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RESEARCH ARTICLE

Growth and Radiation Use Efficiency of Sugarcane Under Irrigated and Rain-fed Conditions in Sri Lanka

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Abstract A field experiment was conducted to evaluate sugarcane varieties based on their radiation use efficiencies (RUE) at the Sugarcane Research Institute, Uda Walawe, Sri Lanka. Sugarcane was grown under irrigated (soil water potential >−0.05 MPa) and rain-fed conditions in a split-plot design. Biomass accumulation, canopy development, leaf angle and radiation intercepted by the sugarcane canopy were measured. Seasonal and fractional incoming radiation intercepted, light extinction coefficient (k) and RUE were estimated. Rain-fed crop reduced RUE by 53 % compared to the irrigated crop. RUE varied from 1.63 to 2.09 g MJ^{-1} and 0.71 to 1.03 g MJ^{-1} under irrigated and rain-fed conditions respectively. The variety SL 83 06 showed the highest RUE under both water regimes with higher canopy development and lower k values consistently throughout the growing period. The canopy in erect leaves increases biomass production and RUE. As the erect orientation of leaves is genetically governed trait, it could be used for the hybridisation programme of sugarcane to produce highly efficient solar energy-utilising hybrids of sugarcane.

Keywords Sugarcane · Canopy development · Radiation use efficiency · Water regimes

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Introduction

The total radiation interception of a crop canopy over its whole duration provides energy for photosynthesis and biomass production. It is dependent on the crop duration (days), incident daily irradiance (MJ m^{-2} day^{-1}) and the daily fraction of incoming radiation intercepted by the canopy (f_i). The manipulation of crop duration and incident daily irradiance is limited when cultivating sugarcane under Sri Lankan conditions. However, maximising the f_i through optimising crop management offers the greatest scope for increasing biomass production, radiation use efficiency (RUE) and yield of a crop (De Costa 2000). The value of f_i is determined by canopy size (leaf area index—LAI) and its architecture (orientation of leaves within the canopy). Leaf orientation is a genetically-determined character which shows genotypic variations. The development of the sugarcane canopy is dependent on the rates of tillering, leaf appearance, leaf extension and the size of each leaf. Moreover, canopy development and radiation interceptions of sugarcane showed substantial varietal variation (Singels and Donaldson 2000), which was influenced by planting and/or ratooning date/s (Inman-Bamber 1994; Singels et al. 2005), row spacing (Singels and Smit 2002) and planting density (Bell and Garside 2005). Therefore, canopy development can be controlled, to some extent, with knowledge of the interaction between these factors to maximise the RUE of sugarcane. The varieties with slow canopy development but with more vertically-oriented leaves could be planted at higher densities. It could enhance radiation interception, and hence, subsequently the yield. Varieties which develop a higher number of shoots more rapidly establish a larger LAI earlier could intercept more photosynthetically active radiation. However, the efficiency of conversion of total incident solar radiation (RUE) in terms of biomass accumulation in sugarcane is dependent on crop age and growth conditions (Thompson 1978). Moreover, differences in photosynthetic efficiency calculated in terms of incident radiation were associated with differences in leaf canopy development and the interception of radiation, which were strongly dependent on climatic and growing conditions (Robertson et al. 1996; Muchow et al. 1997). Furthermore, all above-mentioned variables could be affected by water stress in different extents.

Water deficit reduces LAI, affecting number of tillers, number of green leaves per stalk, mean leaf area, rates of leaf appearance and senescence, leaf rolling (Inman-Bamber and Smith 2005). Stalk population is relatively insensitive to water stress, and hence, LAI is dependent on leaf appearance and senescence under mild water stress. Moreover, very severe water stress reduces stalk population and final area per leaf (Inman-Bamber 2004). LAI of sugarcane grown under different conditions did not exceed three until about 4 months after planting (Bull and Glasziou 1975). It rises gradually to about four by greater retention of tillers in the stressed crop and continues to increase up to about 5.5 in the well-watered crop. Maintenance of higher LAI during water stress leads to reduce RUE (Robertson et al. 1999). Sugarcane varieties show considerable variations in these responses to water stress (Inman-Bamber and de Jager 1986). Therefore, the objective of this study was to analyse the differential abilities of Sri Lankan commercial sugarcane varieties in developing leaf canopies to intercept radiation and the efficiency of the use of intercepted radiation to produce biomass under irrigated and rain-fed conditions. It is hypothesised that irrigated crop intercepts more radiation early in the season with early canopy development than rain-fed crop.

Materials and Methods

A field experiment was conducted from April 2002 to September 2003 at the Sugarcane Research Institute (SRI), Uda Walawe (6°21′N latitude, 80°48′E longitude and 76 m altitude) where the annual average rainfall is about 1,450 mm with a distinctly bimodal distribution (Panabokke 1996). The annual average of minimum and maximum temperatures was 22 and 32 °C respectively. The evaporation from a free water surface averages about 5 mm/day (Sanmuganathan 1992). The soil has been classified as Ranna series of reddish brown earths (RBE), great group of Rhodustalfs (order Alfisols, suborder Ustalfa) soils and has a sandy clay-loam texture (De Alwis and Panabokke 1972). It is moderately well-drained with a pH of 6.5–6.7. The bulk density of the soil ranges from 1.59 to 1.85 g cm^{-3}. The respective soil water contents at saturation, field capacity and permanent wilting point are 30, 20 % (10 kPa) and 8 % (1,500 kPa), respectively (Sanmuganathan 1992).

The experiment was conducted in a split-plot design which contained 16 treatment combinations, composed of two main plot treatments as 'irrigated' ('well-watered') and 'rain-fed' ('water-stressed') and eight commercial sugarcane (*Saccharum* hybrid L.) varieties (i.e., SL 71 03, SL 71 30, SL 83 06, SL 86 13, SL 88 116, SLI 121, M438/59 and Co775) as sub-plot treatments. The irrigated treatment received irrigation (2 m^3 of water per irrigation) at 5–10 day intervals so that its soil water potential in the top 1 m was maintained above −0.05 MPa. One-metre deep trenches were made between irrigated and rain-fed plots to avoid lateral movement of water. Each treatment combination was replicated thrice. Plot size was 9 × 8.22 m, each of which contained six furrows spaced at 1.37 m. The sugarcane was planted and maintained adopting the recommended practices.

Soil moisture content in each plot down to 1-m depth and at 20-cm intervals was measured gravimetrically and at fortnightly. Daily sunshine duration (h), daily rainfall (mm) and daily pan evaporation (mm) were obtained from the SRI meteorological station which was <200 m from the experimental site. Incident daily irradiance on sugarcane canopies [(H) MJ m^{-2} day^{-1}] was estimated from measured daily sunshine duration in hours (S) using the Angstrom formula shown below (Samuel 1991 and De Costa 2000):

$$H = H_0[a + b(S/Z)]$$

where, H_0 is daily global radiation (MJ m^{-2} day^{-1}) at the top of the atmosphere and Z is day length (h). The parameters a and b depends on the location (i.e., latitude). In any location in Sri Lanka, $a = -0.14 + 1.20\ (S/Z) - 0.82\ (S/Z)$ and $b = 1.32 - 2.89\ (S/Z) + 2.24\ (S/Z)^2$. The amount of radiation transmission through the green leaf canopy at clear mid-days from 10.00 to 14.00 h was measured using 1-m line tube solarimetre. The tube solarimetre was placed first outside the plot to measure total incoming radiation at the top of the canopy (I_0) and then inside the plot at the base of the canopy in two ways, i.e., parallel to the cane row and perpendicular to the cane row to measure amount of radiation transmission through the sugarcane canopy to the ground surface (I). Measurements were taken commencing 75 DAP (days after planting) onwards and continued at 2 week intervals until canopy closure to determine the radiation interception, leaf orientation and light extinction coefficient (k) of each variety. RUE was calculated by fitting a linear regression to the relationship between cumulative radiation interception and above–ground dry weight of the crop.

LAI and accumulation of total biomass were measured by destructive sampling of five randomly-selected stalks from two rows close to the two boarder rows on either side of the plot at ∼2 week intervals. Leaf area was measured by length and width method using a pre-calculated leaf area co-efficient. Calculated LAI and measured I_0 and I were used to estimate the k using Beer and Lambert's law as shown below (De Costa 2000):

$$I = I_0 e^{-kL}$$

where, I is radiation transmitted to the ground surface; I_0 is the radiation at the top of the canopy; L is LAI of the canopy.

Significance of treatment differences was tested by analysis of variance (ANOVA). Means were separated by using the least significant difference (LSD). Correlations between yield and yield components were determined by correlation analysis. The SAS statistical computer package was used to analyse the data.

Results and Discussion

Variation of Soil Moisture Content and Important Meteorological Conditions

Average entire-profile (0–100 cm) soil moisture content of the irrigated plots was greater than that of the rain-fed plots during first 12 months of the experiment (Table 1). There was a substantially lower rainfall than the 75 % probable rainfall between the second and fourth months, i.e., June–August and significantly higher pan evaporation than the actual rainfall between the second and fifth months, i.e., June–September in the life of the crop. This low rainfall and higher pan evaporation created a substantial difference in the average soil moisture content in the top 1-m of the soil profile between the two water regimes. However, the actual total rainfall (1,871 mm) was greater than the annual average rainfall (1,450 mm). Moreover, total pan evaporation (1,629 mm) was less than the actual total rainfall (1,871 mm) during the first 12 months of the experiment at the experimental site. The average daily sunshine duration was 6.9 h day^{-1}.

Canopy Development and Biomass Accumulation

The variables responsible for canopy development, i.e., number of tillers per square metre and number of leaves per stalk showed significant ($p < 0.05$) varietal variation under both water regimes and variation between water regimes (Table 2). Water deficit at early stages of growth [3–6 MAP (months after planting)] could affect tillering and the number of leaves per stalk. Water deficits markedly reduced stalk number, LAI and ultimately biomass production by the end of the deficit period, and it was consistent throughout the growing period (Fig. 1). This agreed with the observations of Bull and Glasziou (1975). They showed that the number of green leaves on stalk varied between about 6 and 12, with fewer leaves being maintained during dry and cold conditions.

During the early stages of crop growth, there was an overproduction of stalks (Fig. 1a$_1$, 1a$_2$). The peak number of stalks was attained about 3–5 months from planting. However, up to 50 % of the stalks died, and the stalk population stabilised before 9 months (Bull and Glasziou 1975). When averaged across varieties, irrigated crops achieved a maximum population density 1 month earlier (Table 2) and the maximum LAI 2 months earlier than the rain-fed crops (De Silva and De Costa 2004). In general, maximum LAI is achieved about 6 months from planting and then slowly declines, but this may be affected by both variety and conditions of growth (Bull and Glasziou 1975).

Table 1 Seasonal variation of soil moisture contents (% dry weight basis) in the top 1-m soil profile under irrigated (SM $\%_{Ir}$) and rain-fed (SM $\%_{Rf}$) conditions, actual rainfall (RF_{Ac}), daily average sunshine hours (Su-Shi) and pan-evaporation (PEV) at the experimental site during first 12 months of the experiment

Crop—age (month)	SM $\%_{Ir}$	SM $\%_{Rf}$	RF_{Ac} (mm month^{-1})	Su-Shi (h day^{-1})	PEV (mm month^{-1})
1st (May-2002)	16.17 ± 1.48	14.76 ± 1.29	158.4	7.53	137.1
2nd (June-2002)	12.91 ± 1.66	11.98 ± 1.61	10.2	6.05	167.0
3rd (July-2002)	12.72 ± 2.13	9.61 ± 2.29	29.0	8.34	192.8
4th (Aug-2002)	12.81 ± 2.49	8.68 ± 1.69	32.5	7.45	177.9
5th (Sep-2002)	13.54 ± 2.01	6.62 ± 1.58	54.0	8.85	195.9
6th (Oct-2002)	14.62 ± 2.23	9.43 ± 1.49	264.3	6.49	112.4
7th (Nov-2002)	16.88 ± 2.14	13.56 ± 1.52	350.6	4.80	89.1
8th (Dec-2002)	15.57 ± 2.03	14.47 ± 1.44	68.5	5.15	45.8
9th (Jan-2003)	13.05 ± 1.38	11.99 ± 1.42	49.2	6.86	127.0
10th (Feb-2003)	13.91 ± 1.38	11.37 ± 1.21	60.3	7.93	134.7
11th (Mar-2003)	18.00 ± 1.27	16.81 ± 1.73	542.3	7.34	128.3
12th (Apr-2003)	16.86 ± 1.38	14.27 ± 2.02	251.7	6.02	120.5
Mean	14.75	11.96	155.9	6.9	135.71

Soil moisture values (SM %) are means ± SD of 120 observations (eight varieties in three replicates and five levels of soil depth) and average values for the whole soil profile

Table 2 Maximum number of tillers per m^2, maximum number of leaves per stalk (±standard error) and age of achieving those maximum values (days after planting—given in the parentheses) in different sugarcane varieties under irrigated and rain-fed conditions

Variety	Maximum no. of tillers m^{-2}		Maximum no. of leaves $stalk^{-1}$	
	Irrigated	Rain-fed	Irrigated	Rain-fed
SL8306	11.57 ± 0.47 (104)	10.64 ± 0.73 (75)	15.22 ± 0.95 (224)	13.34 ± 0.33 (405)
SL8613	10.72 ± 0.29 (104)	10.21 ± 0.52 (56)	14.77 ± 0.80 (195)	14.5 ± 0.76 (332)
Co775	10.41 ± 0.68 (104)	8.27 ± 1.36 (104)	10.27 ± 0.15 (195)	10.83 ± 0.44 (224)
M438/59	10.33 ± 0.81 (104)	8.34 ± 0.60 (75)	11.79 ± 1.47 (242)	10.50 ± 0.58 (242)
SL7130	10.24 ± 0.24 (104)	9.38 ± 0.26 (75)	11.34 ± 1.27 (242)	10.83 ± 0.44 (242)
SLI121	9.44 ± 0.88 (104)	9.13 ± 0.10 (75)	11.21 ± 0.67 (224)	10.67 ± 0.33 (242)
SL88116	9.08 ± 0.25 (104)	7.06 ± 0.39 (75)	10.67 ± 0.67 (224)	10.00 ± 0.29 (242)
SL7103	8.32 ± 0.94 (104)	7.83 ± 0.25 (56)	14.66 ± 0.84 (242)	12.44 ± 1.11 (276)
Mean	10.01 (104)	8.86 (74)	12.49 (223)	11.64 (266)

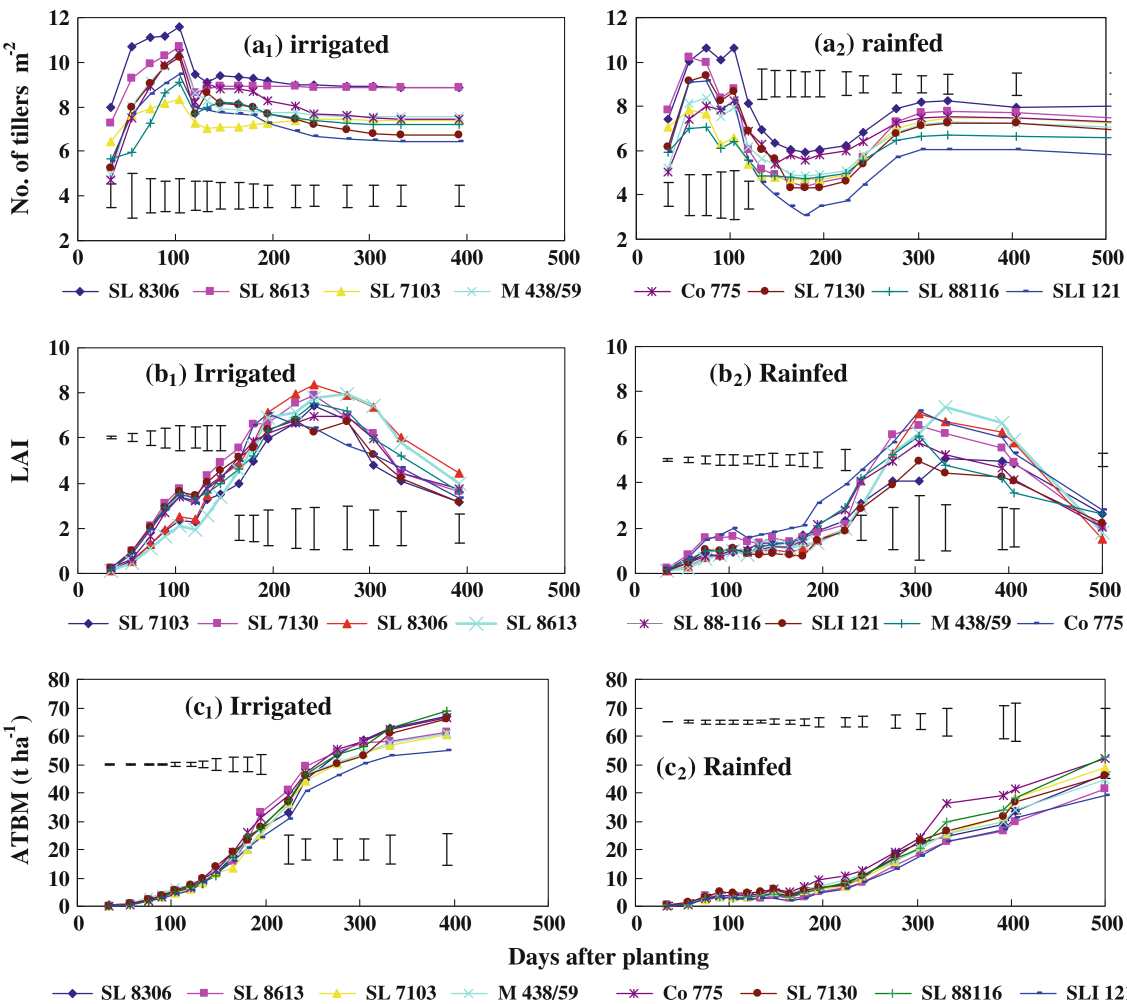

Fig. 1 Seasonal variation of number of tillers m^{-2}, leaf area index (LAI) and above–ground total biomass (ATBM) with age of different sugarcane varieties under irrigated and rain-fed conditions. [*Note Each data point* in the graphs is the average of three replicates and *error bars* indicate the standard error of means and LSD]

The water deficit imposed prior to achieving an LAI of two could have a large impact on tillering, leaf area, biomass accumulation and final yield. Robertson et al. (1999) found a similar impact of early season water deficit on growth and development, but the impact on final yield was small. On the other hand, water deficits severely reduced biomass production and final yield when they occurred when LAI was greater than two. In the present experiment, LAI of all varieties in both treatments reduced rapidly after achieving their respective maxima. This could be due to the start of maturation of cane, which is associated with an increased demand for nitrogen and a higher rate of respiration (Wolf et al. 1988). Growth analysis of world sugarcane has revealed similar growth patterns, but with some differences arising due to the variation in the length of cropping cycle (Bull and Glasziou 1975; Gascho and Shih 1983).

In the present experiment, these variables of canopy growth showed varietal variation under both water regimes. The variety SL 83 06 showed the maximum LAI under both conditions and the highest LAI at harvest under irrigated conditions. This could be due to the fact that SL 83 06 showed the highest germination counts, tiller numbers and highest population densities under both conditions and the highest number of leaves per stalk under irrigation and second highest leaf number per stalk under rain-fed conditions (Table 2). Recovering and maintaining the higher LAI up to harvesting could lead to higher yield. Accordingly, the varieties SL 83 06 and Co775, which had the highest LAI at harvest, recorded comparatively high yields (De Silva and De Costa 2004).

Canopy Architecture, Radiation Interception and RUE

Radiation intercepted per day (RI_{dy}), seasonal totals of incoming radiation intercepted (S_i) and mean seasonal fraction of radiation interception (F_i) showed significant ($p < 0.05$) variation between water regimes and water *x* variety interaction. Moreover, RI_{dy}, S_i and F_i showed significant ($p < 0.05$) varietal variation under rain-fed conditions (Table 3).

When averaged across varieties, RI_{dy}, and F_i significantly ($p < 0.05$) increased while k and S_i significantly ($p < 0.05$) reduced under irrigated conditions compared to the rain-fed conditions. S_i was grater in the rain-fed treatment because the rain-fed crops took a longer time to mature. It ranged from 3,242 to 3,645 MJm^{-2} and 3,310 to 4,627 MJm^{-2} under irrigated and rain-fed conditions respectively. The highest S_i value was recorded with variety Co775 under both water regimes whereas the lowest S_i values were recorded with varieties SL 83 06 and SLI 121 under irrigated and rain-fed conditions respectively. Also, varieties Co775 and SL 71 30 had lower F_i under irrigated conditions than rain-fed conditions, whereas all other varieties had higher F_i under irrigated conditions. F_i ranged from 0.54 to 0.60 and from 0.45 to 0.63 under irrigated and rain-fed conditions respectively (Table 3). The leaf angle ranged from 66.4 to 76.2 and from 69.2 to 76.0 under irrigation and rain-fed conditions respectively. The k values ranged from 0.22 to 0.28 and from 0.31 to 0.47 under irrigation and rain-fed conditions respectively. Under irrigation, varieties SLI 121 and SL 7103 had the highest and lowest leaf angles and the lowest and the highest k values respectively (Table 4).

A higher k value indicates a canopy with relatively horizontal leaves whereas a lower k value indicates a canopy with relatively erect leaves (De Costa 2000). When k was correlated with yield parameters and RUE (De Silva and De Costa 2004), k had highly significant ($p = 0.0001$) negative correlation with cane yield ($r = 0.71$), cane biomass ($r = 0.62$), total biomass ($r = 0.70$) and RUE ($r = 0.87$), and it had highly significant ($p = 0.0001$) positive correlation with S_i ($r = 0.77$) under both water regimes. It confirmed that, although the canopy of horizontally-oriented leaves which has a higher k value increases S_i, a canopy with erect leaves which has a lower k value important for increasing biomass production and ultimately increasing RUE.

The calculated daily fraction of the incident radiation intercepted by the crop (f_i) using the predicted daily LAI from 50 DAP (which is the time of appreciable radiation interception as can be measured by a tube solarimetre) up

Table 3 Radiation intercepted per day (RI_{dy}), seasonal totals of incoming radiation intercepted (S_i) and mean seasonal fraction of radiation intercepted (F_i) (±standard error) of different sugarcane varieties at plant crop under irrigated (for 332 days of growing period) and rain-fed conditions (for 402 days of growing period)

Variety	RI_{dy} ($MJ\ m^{-2}\ day^{-1}$)		S_i ($MJ\ m^{-2}$)		F_i	
	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed
Co775	11.0 ± 0.2	11.5 ± 0.3	3,645 ± 69	4,627 ± 121	0.55 ± 0.01	0.52 ± 0.02
M438/59	10.5 ± 0.4	10.6 ± 0.3	3,498 ± 127	4,247 ± 111	0.60 ± 0.01	0.63 ± 0.02
SL7103	10.0 ± 0.4	9.2 ± 0.7	3,330 ± 120	3,703 ± 283	0.54 ± 0.02	0.51 ± 0.02
SL7130	10.9 ± 0.1	11.5 ± 0.3	3,616 ± 41	4,625 ± 126	0.56 ± 0.02	0.47 ± 0.01
SL8306	9.8 ± 0.4	9.3 ± 0.4	3,242 ± 124	3,725 ± 168	0.60 ± 0.01	0.63 ± 0.02
SL8613	10.2 ± 0.4	8.6 ± 0.1	3,370 ± 134	3,439 ± 37	0.58 ± 0.02	0.58 ± 0.02
SL88116	10.1 ± 0.1	9.5 ± 0.3	3,339 ± 41	3,808 ± 110	0.55 ± 0.02	0.51 ± 0.04
SLI121	9.9 ± 0.2	8.2 ± 0.3	3,308 ± 51	3,310 ± 118	0.55 ± 0.01	0.45 ± 0.02
Mean	10.3 ± 0.3	9.8 ± 0.3	3,418 ± 88	3,935 ± 134	0.57 ± 0.01	0.54 ± 0.02
LSD_v	0.889	1.003	295.15	403.21	0.048	0.055
LSD_w	0.3428		128.39		0.018	

LSD_v = LSD ($p = 0.05$) for varietal comparisons within a water regime; LSD_w = LSD ($p = 0.05$) for comparison of mean values of water regimes

Table 4 Calculated mean seasonal radiation use efficiency (RUE), mean angles of third and fourth leaves in the canopy and light extinction coefficient (k) (±standard error) of different sugarcane varieties under irrigated and rain-fed conditions

Variety	RUE (g MJ^{-1})		Mean leaf angle (°)		k	
	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed
SL88116	1.76 ± 0.03	0.82 ± 0.11	74.58 ± 1.5	73.16 ± 1.8	0.23 ± 0.02	0.38 ± 0.02
Co775	1.75 ± 0.20	0.76 ± 0.08	71.17 ± 1.7	69.19 ± 1.7	0.27 ± 0.02	0.41 ± 0.02
SL8306	1.81 ± 0.06	0.93 ± 0.09	74.96 ± 1.3	76.04 ± 1.6	0.23 ± 0.01	0.31 ± 0.02
SL8613	1.69 ± 0.11	0.71 ± 0.07	72.04 ± 1.5	75.05 ± 1.1	0.27 ± 0.02	0.38 ± 0.04
SL7130	2.09 ± 0.10	1.03 ± 0. 05	71.85 ± 1.3	75.47 ± 1.2	0.25 ± 0.01	0.47 ± 0.04
M438/59	2.00 ± 0.09	0.83 ± 0.08	70.78 ± 1.4	72.17 ± 1.7	0.25 ± 0.02	0.47 ± 0.06
SL7103	1.91 ± 0.09	0.95 ± 0.03	66.40 ± 2.1	72.27 ± 2.0	0.28 ± 0.02	0.38 ± 0.04
SLI121	1.63 ± 0.08	0.88 ± 0.05	76.22 ± 1.1	71.89 ± 1.8	0.22 ± 0.02	0.35 ± 0.03
Mean	1.83 ± 0.10	0.86 ± 0.07	72.25	73.16	0.25 ± 0.01	0.41 ± 0.01
LSD_v	0.276	0.206	4.21	4.45		
LSD_w	0.084		1.46			

LSD_v = LSD ($p = 0.05$) for varietal comparisons within a water regime; LSD_w = LSD ($p = 0.05$) for comparison of mean values of water regimes

to 365 DAP showed that the irrigated crop intercepted more radiation during early growth period compared to the rain-fed crop (Fig. 2). It happened due to the period of significant soil moisture deficits experienced by the rain-fed crops from 3 to 6 MAP (Table 1), which resulted in significant reductions in LAI (Fig. 1b$_2$). The irrigated crop achieved a maximum f_i value of about 0.9 at 250 DAP, whereas the rain-fed crop achieved f_i value of about 0.65 at the same age and the maximum f_i was achieved around 350 DAP. A greater varietal variation in f_i was shown under rain-fed conditions than under irrigated conditions (Fig. 2). A rapid reduction of f_i was observed after achieving the respective maxima under irrigated conditions.

The slope of the fitted linear relationship of above–ground biomass accumulation and calculated cumulative intercepted solar radiation which was the mean seasonal RUE showed significant ($p < 0.05$) water x variety interaction (Fig. 3). Moreover, it showed significant ($p < 0.05$) varietal variation under irrigated conditions (Table 4). Water deficits significantly reduced the RUE in all the varieties tested, on average by 53 %, whereas increased total seasonal radiation interception. RUE varied from 1.63 to 2.09 g MJ^{-1} and from 0.71 to 1.03 g MJ^{-1} under irrigated and rain-fed conditions respectively (Table 4). RUE was largely affected than S_i by mid and later-season water deficit imposed after full canopy cover was reached in sugarcane (Robertson et al. 1999) and other C_4 crops of sorghum and maize (Muchow 1989). The maximum RUE for sugarcane ranges from 1.7 (Robertson et al. 1996) to 2.0 g MJ^{-1} (Muchow et al. 1997). Pathirage (1996) studied seven sugarcane varieties and showed that its RUE varied between 1.3 and 1.9 g MJ^{-1} under rain-fed conditions during the period from germination up to 150 DAP. Sinclar and Horie (1989) calculated maximum RUE for a C_4 crop of 1.7 g MJ^{-1}, and Muchow and Davis (1988) measured a maximum RUE of 1.6 g MJ^{-1} in maize. Moreover, current study confirms that sugarcane is more energy efficient than cereal crops, as RUE values approach 2.0 g MJ^{-1}.

When RUE under both water regimes was considered, RUE had highly significant ($p = 0.0001$) positive correlation with cane yield ($r^2 = 0.90$), cane biomass ($r^2 = 0.86$) and total biomass ($r^2 = 0.95$) and highly significant ($p = 0.0001$) negative correlation with k ($r^2 = 0.82$) and S_i ($r^2 = 0.58$) (De Silva and De Costa 2004). The importance

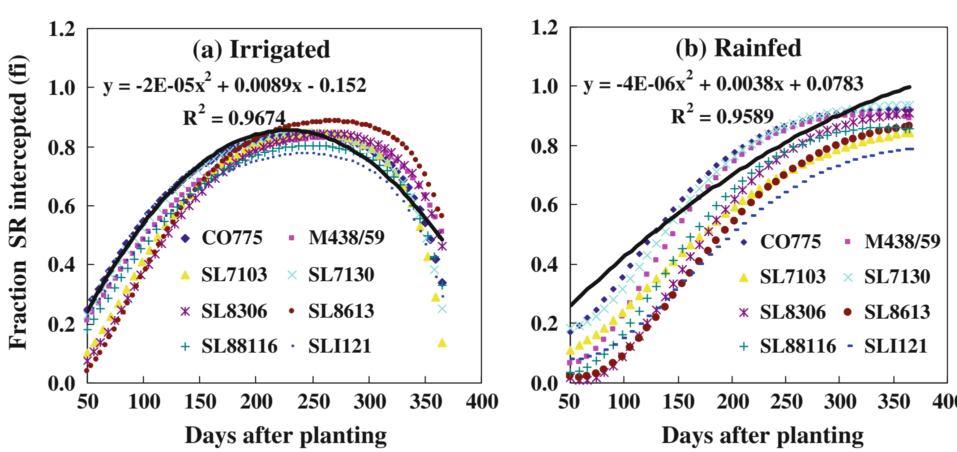

Fig. 2 Seasonal variation of estimated daily fractional interception of solar radiation (SR) from 50 to 365 DAP in different sugarcane varieties under irrigated and rain-fed conditions. The respective equations and R^2 values of the fitted polynomial curve for the standard variety Co775 are shown within the figures

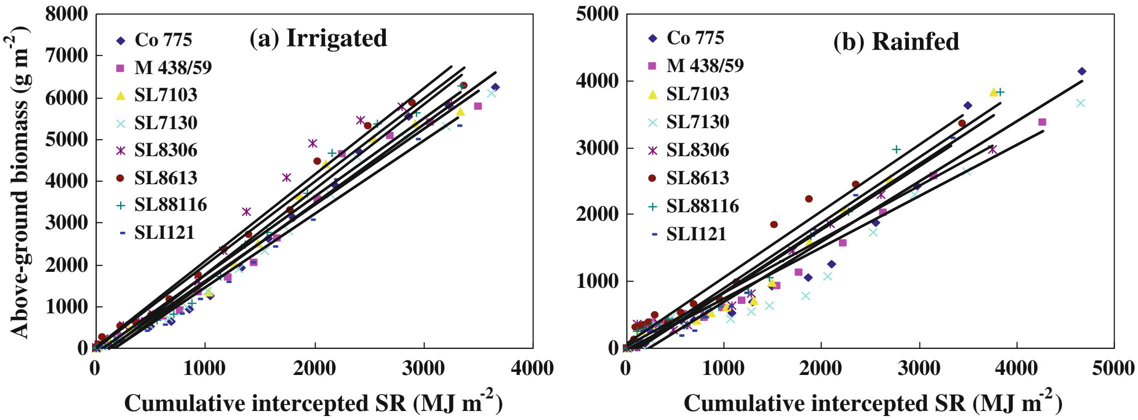

Fig. 3 Relationship between above–ground biomass and cumulative intercepted solar radiation (SR) with fitted linear relationship for different sugarcane varieties under irrigated and rain-fed conditions. $R^2 > 0.95$ for all the fitted linear equations

of RUE in yield determination under both water regimes varied for different varieties. The variety SL 83 06 which had lower *k* values recorded the highest RUE under both conditions, whereas varieties SLI 121 and SL 71 30 had the lowest RUE under irrigated and rain-fed conditions respectively. Moreover, Kumara and Bandara (2001) confirmed that the variety SL 83 06 has greater RUE at 210 and 270 DAP compared to the varieties Co775 and SL 71 30 under irrigated conditions. The variety SL 88 116 had comparatively low *k* values and high RUE under both water regimes (Table 4).

Conclusions

The present study showed that there is a satisfactory genotypic variation in the agronomic (seasonal variation in number of stalks per ha, LAI and accumulation of above–ground biomass, and mean leaf angles and light extinction coefficients) and ecophysiological characters (canopy radiation interception and RUE), which determine cane yields under different sugarcane-growing environments in Sri Lanka. The variety SL 83 06 showed comparatively high utilisation of radiation with higher canopy development and low *k* values consistently through out the growing period. However, none of the varieties tested in the present experiment showed all characters at favourable levels. Different characters were responsible for higher RUE in different varieties under two water regimes. Consequently, canopy development, radiation interception and utilisation of intercepted radiation of the eight varieties tested showed a comparatively narrow range. Based on these findings, we conclude that selecting varieties on the basis of agronomic and ecophysiological characters which have shown significant correlations with cane yield and using them in hybridisation will make possible developing hybrids with several characters combined at favourable levels and suitable for sugarcane-growing environments in Sri Lanka.

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