating soil water status using the Canesim model (formerly the IRRICANE model) (Singels *et al*., 1998) and profit and loss balances. Irrigation water was delivered by dripper lines, placed in alternate interrows. The experiments were well supplied with nutrients, using guidelines from the South African Sugarcane Research Institute (SASRI) Fertiliser Advisory Service (FAS) at Mount Edgecombe. The experiments were kept free of weeds at all times by the use of herbicides and manual control. Weather stations, within 100 m of each experiment, provided daily data to develop relationships between growth and radiation.

Light interception measurements

The fraction of PAR (Photosynthetically Active Radiation) was measured on several occasions before canopy closure, using a ceptometer (SF-80 model, Decagon Devices, Pullman, WA, USA). One above-canopy and eight to ten below-canopy readings were done on each plot between 11h00 and 13h00 on cloudless days. Daily fractions were estimated by interpolation and applied to daily incident short wave radiation measured at the weather stations, and the products summed over the season to derive seasonal intercepted short wave radiation (Singels *et al.,* 2005a). Annual RUE (RUEann) was calculated by dividing annual intercepted radiation into annual biomass yield. Similarly, cumulative radiation was divided into biomass yields at each sampling occasion to derive the highest RUE values (RUEmax) during the growth of the crops.

Experiment 1 - Pongola

Ratoon crops of nine cultivars in two replications were started in March, April, May, August and December 1998 at Pongola. Of the nine cultivars, only NCo376, N25 and N26 were common to each of the five crop start dates. Cultivars N19 and N22 were in the March and December cycles, N24 and CP66/1043 were in the April and August cycles and N17 and Q124 were in the May cycle only (Table 1). Row spacing was set at 1.4 m.

Experiment 2 - Mount Edgecombe

Nine cultivars were planted in two replications during December at Mount Edgecombe. Half the number of plots was then harvested on 6 June 2000 and the other half on 7 December 2000, to create a winter and a summer cycle (Table 1). Row spacing was set at 1.2 m.

Table 1. Crop start dates and sugarcane cultivars in experiments conducted at Pongola and Mount Edgecombe and age of final sampling.

Site, crop and plot size	Crop start date	Final age (days)	Cultivar
Experiment 1 Pongola Second ratoon Plot size: 18-23 m x 11 rows 1.4 m row spacing	03/03/1998	364	NCo376, N25, N26, N19, N22
	08/04/1998	365	NCo376, N25, N26, N24, CP66/1043
	06/05/1998	362	NCo376, N25, N26, N17, Q124
	06/08/1998	362	NCo376, N25, N26, N24, CP66/1043
	08/12/1998	357	NCo376, N25, N26, N19, N22
Experiment 2 Mount Edgecombe First ratoon Plot size: 9.5 m x 10 rows 1.2 m row spacing	06/06/2000	364	CP66/1043, N12, N14, N16, N17, N21, N27, N29, NCo376
	07/12/2000	348	

Sample analysis

Samples of 15 stalks were taken from four points in each plot when crops were about 4, 8, 10, 11 and 12 months old. Total plant biomass was measured on these occasions in the following manner. Dead plant material on and around stalks was collected as trash. The trash thus comprised dead and dying shoots, together with dead leaves on living stalks. Green foliage was then separated from the stalks and measured separately as a green component of trash. The soft top sections of the stalk (called meristem) were analysed as a separate component and added to the stalk biomass. Each component was weighed immediately after collection. Sub-samples from each component were weighed and then dried to a constant mass, and weighed again to determine dry matter content. Dry matter content of each component was calculated from fresh and dry mass, and aerial biomass (dry mass) was the sum of dead trash, green foliage and stalks, and stalk tops. Shoot numbers were counted approximately every second week in defined undisturbed areas. Yields per stalk were calculated from sample data and then multiplied by stalk numbers, and are expressed as g/m².

Data were analysed using the residual maximum likelihood (REML) procedure (Genstat, 10th Edition, VSN International Ltd, 2007) to determine standard error of difference (SED) for each cultivar and harvesting cycle. Yield variables (biomass) were analysed using the Chi square test at the 5% significance level.

Results and Discussion

Incident radiation

The annual incident short wave radiation was similar for all cycles, except for the March cycle, at Pongola. The difference between the lowest (March crop) and the highest (April crop) radiation received was 126 MJ/m², which is equivalent to 0.29 MJ/m²/day. Radiation was lower in the December crop at Mount Edgecombe than at Pongola, having received 16.3 and 18.5 MJ/m²/day, respectively (Table 2).

Table 2. Incident short wave radiation (MJ/m²) for the duration (days) of measurements in Experiment 1 (1998) at Pongola and Experiment 2 (2000) at Mount Edgecombe.

Crop cycle	Mar	Apr	May	Jun	Aug	Dec
Experiment 1: 1998						
Radiation (MJ/m²)	6 569	6 695	6 623		6 638	6 614
Period (days)	364	365	362		362	357
Experiment 2: 2000						
Radiation (MJ/m²)				6 000		5 686
Period (days)				365		348

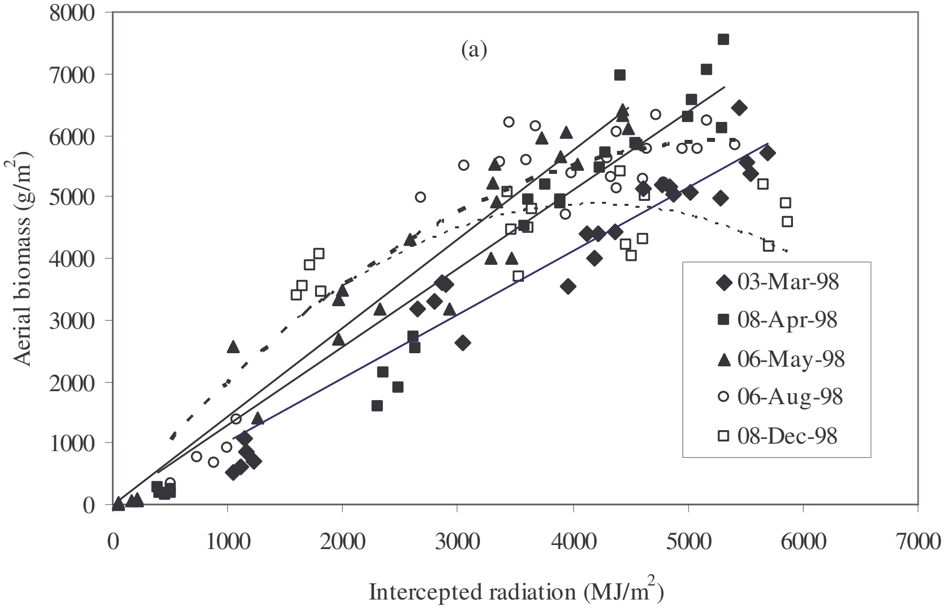
Biomass production

March, April and May crops of Experiment 1 (Figure 1a) and the June crop of Experiment 2 (Figure 1b) tended to accumulate biomass linearly in relation to intercepted radiation. The August and December crops accumulated biomass rapidly during early growth and then increased little or not at all thereafter. The slowing of biomass accumulation rates in the August and December crops coincided with winter conditions (Figure 1). Thus the change in the rate of biomass accumulation occurred sooner in the December crops than in the August crops and consequently biomass yields of December crops were 33% (P=0.05) lower than April crops and 16% (not statistically significant) lower than the August crops. March crops generally accumulated biomass at lower rates than April and May crops (Experiment 1) but differences between annual biomass yields were relatively small (and not statistically different) between March, April and May crops (Figure 1a and Table 3). In Experiment 2, the mean annual biomass yields of December crops were 31% lower than June crops (P=0.05) (Table 4).

Cultivar Q124 yielded significantly less biomass than all other cultivars during May (Experiment 1, Table 3). The very low yield of Q124 was due to very slow production of shoots and low stalk numbers throughout (data not shown). The early growth of N26 was also retarded by the low temperatures in winter. N26 yields were significantly lower in March than in April crops. A comparison of the same group of cultivars grown in March and December shows that N26 yields were no different for the two starting times; however, yields of N22 and NCo376 were significantly lower (42 and 24%, respectively, P=0.05) in December crops (Table 3). In Experiment 2, the December crop of CP66/1043 yielded 62% less than the June crop and, in contrast, the yield of the N14 December crop was only 12% less than the June crop (Table 4). N12 and N16 also yielded relatively well in the December crop, although the yields were 20 and 22% less than the June crops, respectively. Yields of all other cultivars started in December were more than 25% lower than in June crops.

Radiation use efficiencies (RUE) and fractional light interception

On average May and June crops intercepted the lowest fractions of incident radiation, and December crops the highest (Tables 3 and 4). The fractions of light interception decreased from March to May and then increased through August to December in Experiment 1 (Table 3). The fractions of light intercepted by Q124 and N26 in the May crops were low at 0.52 and 0.56, respectively, compared with the mean fraction of 0.62 in Experiment 1. The August crop of CP66/1043 also intercepted a relatively low fraction (0.66) when compared with the mean August value (0.75) in Experiment 1. This cultivar also intercepted relatively low values in both June and December crops in Experiment 2. Other cultivars intercepted similar fractions throughout the season (March to December).



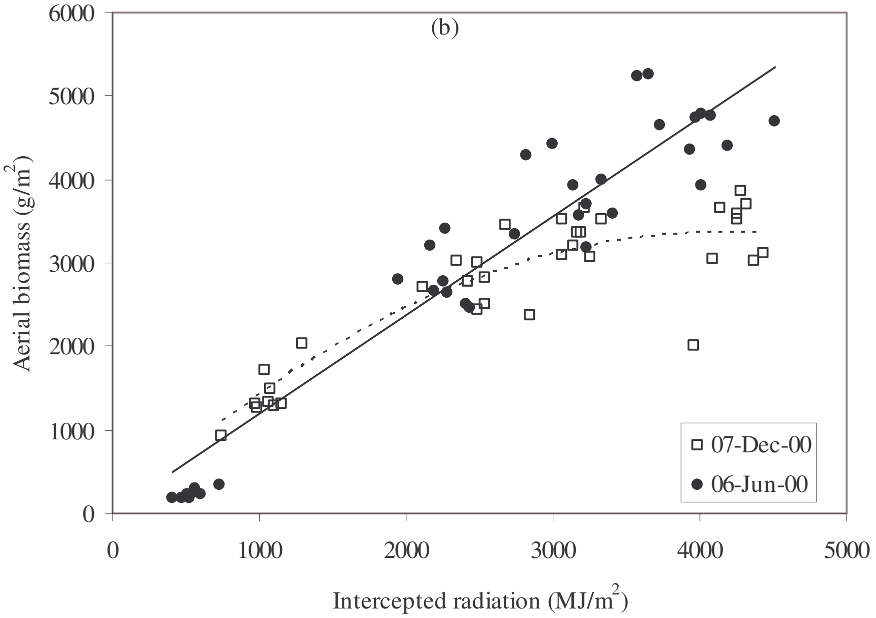


Figure 1. Trends in accumulation of above-ground biomass in relation to intercepted radiation of annual sugarcane crops in (a) Experiment 1 and (b) Experiment 2. Linear trend lines relate to March, April, May and June crops, and curvilinear trends relate to August and December crops.

The general trend in RUEmax was a linear increase from May to December (Table 3). This suggested that early RUE values were correlated to temperatures. To verify whether temperature had an influence on RUE, the data from the early growth stages of NCo376, N25 and N26 in Experiment 1 were analysed (Donaldson *et al*., 2006). They found that RUE increased with increasing mean temperatures (Figure 2).

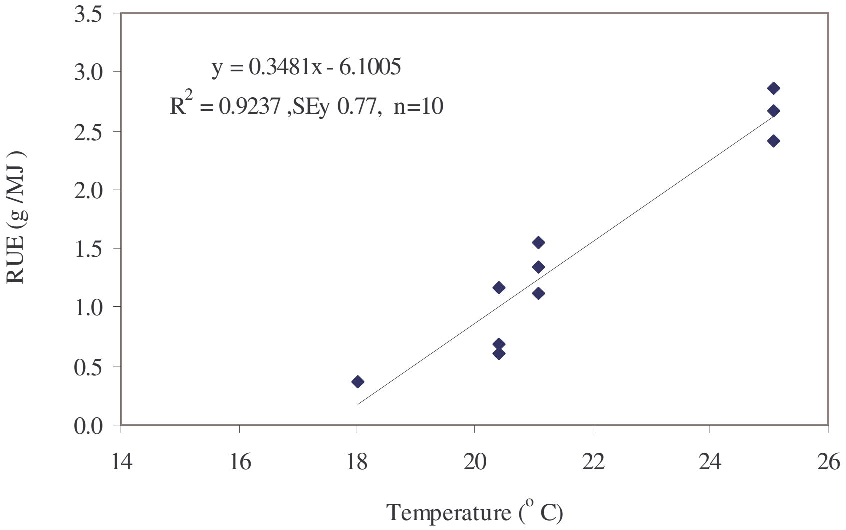


Figure 2. Relationship between radiation use efficiencies (RUE) and mean temperatures during early growth stages of sugarcane cultivars NCo376, N25 and N26 at Pongola (after Donaldson *et al.,* 2006).

The merits of using early growth data to determine RUE are in avoiding possible influences that lodging, flowering and decreasing levels of nitrogen have on photosynthesis and therefore on RUE. Data associated with green leaf area indexes of less than one were not included in the analysis, as RUEs then tend to decrease (Sinclair and Muchow, 1999). Similar relationships between RUE and temperature have been reported for maize (Andrade *et al*., 1993). Mean daily temperatures fall below 18°C during winter at Pongola and therefore RUEs will drop to very low levels according to Figure 2.

A comparison between the highest radiation use efficiencies (RUEmax) and annual radiation use efficiencies (RUEann) could be a useful measure of how RUE changes during crop growth. Differences between RUEmax and RUEann are generally much smaller in crops started between March and June than in August and December crops (Tables 3 and 4). These differences were bigger in the December crops at Pongola than at Mount Edgecombe. This indicates that some factor is present during the growth of the August and December crops that reduces RUEs more than in crops starting from March to June, and that it is more severe at Pongola than at Mount Edgecombe. Low temperatures induced natural ripening in these stalks (data not shown), and may reduce photosynthetic activity. The slow recovery from the low winter temperatures may be due to limited photosynthetic activity and low sink storage capacity in stalks with high sucrose contents after natural ripening. The December crops, which are six months old when they are subjected to low winter temperatures, appear to be most vulnerable and display slow recovery rates that impact on yields. It is postulated that December crops are prematurely ripened by low temperatures and that a 'feed back' signal from the high sucrose content in the stalks suppresses photosynthesis in the leaves, leading to reduced biomass production (for a review on source-sink regulation see McCormick *et al*., 2006). Only when new leaves and new internodes develop in response to rising temperatures does the crop resume more rapid rates of biomass accumulation.

Table 3. Fractions of annually intercepted radiation (fiRad), annual above-ground biomass, maximum RUE (RUEmax), crop age at RUEmax and annual RUE (RUEann) of nine sugarcane cultivars and five starting dates at Pongola in Experiment 1.

Cultivar and start month		fiRad	Biomass (g/m²)	RUEmax (g/MJ)	Crop age at RUEmax (days)	RUEann (g/MJ)
NCo376	Mar	0.83	6451	1.19	364	1.19
	Apr	0.79	7536	1.42	365	1.42
	May	0.67	6413	1.46	336	1.45
	Aug	0.78	6227	1.80	243	1.20
	Dec	0.88	4894	2.27	114	0.84
N25	Mar	0.87	5710	1.02	309	1.00
	Apr	0.79	6119	1.29	329	1.15
	May	0.67	6319	1.69	245	1.42
	Aug	0.81	5829	1.66	243	1.08
	Dec	0.88	4576	1.90	114	0.78
N26	Mar	0.80	4983	1.20	245	0.95
	Apr	0.75	6563	1.36	301	1.30
	May	0.56	5952	1.67	301	1.60
	Aug	0.72	5213	1.80	243	1.09
	Dec	0.86	5187	2.12	114	0.84
N22	Mar	0.84	5364	1.23	245	0.97
	Dec	0.87	3110	2.27	114	0.54
N19	Mar	0.83	5563	1.29	245	1.02
	Dec	0.86	4576	2.13	114	0.73
CP66/1043	Apr	0.75	6276	1.29	329	1.26
	Aug	0.66	5120	1.86	243	1.17
N24	Apr	0.77	7038	1.58	329	1.36
	Aug	0.77	5785	1.65	329	1.14
N17	May	0.68	6103	1.75	245	1.36
Q124	May	0.52	3991	2.44	245	1.15
Means	Mar	0.83	5614	1.19	282	1.03
	Apr	0.76	6706	1.39	331	1.30
	May	0.62	5756	1.80	274	1.40
	Aug	0.75	5635	1.75	260	1.14
	Dec	0.87	4469	2.14	114	0.75
Cultivars	SED		264.2			
	LSD (0.05)		517.8			
Cultivar*month	SED		719.5			

CP66/1043 had exceptionally low RUEann in the December crop at Mount Edgecombe (Table 4) and this was the reason for its poor yield, rather than inadequate light interception. The June CP66/1043 crop was in stark contrast to its December crop, in having the highest

RUEann and biomass yields in the group of cultivars. At Pongola the CP66/1043 August crop seemingly intercepted smaller fractions of light, had lower RUEann and yielded less than the April crop. N22 at Pongola also had very low RUEann in the December crop compared to all March crops. The low RUEann of the N22 December crop followed after a very high RUEmax during its early growth.

Table 4. Fractions of annually intercepted radiation (fiRad), annual above-ground biomass, maximum RUE (RUEmax), crop age for RUEmax and annual RUE (RUEann) of nine sugarcane cultivars started during June and December at Mount Edgecombe in Experiment 2.

Crop cycle and cultivar	fiRad	Biomass (g/m²)	RUEmax (g/MJ)	Crop age at RUEmax (days)	RUEann (g/MJ)
June					
CP66/1043	0.60	5 220	1.52	307	1.46
N12	0.66	4 360	1.24	307	1.11
N14	0.70	4 390	1.05	307	1.04
N16	0.67	4 770	1.23	252	1.18
N17	0.67	3 920	1.16	252	0.97
N21	0.61	5 250	1.48	252	1.43
N27	0.75	4 680	1.25	307	1.03
N29	0.66	4 730	1.50	252	1.19
NCo376	0.68	4 750	1.20	307	1.16
December					
CP66/1043	0.70	2 000	1.27	235	0.50
N12	0.75	3 510	1.28	123	0.82
N14	0.76	3 860	1.33	123	0.90
N16	0.76	3 700	1.65	123	0.85
N17	0.77	3 010	1.17	123	0.69
N21	0.73	3 650	1.33	123	0.88
N27	0.78	3 120	1.58	123	0.70
N29	0.72	3 050	1.24	123	0.74
NCo376	0.75	3 580	1.39	123	0.84
Means					
June	0.67	4 774	1.29	289	1.17
December	0.75	3 276	1.36	135	0.77
Cultivars					
SED		245.3			
LSD (0.05)		480.8			
Month*cultivar					
SED		346.8			

Radiation use efficiencies at Pongola and Mount Edgecombe

Biomass production is strongly correlated with intercepted radiation during the linear phase of growth when crops are healthy and well supplied with nutrients and water (Robertson *et al*., 1996). The amount of radiation that is intercepted during annual sugarcane crops is affected by the time taken for the canopy to reach maximum light interception. For example, the slow canopy development of crops started in winter leads to substantially lower fractions of incident radiation being intercepted than in summer crops when canopy development is quick (Inman-Bamber, 1994; Singels *et al*., 2005b). It would therefore be reasonable to expect December crops to produce higher biomass yields than June crops if RUE is relatively constant (Sinclair and Horie, 1989; Muchow *et al*., 1994). However, it has been shown that

RUE is not constant and that autumn/winter crops produce better yields than summer crops (Singels *et al.*, 2005a) despite lower fractions of radiation being intercepted. The assumption that intercepted radiation is the sole driving force of biomass accumulation was tested by regressing biomass (g/m²) of two winter ratooning crops of NCo376 grown at Pongola (Experiment 1) and Mount Edgecombe (Experiment 2) against intercepted radiation (MJ/m²). The Pongola crop was started on 6 May 1998 and the Mount Edgecombe crop on 6 June 2000. The slopes of the lines in Figure 3 show that RUE was higher at Pongola than at Mount Edgecombe (1.36 g/MJ vs 1.15 g/MJ, respectively). The mean maximum and minimum temperatures for the duration of the May crop at Pongola (Experiment 1) were 27.9°C and 15.3°C, respectively. For the June crop at Mount Edgecombe the mean maximum and minimum temperatures were 24.9°C and 16.0°C, respectively. The indications are that the higher RUEs at Pongola are related to higher temperatures, but may also be due to the wider row spacing at Pongola (Singels and Smit, 2002). Other factors may also influence RUE in stress-free crops. For example, the radiation environment, i.e. the ratio between diffuse and direct radiation, may also affect RUE. RUEs increase as the diffuse:direct ratio of incident radiation increases (Sinclair and Muchow, 1999). Although the effect may be relatively small over the entire crop, it may nevertheless be substantial over shorter intervals. RUEs are also reported to be different between plant and ratoon crops (Robertson *et al.*, 1996) and cultivars (Muchow *et al.*, 1997). A clearer understanding of the factors that influence RUE is needed, particularly when comparisons are made between environments.

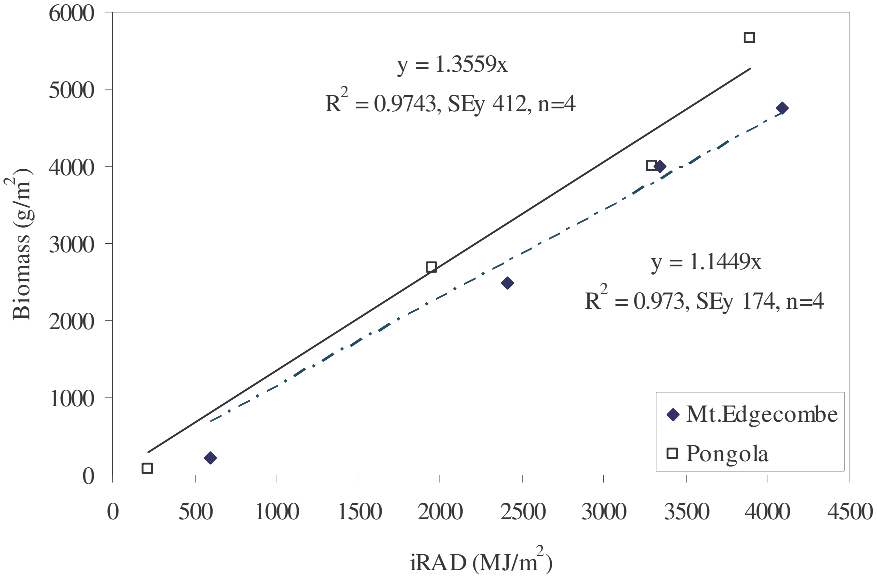


Figure 3. Biomass yields relative to intercepted solar radiation (iRAD) of two winter crops of sugarcane cultivar NCo376 grown at Pongola (Experiment 1, solid line) and Mount Edgecombe (Experiment 2, broken line) with fitted linear models; y intercepts set at zero.

Conclusions

Crops harvested in December yield less than those harvested in autumn and winter. This is mainly due to lower radiation use efficiencies. The reason for the reduction in RUE in these December crops appears to be associated with premature ripening by low winter temperatures experienced when the crops are about six months old. The cultivars CP66/1043 and N22 appear to be affected more than other cultivars, while N14 is least affected by the low winter temperatures. This study suggests that there are numerous cultivars that will yield well in autumn/winter but few that will yield well in late summer. Cultivars N14, N16 and N21 yield relatively well in late summer crops, but yields of N14 may still be adversely affected by flowering.

Acknowledgements

The authors would like to acknowledge the field work carried out by Soobramony Kanniappen, and the statistical analyses done by Chandani Sewpersad at SASRI.

REFERENCES

Andrade FH, Uhart SA and Cirilo A (1993). Temperature affects radiation use efficiency in maize. *Field Crops Res* 32: 17-25.

Donaldson RA, Redshaw KA, Rhodes R and van Antwerpen R (2008). Season effects on productivity of some commercial South African cultivars, II: Trash production. *Proc S Afr Sug Technol Ass* (in press).

Donaldson RA, Singels A and Smit MA (2006). Effect of crop start date on radiation use efficiency in ratoon crops of three sugarcane cultivars. SASCP Conference at Durban January 2006.

Gilbert RA, Shine Jr JM, Miller JD, Rice RW and Rainbolt CR (2006). The effect of genotype, environment and time of harvest on sugarcane yields in Florida, USA. *Field Crops Res* 95: 156-170.

Inman-Bamber NG (1994). Temperature and seasonal effects on canopy development and light interception of sugarcane. *Field Crops Res* 36: 41-51.

McCormick AJ, Cramer MD and Watt DA (2006). Sink strength regulates photosynthesis in sugarcane. *New Phytologist* 171(4): 759-770.

McDonald L (2006). The effect of time of ratooning on sugarcane growth in the Burdekin. *Proc Aust Soc Sug Cane Technol* 28: 261-272.

Muchow RC, Evensen CI, Osgood RV and Robertson MJ (1997). Yield accumulation in irrigated sugarcane: II. Utilization of intercepted radiation. *Agron J* 89: 646-652.

Muchow RC, Spillman MF, Wood AW and Thomas MR (1994). Radiation interception and biomass accumulation in a sugarcane crop grown under irrigation tropical conditions. *Aust J Agric Res* 45: 37-49.

Robertson MJ, Wood AW, and Muchow RC (1996). Growth of sugarcane under high input conditions in tropical Australia. I. Radiation use, biomass accumulation and partitioning. *Field Crops Res* 48: 11-25.

Rostron H (1974). Some effects of environment, age and growth regulating compounds on the growth, yield and quality of sugarcane in southern Africa. PhD Thesis, University of Natal, Pietermarizburg, South Africa.

Sinclair TR and Horie T (1989). Leaf nitrogen, photosynthesis, and crop radiation use efficiency: A review. *Crop Sci* 29: 90-98.

Sinclair TR and Muchow RC (1999). Radiation use efficiency. *Advances in Agronomy* 65: 215-265.

Singels A and Smit MA (2002). The effect of row spacing on irrigated plant crop of sugarcane variety NCo376. *Proc S Afr Sug Technol Ass* 74: 151-154.

Singels A, Donaldson RA and Smit MA (2005a). Improving biomass production and partitioning in sugarcane: Theory and practice. *Fields Crops Res* 92: 291-303.

Singels A, Kennedy AJ and Bezuidenhout CN (1998). IRRICANE: a simple computerised irrigation scheduling method for sugarcane. *Proc S Afr Sug Technol Ass* 72: 117-122.

Singels A, Smit MA, Redshaw K and Donaldson RA (2005b). The effect of crop start date, crop class and cultivar on sugarcane canopy development and radiation interception. *Field Crops Res* 92: 249-260.

Thompson GD (1978). The production of biomass by sugarcane. *Proc S Afr Sug Technol Ass* 52: 180-187.