Varietal Variation of Growth, Physiology and Yield of Sugarcane in Sri Lanka under Two Contrasting Water Regimes

A.L. Chandrajith DeSilva[1], W.A. Janendra and M. DeCosta[2]

[1] Sugarcane Research Institute, Uda Walawe 70190, Sri Lanka. Email chandrajithdesilva@yahoo.com or mailto:rice@slt.lk

[2] Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya 20400, Sri Lanka.

Email janendrad@yahoo.com

Abstract

The objective of this study was to determine the effects of soil moisture deficits on growth, physiology and yield of Sri Lankan sugarcane varieties to identify drought tolerant varieties and specific traits. The experiment was conducted in 2002/03 at the Sugarcane Research Institute, Sri Lanka (6°21'N, 80°48'E). Eight commercial varieties were grown under irrigated (soil water potential > -0.05 MPa) and rainfed conditions. The improved variety, SL88-116, showed the highest cane and sugar yields under both water regimes. Cane yields of all varieties under irrigation were significantly ($P<0.05$) greater (38%-74%) than under rainfed conditions. Higher levels of weight per stalk, leaf area index at harvest and the number of stalks per ha were needed to achieve higher rainfed yields. However, the importance of these traits in yield determination under rainfed conditions varied for different varieties. Water conservation through lower stomatal conductance, both at the individual leaf and whole canopy levels, and greater root length densities in the middle soil layer (30-60 cm depth) to survive periods of significant water deficits in the top soil layer (0-30 cm) were identified as mechanisms responsible for achieving higher rainfed yields in the sugarcane-growing environments of Sri Lanka.

Media summary

Sugarcane varieties selected on the basis of greater root length density and lower stomatal conductance could have better adaptation to rainfed conditions in Sri Lanka

Key Words

Sugarcane, yield, water regimes, root length density, stomatal conductance.

Introduction

Sugarcane contributes more than 72% to the world sugar production (Anonymous, 2003a). Its average productivity has increased from 75 to 95 Mt cane ha^{-1} and from 5 to 12 Mt sugar ha^{-1} during the period from 1960 to 1999 (Cock 2003). However, in Sri Lanka, cane and sugar production has declined and at present the domestic production of sugar is less than 7% of the national demand (Anonymous, 2003b). The average sugarcane yield in Sri Lanka during the last decade has remained 58 mt cane ha^{-1} and 4.9 mt sugar ha^{-1} which are well below the potential (Anonymous, 2003b). In Sri Lanka, most of the sugarcane is grown under rainfed conditions (Mettananda, 1990) in a subhumid climate which experience significant soil moisture deficits during a considerable part of the year. The low cane yield is mainly due to lower soil moisture availability under rainfed conditions (Dharmawardene and Krishnamurthi, 1992). Hence, development of drought resistant varieties is the most promising pathway to increase sugarcane yields in Sri Lanka. Therefore, the objectives of this study were: (a) to determine the effects of soil moisture deficits on growth, yield and physiology of selected sugarcane varieties in Sri Lanka and to identify with better adaptation to rainfed conditions and (b) to identify traits responsible for achieving higher yields under rainfed conditions to enable their use in a breeding program aimed at developing drought tolerant varieties.

Methods

A field experiment was conducted from April 2002 to September 2003 at the Sugarcane Research Institute, Uda Walawe, Sri Lanka (6°21'N, 80°48'E) where the annual average rainfall is about 1450 mm with a distinctly bimodal distribution (Panabokke 1996). The experiment consisted of 16 treatment combinations with two main plot treatments as 'irrigated' ('well-watered') and 'rainfed' ('water-stressed') and eight commercial sugarcane varieties as subplot treatments. The irrigated treatment received irrigation at 5-10 day intervals so that its soil water potential in the top 1 m was maintained above 0.05 MPa. Each treatment combination was replicated thrice in a split plot design. Plot size was 9 x 8.22 m comprising 6 rows spaced at 1.37 m. The crop was maintained under recommended fertilizer and crop protection. Vegetative growth was measured by destructive sampling. Root length density down to 1-m soil depth at 10-cm intervals was measured at 184 days after planting using core sampler method (Schurman and Goedewaagen 1971). Soil moisture content was measured gravimetrically at fortnightly intervals down to 1-m depth. Stomatal conductance and instantaneous transpiration rate per unit leaf area were measured in leaves of top, middle and bottom canopy layers using a steady-state porometer at 6 and 9 months after planting (MAP). Canopy stomatal conductance and instantaneous canopy transpiration rate were computed by summing the products of mean leaf stomatal conductance and partial leaf area index in the three canopy layers (Squire and Black, 1981). The irrigated plots were harvested at 12 MAP. Rainfed plots were harvested at 16 MAP because of their delayed maturity.

Results

Soil moisture content of the irrigated plots was greater than that of the rainfed plots throughout the experimental period (data not shown). Water deficits reduced total biomass at harvest (W_{hv}), cane yield (Y_c) and sugar yield (Y_s) significantly in all varieties (Table 1). However, harvest index was not significantly affected by either varieties or water deficits. When averaged across varieties, water deficits reduced mean $W_{hv\ by\ 37\%}$, Y_c by 51% and Y_s by 55% . Variety SL 88-116 showed the highest Y_c, Y_s, and W_{hv} under both water regimes (Table 1). The number of stalks per ha (N_{st}), weight per stalk (W_{st}) and leaf area index at harvest (L_h) and maximum leaf area index (L_m) showed significant ($p<0.05$) variation between varieties (Table 2). All the above variables showed reductions under rainfed conditions in all varieties, with the exceptions of N_{st} in SL 7130 and L_m in Co 775. When yields under both water regimes were considered, Y_c was positively correlated with N_{st} (r^2 = 0.43 with p=0.0022), W_{st} (r^2 = 0.86 with p=0.0001), L_h (r^2 = 0.82 with p=0.0001), mean stalk diameter (r^2 = 0.29 with p=0.0485), number of leaves at harvest (r^2 = 0.61 with p=0.0001) and plant height at harvesting (r^2 = 0.69 with p=0.0001). Under rainfed conditions, Y_c showed significant positive correlations with W_{st} (r^2 = 0.73 with p=0.0001), L_h (r^2 = 0.50 with p=0.01) and plant height at harvesting (r^2 = 0.64 with p=0.0008) and a moderate positive correlation with N_{st} (r^2 = 0.31 with p=0.14). The importance of these characters in deteriming yield under rainfed conditions varied for different varieties. For example, SL 88-116, which showed the highest rainfed Y_c (Table 1), had the highest W_{st} among the varieties tested. A higher L_h rather than a higher W_{st}, was responsible for the higher rainfed yield in Co 775. In contrast, N_{st} was lowest in SLI 121, which showed the second lowest rainfed Y_c.

Table 1. Total biomass (oven dried weight of cane, trash and foliage), cane yield (cane fresh weight), sugar yield and harvest index of different sugarcane varieties grown under irrigated and rainfed conditions.

Variety	Total biomass (t/ha)		Cane yield (t/ha)		Sugar yield (t/ha)		Harvest index	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
SL 88-116	68.74	52.37	156.55	98.01	21.96	14.08	0.62	0.60
Co 775	66.32	51.97	147.81	97.78	17.89	13.68	0.64	0.61
SL 8306	67.17	46.30	145.53	88.66	19.26	11.74	0.62	0.62
SL 8613	61.53	41.29	137.60	78.77	19.11	10.27	0.63	0.60
SL 7130	66.19	46.26	137.01	91.54	18.06	11.99	0.61	0.61
M 438/59	60.74	44.66	135.80	93.22	17.37	12.00	0.62	0.64
SL 7103	60.38	48.68	135.42	97.63	17.27	13.50	0.63	0.64
SLI 121	54.94	39.03	125.23	79.30	17.88	11.15	0.67	0.61
Mean	63.25	46.32	140.12	90.61	18.60	12.30	0.63	0.62
LSD_v (p=0.05)	10.89	9.97	23.48	19.77	4.12	3.48	0.05	0.08
LSD_w (p=0.05)	3.43		7.17		1.26		0.02	

Note: LSD_v – LSD for varietal comparisons; LSD_w - LSD for comparison of water regimes.

Significant variety x water regime interaction effects were shown on stomatal conductance and instantaneous transpiration rate in terms of both individual leaves in the top leaf layer (g_s, E_l) and the whole canopy (g_c, E_c) (Table 3). Soil water deficits decreased g_s, E_l, g_c, and E_c in a majority of varieties. When yields under both water regimes were considered, cane yield (Y_c) showed significant positive correlations with g_s (r^2 = 0.49 with p=0.05), E_l (r^2 = 0.51 with p=0.04), g_c (r^2 = 0.80 with p=0.0002) and E_c (r^2 = 0.74 with p=0.0001). This indicated that greater stomatal opening and water use are pre-requisites for increasing overall cane yields in this environment. On the other hand, Y_c under rainfed conditions showed moderate negative correlations with g_s (r^2 = -0.53 with p=0.18), E_l (r^2 = -0.30 with p=0.47) and g_c (r^2 = -0.22 with p=0.60). This indicated that water conservation mechanisms (i.e. lower g_s and E_l) are needed in a variety, to achieve higher yields under rainfed conditions. For example, the variety which showed the highest rainfed Y_c (SL 88116 – Table 1) had the lowest g_s, E_l and g_c under rainfed conditions. Conversely, SL 8613 which had the lowest rainfed Y_c had the highest g_s and E_l and the second highest g_c and E_c under rainfed conditions.

Table 2. No. of stalks per ha (N_{st}), weight per stalk (W_{st}) and LAI at harvest (L_h), maximum LAI (L_m) and age of achieving L_m (days after planting - given within parentheses) of different sugarcane varieties grown under irrigated and rainfed conditions.

Variety	No. of stalks per ha		Weight per stalk (kg)		LAI (L_h)		LAI (L_m)	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
SL 88-116	72232	65693	2.16	1.50	3.74	2.02	6.95 (242)	5.75 (304)
Co 775	74513	73145	1.98	1.34	3.35	2.81	7.09 (195)	7.17 (304)
SL 8306	88656	79988	1.64	1.11	3.95	1.82	7.93 (276)	7.35 (332)
SL 8613	88656	74513	1.56	1.05	4.44	1.52	8.35 (242)	7.03 (304)
SL 7130	67518	69495	2.03	1.31	3.61	2.01	7.87 (242)	6.51 (304)
M 438/59	75426	70560	1.79	1.32	3.60	2.60	7.53 (242)	6.04 (304)
SL 7103	73905	72385	1.83	1.36	3.14	2.64	7.40 (242)	5.06 (332)
SLI 121	64477	57938	1.94	1.37	3.13	2.19	6.80 (224)	4.95 (304)
Mean	75673	70465	1.87	1.29	3.62	2.20	7.33	5.96
LSD_v (p=0.05)	9506	9494	0.26	0.27	1.29	0.60		
LSD_w (p=0.05)	3570		0.09		0.34			

Note: LSD_v – LSD for varietal comparisons; LSD_w - LSD for comparison of water regimes.

Table 3. Stomatal conductance and instantaneous transpiration rate of top leaves and the overall canopy of different sugarcane varieties grown under irrigated and rainfed conditions.

Variety	Mean stomatal conductance of top leaves, g_s, (cm s^{-1})		Instantaneous transpiration rate of top leaves, E_l, (μg cm^{-2} [leaf area] s^{-1})		Canopy stomatal conductance, g_c, (cm s^{-1})		Instantaneous canopy transpiration rate, E_c, (μg cm^{-2} [land area] s^{-1})	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
SL 88-116	0.142	0.057	5.028	1.765	1.251	0.279	37.93	10.25
Co 775	0.177	0.095	4.178	1.992	0.941	0.344	32.53	9.78
SL 8306	0.172	0.077	4.647	2.183	0.899	0.420	31.19	9.52
SL 8613	0.072	0.132	1.792	4.588	0.719	0.499	18.49	15.79
SL 7130	0.173	0.103	4.387	3.498	0.559	0.669	14.04	22.65
M 438/59	0.079	0.108	2.793	3.912	0.624	0.324	17.45	7.56
SL 7103	0.195	0.069	6.163	1.798	0.704	0.296	18.40	7.75
SLI 121	0.147	0.112	4.457	2.613	1.090	0.349	34.93	8.32
Mean	0.145	0.094	4.181	2.794	0.838	0.386	25.21	11.33
LSD_v ($p=0.05$)	0.100	0.060	2.706	1.885	0.673	0.256	19.743	8.620
LSD_w ($p=0.05$)	0.028		0.814		0.189		5.379	

Note: LSD_v – LSD for varietal comparisons; LSD_w - LSD for comparison of water regimes.

Root length density (RLD) varied significantly ($p<0.0001$) between different soil layers (Fig. 1). The top soil layer (0-30 cm) had greater RLD than the middle layer (30-60 cm) which in turn had greater RLD than the bottom layer (60-100 cm). Within each depth layer, there was a significant ($p<0.05$) variety x water regime interaction effect on RLD. The variety SL 88-

116, which showed the highest rainfed cane yield (Table 1), had substantially greater RLD under rainfed conditions in the top and middle layers. In these two depth layers, except for SL 88-116, the majority of varieties had lower RLD under rainfed conditions than under irrigated conditions. In the bottom layer, a majority of varieties had greater RLD under rainfed conditions. It is notable that SL 88-116 had comparatively higher levels of RLD in the bottom layer under both rainfed and irrigated conditions. There was a significant ($p<0.05$) variety x water regime interaction on RLD of the entire soil profile (0-100 cm) as well. The comparative variation pattern of RLD in the entire soil profile was similar to that shown for the top soil layer, with all varieties except SL 88-116 showing a lower RLD under rainfed conditions. Total profile RLD showed moderate positive correlations with Y_c ($r^2 = 0.21$ with $p=0.14$) when both irrigated and rainfed data were used in the correlation analysis. A higher total RLD allowed greater water absorption and thereby achieved higher cane yields through increased stomatal conductance and water use (as shown earlier from Tables 3 and 1). On the other hand, rainfed Y_c showed a significant positive correlation with RLD in the middle soil layer ($r^2 = 0.42$ with $p=0.04$) and a moderate correlation with total RLD ($r^2 = 0.26$ with $p=0.23$). As water conservation mechanisms were needed to achieve higher yields under rainfed conditions (Tables 3 and 1), it is highly probable that higher RLD in the middle soil layer was used as a means of absorbing water to maintain plant functioning during periods of significant soil water deficits in the top soil layer rather than as a means of increasing water use and thereby increasing rainfed cane yields.

Figure 1. Root length density (RLD) in different layers of the soil profile at 184 days after planting in different sugarcane varieties grown under irrigated (solid bars) and rainfed (open bars) conditions.

Conclusion

The present study showed that there was adequate genotypic variation in the agronomic (mean stalk weight, LAI at harvest and number of stalks per ha) and ecophysiological characters (root length density and stomatal conductance), which determined cane yields under rainfed conditions in the sugarcane-growing environments of Sri Lanka. However, among the eight varieties tested in the present experiment, there was no single variety in which all above characters were present at favourable levels. Different characters were responsible for higher rainfed yields in different varieties. Consequently, rainfed yields of the eight varieties tested showed a comparatively narrow range, thus indicating a relatively narrow genotypic variation for selecting drought tolerant varieties on the basis of yield alone. Based on these conclusions, we recommend the following approaches to development of drought tolerant varieties for sugarcane-growing environments in Sri Lanka: (a) Selecting varieties on the basis of agronomic and ecophysiological characters which have shown significant correlations with rainfed cane yield and using them in hybridisation programmes to obtain hybrids in which several characters are combined at favourable levels; (b) Introduction of foreign germplasm into breeding programmes to broaden the presently narrow genetic base for rainfed cane yield.

References

Anonymous (2003a) World Sugar Statistics. Agra Europe (London) LTD, FO Licht GmbH, UK.

Anonymous (2003b) Annual Report 2002. Central Bank of Sri Lanka. Colombo, Sri Lanka.

Cock JH (2003) Sugarcane growth and development. International Sugar Journal 105 (no. 1259), 540-552.

Dharmawardene MWN and Krishnamurthi M (1992) Outline Plan for Development of Sugar Industry of Sri Lanka. Sugarcane Research Institute, Uda Walawe, Sri Lanka.

Mettananda C (1990) Sugarcane Growing in Sri Lanka. SRI publication No. 2, Sugarcane Research Institute, Uda Walawa, Sri Lanka.

Panabokke CR (1996) Soils and Agroecological Environments of Sri Lanka. Natural Resources, Science and Energy Authority of Sri Lanka.

Schuurman JJ and Goedewaagen MAJ (1971) Methods of Examination of Root Systems and Root. Center for Agricultural Publishing and Documentation, Wageningen.

Squire GR and Black CR (1981) In 'Stomatal Physiology' (Eds. PG Jarvis and TA Mansfield) pp. 223-245. ambridge University Press, Cambridge.