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Growth and Physiological Responses of Sugarcane to Drought Stress at an Early Growth Stage

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Abstract

A pot experiment was conducted in a net house to evaluate the effects of drought stress (a 20-day water withholding treatment from 100-120 days after planting) on the growth and physiology of five sugarcane cultivars. The results showed that water stress at an early stage significantly affected sugarcane growth and physiology. Water stress resulted in reductions in plant height, stalk diameter, and leaf number of sugarcane, in addition to reductions in the photosynthetic pigment content, *Fv/Fm*, and SPAD (Soil Plant Analysis Development) readings after the 20-day withholding water period (120 DAP), and in stem, root, and leaf fresh weights, and leaf area at 150 DAP. Besides, drought stress led to increases in stomata density and decreases in stomata length. Variation was also found among the cultivars in response to water stress. Significant genotypic differences in stem fresh weight and leaf area under water stress among the cultivars were observed. The highest value of stem fresh weight under stressed conditions was recorded in ROC22 (50.6g), followed by QĐ159 (46.5g), ROC16 (46.2g), ROC10 (46.1g), and VL06 (44.4g). However, the highest DTI was recorded in ROC16, followed by VL06, ROC10, QĐ93-159, and ROC22, respectively.

Keywords

Sugarcane, drought stress, growth, physiological response

Introduction

Drought is considered a major abiotic stress that limits crop production, resulting in severe reductions of their growth rate and development (Begcy *et al.*, 2012). Sugarcane (*Saccharum* spp.) is an important crop used in the production of approximately 60% of the global sugar supply as well as in the production of ethanol and bio-energy (Amalraj *et al.*, 2010). As a C4 plant with a high photosynthetic capacity, sugarcane is highly dependent on water

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availability. Sugarcane is mostly cultivated in tropical and sub-tropical rain-fed regions on both sides of the equator (from 35° North to 35° South) (Silva *et al.,* 2013). In many of these regions, rainfall does not provide the amount of water required for the growth and photosynthetic activities of the crop, and thus water shortages remain a major limiting factor for achieving high yields of sugarcane. Even in humid tropical areas, inequality in rainfall distribution leads to reductions in growth or yield loss (Silva *et al.,* 2013). A yield loss up to 60% due to drought has been recorded in sugarcane (Robertson *et al.,* 1999). In Vietnam, the largest growing region of sugarcane is located along the central coast where drought is a recurring problem. Apart from irrigation practices, drought tolerance improvement is required to alleviate drought and water deficit problems, and to reduce yield losses. Successful selection and breeding for cultivars with drought tolerance can only be achieved when the mechanisms underlying drought tolerance in sugarcane are fully understood. Better understanding of the physiological mechanisms employed by the plant to better cope with drought and water deficits will enhance the success rate in selecting and breeding sugarcane for drought tolerance (Silva *et al.,* 2013). Thus, the objectives of this study were to evaluate the effects of a water deficit on the growth of five sugarcane cultivars and analyze the genotypic differences in their levels of drought tolerance.

Materials and Methods

Plant culture and water deficit treatment

Five sugarcane cultivars (Table 1) were used in this study. A pot experiment was conducted in greenhouse conditions at the Faculty of Agronomy, Vietnam National University of Agriculture. The mature stalks (8 months old) of five cultivars were selected, cut into short pieces of which each had one active bud, and used for propagating in germination trays containing moist sand. The uniformly germinated seedlings (buds 5-7cm in height) were then transplanted into plastic containers with the dimensions of 25cm in diameter and 35cm in height, and filled with 15kg of dry soil.

A two factorial experiment was laid out with five replications following a completely randomized design (CRD). The two water regimes (field capacity as the control and drought stress followed by recovery) were designated factor A, while the five sugarcane cultivars were designated factor B. Water was supplied to all the treatments at the field capacity level from the time of seed cane planting to 100 days after planting (100 DAP). For the drought stress treatment, water was withheld for 20 days from 100 to 120 DAP. Re-watering then was done in the drought stress treatment to bring the soil back to the level of field capacity and maintained in that condition from 120 to 150 DAP. Soil moisture was regularly measured at a depth of 20 cm using a soil tester Takemura DM15 (Japan) every five days during the drought stress period. Mean values of the recorded soil moistures in the stressed treatment ranged from 78-85%, 75-82%, 62-68%, and 46-54% on the 5^{th}, 10^{th}, 15^{th}, and 20^{th} days of withholding water, respectively.

Measurements

Plant height, stalk diameter, and leaf number were measured at 100, 120 (end of the drought stress treatment), and 150 DAP (30 days after re-watering). The number of fully expanded leaves was counted, and the center point of the stalk was measured for stalk diameter using a vernier caliper.

Table 1. Origin of the five sugarcane cultivars used in the study

Cultivar	Origin
QĐ93-159 (Yuetang 93-159)	GSIRI, China
ROC10	TSRI, Taiwan
ROC16	TSRI, Taiwan
ROC22	TSRI, Taiwan
Vien Lam 6 (VL6)	TSRI, Taiwan

Note: NTSRI: Taiwan Sugar Research Institute; GSIRI: Guangzhou Sugarcane Industry Research Institute.

Stomatal density and size were measured according to the methods of Camargo & Marenco (2011). The youngest fully expanded leaves (5 leaves and 4 samples per leaf) were selected, and the midrib vein was removed. Stomatal density and stomatal size were determined from nail polish imprints taken from both the adaxial and abaxial leaf surfaces. Stomata were counted by calculating the view field using a stage micrometer placed under the microscope (Nikon Ys100) with a 10x objective lens. Stomatal size was measured from a sample of 20 stomata per leaf at 100x magnification.

Chlorophyll a fluorescence and photosynthetic pigments measurements

The emission of chlorophyll *a* fluorescence was evaluated at 12:00 pm, using a modulated fluorometer (Opti-Sciences, OS30p+, USA), as described by Medeiros *et al.* (2013). The initial fluorescence (*F0*), the maximum fluorescence (*Fm*), and the maximum quantum efficiency of photosystem II (*Fv /Fm*) were then recorded after 30 minutes of dark adaptation using leaf-clips on the first fully expanded leaf.

For the quantification of chlorophyll *a*, chlorophyll *b*, and the carotenoids, 0.1g of fresh, fully expanded leaves was collected, ground, and soaked in 10mL of 90% acetone for 48h. Absorbance readings at the wavelengths of 663, 647, and 470nm were measured in a spectrophotometer and used for the calculation of the chlorophyll *a*, chlorophyll *b*, and carotenoid contents (Arnold, 1949), and expressed as mg g^{-1} fresh weight (FW). Root fresh weight, stem fresh weight, leaf fresh weight, and leaf area were measured at 150 DAP. SPAD chlorophyll readings were measured at 100, 110, and 120 DAP using portable chlorophyll meters (SPAD-502, Minolta, Japan). Drought tolerant index (DTI*)* was determined following the methods of Hoang *et al.* (2018) where DTI equaled the dry stem weight under stressed conditions divided by the dry weight under well-watered conditions.

Data analysis

Analysis of variance (ANOVA) tests on the measured traits was performed using CropStat (version 7.2) and Sigmaplot 12.5. Treatment means were compared using the least significant difference (LSD) test.

Results and discussion

Plant height, stalk diameter, and leaf number

Drought stress can reduce leaf size, decrease stem growth and root expansion, increase hair density on leaves and stems, and alter plant and water relations (Farooq *et al.*, 2012). After 20 days of withholding water, significant reductions in plant height, stalk diameter, and leaf number were recorded in the five cultivars (Table 2). This is consistent with the findings of Silva *et al.* (2008) and Smith *et al.* (2005) who reported that cane elongation and stalk height were negatively and strongly affected by drought. At 150 DAP (30 days after re-watering), the plant height and stalk diameter of all the cultivars had not fully recovered as large reductions in stalk diameter and plant height were still observed in the stressed treatments among the five cultivars. Significant differences among the five sugarcane cultivars were recorded in plant height, stalk diameter, and leaf number in the stressed period (120 DAP) and after the recovery period (150 DAP). At 120 DAP, the highest plant height was observed in ROC16 (140.5cm), followed by ROC22, QĐ93-159, ROC10, and VL06 with values of 126.0, 112.8, 98.7, and 79.5cm, respectively. The reduction of stem height may have been caused by the low soil water potential which resulted in smaller leaf sizes and a smaller number of leaves per plant (Reddy *et al.*, 2003). After the recovery period (150 DAP), stalk diameters ranged from 10.9mm (in VL06) to 16.1mm (in ROC10). Jangpromma *et al*. (2012) reported that drought stress did not lead to significant variations in stalk diameter among sugarcane cultivars after a 10-day water withholding period. These differences compared with the current study may indicate differences among the cultivars, experimental conditions, and duration of the stress treatment. A drought occurring for more than 10 days was seen to result in severe reductions in root development and yield (Jangpromma *et al.*, 2012).

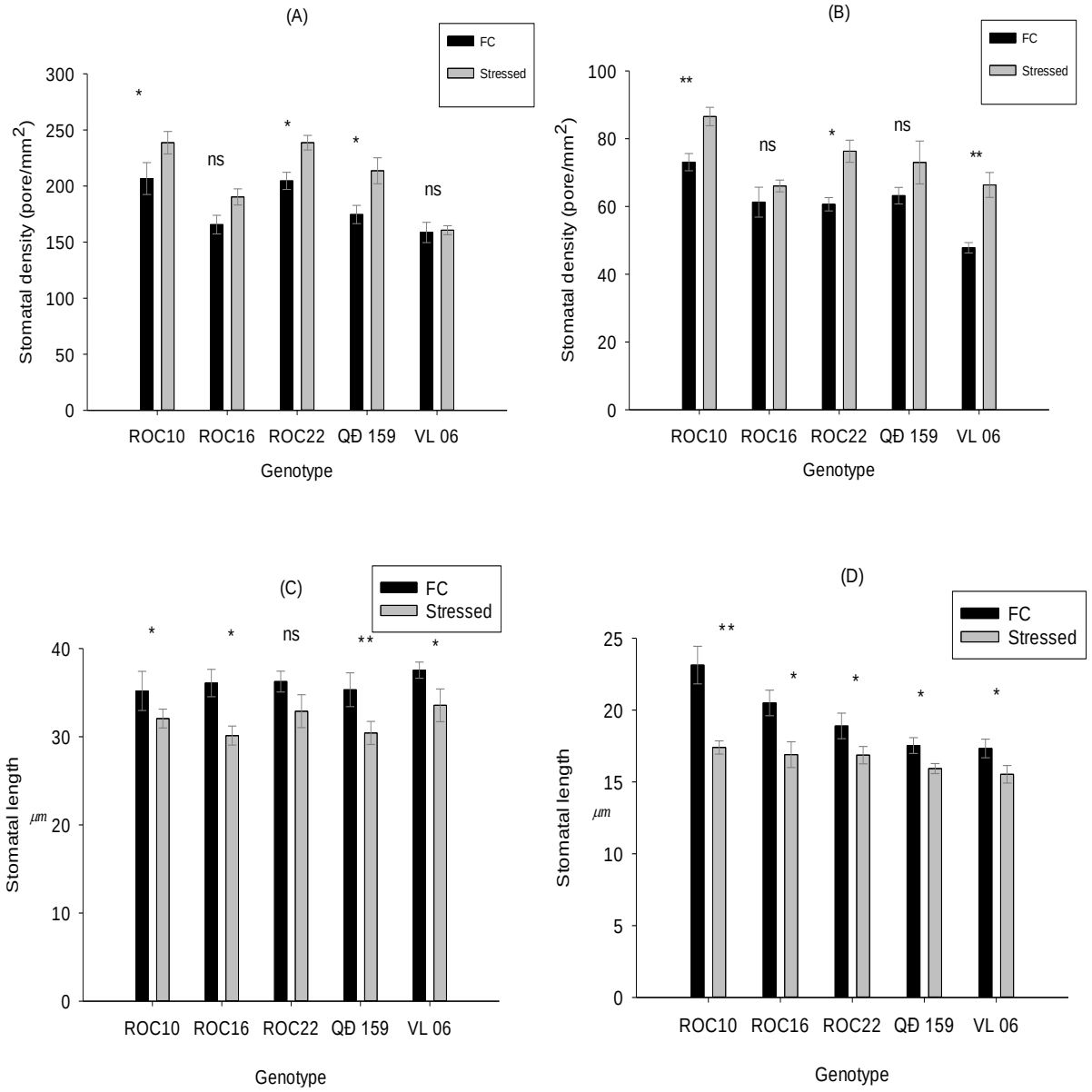
Table 2. Plant height, stalk diameter, and leaf number of different sugarcane genotypes before (100 days after planting, DAP) and after (120 DAP) a 20 day-drought, and 30 days after re-watering (150 DAP)

Treatment		Plant height (cm plant^{-1})			Stalk diameter (mm)			Leaf number (leaves plant^{-1})		
		100 DAP	120 DAP	150 DAP	100 DAP	120 DAP	150 DAP	100 DAP	120 DAP	150 DAP
ROC10	FC	82.3	105.2	152.0	8.7	13.1	17.1	7.0	9.7	10.7
	Stressed	84.0	92.2	146.0	8.3	9.4	15.1	7.0	6.7	7.0
ROC16	FC	100.0	161.7	200.0	8.6	12.2	14.2	5.3	7.0	8.0
	Stressed	96.6	119.3	160.0	8.9	8.7	12.4	5.6	5.7	4.7
ROC22	FC	103.7	139.0	175.3	8.2	12.2	17.9	6.6	9.0	8.7
	Stressed	90.3	112.3	148.4	7.7	8.2	13.8	6.0	6.3	6.3
QĐ93-159	FC	89.5	117.5	158.3	8.5	12.4	17.3	5.3	7.0	9.3
	Stressed	85.6	108.0	148.5	8.3	8.7	13.0	5.3	6.3	7.7
VL06	FC	53.6	92.4	141.5	6.0	8.1	11.6	6.3	8.6	6.0
	Stressed	61.5	68.9	83.1	6.2	7.1	10.3	6.3	5.6	4.3
$LSD_{0.05C*W}$		***14.6***	***12.0***	***16.9***	***2.0***	***1.6***	***2.2***	***0.8***	***1.4***	***1.8***
Mean	ROC10	83.2	98.7	149.4	8.4	11.2	16.1	7.0	8.2	8.8
	ROC16	98.7	140.5	180.1	8.7	10.4	13.3	5.5	6.3	6.3
	ROC22	97.0	126.0	161.8	7.9	10.2	15.9	6.3	7.7	7.5
	QĐ93-159	87.6	112.8	153.4	8.4	10.6	15.2	5.3	6.7	8.5
	VL06	57.5	79.5	112.3	6.6	7.6	10.9	6.3	7.2	5.1
$LSD_{0.05C}$		***10.3***	***8.5***	***11.9***	***1.4***	***1.2***	***1.5***	***0.5***	***1.0***	***1.3***
Mean	FC	86.0	123.3	165.5	8.0	11.6	15.6	6.1	8.3	8.5
	Stressed	83.6	99.6	137.4	8.0	8.4	12.9	6.0	6.1	6.0
$LSD_{0.05W}$		***6.5***	***5.4***	***7.5***	***0.9***	***0.7***	***1.0***	***0.3***	***0.6***	***0.8***
$CV_{\%}$		***10.1***	***6.3***	***6.5***	***14.8***	***9.6***	***8.9***	***7.9***	***11.1***	***14.7***

Note: C: cultivar; W: water treatment; FC: field capacity (control); Stressed: drought stress treatment.

Stomatal density and size

Leaf stomata play a central role in controlling the exchange of CO_2 and water vapor (Xu & Zhou, 2008), and thus, are a crucial part of the stress response of plants to water deficits. Under drought, reductions in the photosynthetic rate can be caused by both stomatal and non-stomatal activities, depending on the drought intensity and species (Chaves *et al.*, 2003). Our results revealed that the stomatal density was higher on the abaxial surface than on the adaxial surface under both the stressed and control (FC) conditions (Figure 1). Drought stress led to significant increases in the stomatal density on the abaxial surface of the cultivars ROC10, ROC22, and QĐ93-159, and on the adaxial surface of the cultivars ROC10, ROC22, and VL06. In addition, the results showed a decrease in the mean values of stomatal length in the sugarcane cultivars under stressed conditions compared to the control. Similar results were observed by Meng *et al.* (1999) and Xu & Zhou (2008) in which stomatal density was negatively correlated with stomatal length under different drought stress conditions. An increase in stomatal density and a decrease in stomatal size are regarded as important adaptations of plants to drought and water deficits (Xu & Zhou, 2008). Although stomatal density was found to increase under drought stress, the number of stomata per leaf decreased as the leaf area was reduced (Xu & Zhou, 2008). However, Yang *et al.* (2007) showed that stomatal density varies according to drought intensification. An increase in stomatal density was recorded under light and moderate drought, but a decrease was observed in severe drought.



*Note: ns = not significant; * = significant at p = 0.05; ** = significant at p = 0.01.*

Figure 1. Mean values of stomatal density on the abaxial (A) and adaxial (B) surfaces, and mean values of stomatal length on the abaxial (C) and adaxial (D) surfaces among cultivars

Photosynthetic pigments

Droughts have negative impacts on photosynthetic pigments. Depending on the drought intensity and duration, drought can cause damage to pigments or even deterioration of thylakoid membranes (Ashraf & Harris, 2013). In this study, the results showed a decrease in both chlorophyll *a* and *b* content as consequences of drought stress in all the cultivars (Table 3). While a decrease of 36% was found in the chlorophyll *a* content, drought stress also reduced the chlorophyll *b* content by 61% compared to the control (FC), leading to changes in the chlorophyll *a/b* ratio. However, no significant differences in carotenoid content were observed regardless of the cultivar or water treatment. Similar results have also been observed by Ashraf & Harris (2013) and Mafakheri *et al.* (2010), who reported that reductions in the chlorophyll content from drought stress are due to

Table 3. Effects of drought stress at an early stage on photosynthetic pigments at 120 DAP

Treatment		Chla (mg g^{-1})	Chlb (mg g^{-1})	Carotenoid (mg g^{-1})	Chla/Chlb	Total chl
ROC10	FC	0.946	0.338	0.208	2.799	1.284
	Stressed	0.729	0.258	0.203	2.826	0.987
ROC16	FC	0.955	0.343	0.207	2.784	1.298
	Stressed	0.651	0.213	0.203	3.056	0.864
ROC22	FC	0.890	0.351	0.206	2.536	1.241
	Stressed	0.763	0.235	0.208	3.247	0.998
QĐ93-159	FC	0.936	0.339	0.207	2.761	1.275
	Stressed	0.704	0.209	0.198	3.368	0.913
VL06	FC	0.954	0.343	0.202	2.781)	1.297
	Stressed	0.579	0.220	0.197	2.632	0.799
$LSD_{0.05C*W}$		***0.163***	***0.043***	***0.009***	-	-
Mean	ROC10	0.838	0.298	0.206	-	-
	ROC16	0.803	0.278	0.205	-	-
	ROC22	0.827	0.293	0.207	-	-
	QĐ93-159	0.820	0.274	0.203	-	-
	VL06	0.767	0.282	0.202	-	-
$LSD_{0.05C}$		***0.011***	***0.0285***	***0.006***	-	-
Mean	FC	0.936	0.343	0.206	-	-
	Stressed	0.685	0.227	0.202	-	-
$LSD_{0.05W}$		***0.072***	***0.018***	***0.041***	-	-
$CV_{\%}$		***0.1***	***8.3***	***2.6***	-	-

Note: C: cultivar; W: water treatment; FC: field capacity (control); Stressed: drought stress treatment.

damage of the photosynthetic pigments and deterioration of the thylakoid membranes. The reduction of the chlorophyll content is mainly due to the destruction of pigments caused by oxidative damage when the plant is exposed to severe drought stress. Generally, drought stress leads to a greater reduction of the chlorophyll *b* content than that of chlorophyll *a* and thus, results in an increased ratio of chlorophyll *a/b (*Ashraf & Harris, 2013). Under adverse conditions such as drought, plants employ different physiological and metabolic strategies for survival. For instance, plants can synthesize antioxidants such as ascorbate, glutathione, and flavonoids (Medeiros *et al.*, 2013), together with increasing the activity of antioxidant enzymes including peroxidase, superoxide dismutase, and catalases.

SPAD readings and maximum photochemical efficiency (Fv/Fm)

The maximum photochemical efficiency (*Fv/Fm)* is positively correlated with the photosynthesis rate of a plant and thus, is used as an important parameter for quantifying a plant's response to drought stress (Silva *et al.,* 2013). Maintaining a similar *Fv/Fm* ratio between plants under drought stress and plants under well-irrigated conditions indicates a high efficiency of carbon assimilation and hence, the plant is better able to adapt to the stressed conditions (Silva *et al.*, 2007). No significant differences in the *Fv/Fm* ratios were found among all the cultivars at 100 and 110 DAP. All the cultivars had a *Fv/Fm* ratio of 0.74 to 0.78. However, at 120 DAP (20 days of withholding water), significant differences in the *Fv/Fm* ratios were observed

Table 4. SPAD meter readings and *Fv/Fm* ratios of different sugarcane cultivars before (100 days after planting, DAP), after 10 days (110 DAP), and after 20 days of drought (120 DAP)

Treatment		***Fv/Fm***			**SPAD readings**			
		100 DAP	110 DAP	120 DAP	100 DAP	110 DAP	120 DAP	150 DAP
ROC10	FC	0.765	0.776	0.742	53.6	43.3	45.5	39.0
	Stressed	0.767	0.764	0.633	51.0	44.2	36.9	44.4
ROC16	FC	0.791	0.786	0.773	52.2	46.0	44.2	42.8
	Stressed	0.781	0.741	0.679	52.7	45.2	40.1	44.3
ROC22	FC	0.788	0.784	0.738	50.7	45.7	45.7	42.6
	Stressed	0.786	0.704	0.581	53.5	46.1	40.9	44.9
QĐ93-159	FC	0.780	0.771	0.755	48.3	46.8	43.7	41.7
	Stressed	0.775	0.756	0.550	53.6	46.1	34.0	43.1
VL06	FC	0.764	0.780	0.752	47.7	44.2	43.9	39.1
	Stressed	0.783	0.701	0.610	52.2	45.3	36.4	42.6
$LSD_{0.05C*W}$		***0.211***	***0.161***	***0.427***	***4.5***	***1.9***	***2.9***	***2.1***
Mean	ROC10	0.766	0.770	0.687	52.3	43.8	41.2	41.7
	ROC16	0.786	0.763	0.726	52.4	45.6	42.2	43.5
	ROC22	0.787	0.744	0.659	52.1	45.9	43.3	43.8
	QĐ93-159	0.778	0.763	0.653	51.0	46.4	38.9	42.4
	VL06	0.773	0.762	0.681	49.9	44.8	40.2	40.9
$LSD_{0.05C}$		***0.149***	***0.114***	***0.303***	***3.2***	***1.4***	***2.1***	***1.4***
Mean	FC	0.778	0.779	0.752	50.5	45.2	44.6	41.2
	Stressed	0.778	0.742	0.610	52.6	45.3	37.7	43.9
$LSD_{0.05W}$		***0.145***	***0.132***	***0.191***	***2.2***	***0.9***	***1.3***	***2.0***
$CV_{\%}$		***1.6***	***1.2***	***3.7***	***5.1***	***2.5***	***4.2***	***2.7***

Note: C: cultivar; W: water treatment; FC: field capacity (control); Stressed: drought treatment.

among cultivars. The highest *Fv/Fm* ratio value was found in ROC16 (0.726) while the rest of the cultivars had no significant differences. Drought stress only led to a significant reduction in the *Fv/Fm* ratio in the stressed treatment compared with the control at 120 DAP (20 days of water withholding). A *Fv/Fm* ratio value of less than 0.75 indicates the beginning of stress and, therefore, a reduction in the photosynthetic capacity of the plant (Maxwell & Johnson, 2010). Low values of the *Fv/Fm* ratio have also been reported by Graca *et al.* (2010) and Silva *et al.* (2007) in sugarcane under severe drought.

A SPAD chlorophyll meter reading (SCMR) is considered a rapid assessment of the chlorophyll content in many crops including sugarcane, corn, and papaya (Jangproma *et al.*, 2010). Our results showed that drought significantly reduced the SCMRs of plants under stressed conditions at the end of the drought stress treatment (120 DAP), which was consistent with the findings of Silva *et al.* (2007). A drought imposed 90 DAP led to reductions in the SCMRs, and more severe reductions were recorded in susceptible genotypes. SCMRs, therefore, can be used for the identification of drought-tolerant genotypes (Silva *et al.,* 2007). Significant differences in the SCMRs were observed among the five cultivars at the end of the drought stress treatment. The highest mean SCMR value was recorded in ROC22 (43.8), followed by ROC16 (42.2), and was lowest in QĐ93-159 (38.6). Under stressed conditions, the

SCMRs were maintained at an average of 40 in ROC22 and ROC16, which were significantly higher compared to those in ROC10, VL06, and QĐ93-159. This suggests a higher capacity of the ROC22 and ROC16 plants to conserve their photosynthetic pigment content during drought stress. According to Silva *et al.* (2013), a SCMR below 40 in sugarcane indicates the start of chlorophyll deficiency, which affects the photosynthetic activities of the plants. Thus, the low SCMRs (below 40) recorded in ROC10, VL06, and QĐ93-159 indicate drought stress sensitivities. No significant difference in terms of the SCMRs was found between the control and stressed treatments at 30 days after re-watering (150 DAP).

Plant fresh weight, leaf area (LA), and drought tolerance index (DTI) at recovery (150 DAP)

Sugarcane plants exposed to prolonged drought have been reported to experience a reduction in growth (Jaiphong *et al.,* 2016). Our results showed that root, leaf, and stem fresh weights, and leaf area were significantly reduced in plants under the drought treatment relative to the control (Table 5). Fresh root weight was reduced by 51.5% compared to the drought stress treatment at 150 DAP. This matches with the findings in early studies by Medeiros *et al.* (2013), Jaiphong *et al.* (2016), and Silva *et al.* (2013). Significant differences in root fresh weight, leaf fresh weight, stem fresh weight, and

Table 5. Effects of drought stress at an early stage on the plant fresh weight, leaf area, and drought tolerance index (DTI) of five cultivars at 150 DAP

Treatment		Root fresh weight (g plant^{-1})	Leaf fresh weight (g plant^{-1})	Stem fresh weight (g plant$^{-1)}$	Leaf area (cm^2)	Drought tolerance index (DTI)
ROC10	FC	57.2	158.6	79.3	18.2	-
	Stressed	30.7	76.5	46.1	9.5	0.59
ROC16	FC	50	188.8	71.2	22.5	-
	Stressed	31.3	78.8	46.2	10.5	0.69
ROC22	FC	93.1	176.5	96.7	23	-
	Stressed	41.3	115.6	50.6	17.1	0.55
QĐ93-159	FC	58.1	164.6	80.5	14.9	-
	Stressed	21.2	82.5	46.5	8.8	0.57
VL06	FC	46.5	91.3	64.7	17.2	-
	Stressed	26.7	54.9	44.4	5.7	0.68
LSD $_{0.05C*W}$		***4.1***	***10.5***	***4.4***	***1.9***	
Mean	ROC10	43.9	117.5	62.7	13.9	
	ROC16	40.6	133.8	58.7	16.5	
	ROC22	67.2	146.1	73.6	20.1	
	QĐ93-159	39.6	123.5	63.5	11.8	
	VL06	36.6	73.1	54.5	11.4	
LSD$_{0.05C}$		***2.8***	***7.4***	***3.1***	***1.3***	
Mean	FC	60.9	155.9	78.5	19.2	
	Stressed	30.2	81.6	46.8	10.3	
LSD $_{0.05W}$		***1.8***	***4.7***	***2***	***0.9***	
CV$_{\%}$		***5.2***	***5.2***	***4.2***	***7.8***	

Note: C: cultivar; W: water treatment; FC: field capacity (control); Stressed: drought treatment.

leaf area were found among sugarcane cultivars. The mean values of stem fresh weight ranged from 54.5g (in VL06) to 73.6g (in ROC22). Significant differences in stem fresh weight and leaf area were also found among the cultivars under drought stress. The highest value of stem fresh weight under stressed conditions was recorded in ROC22 (50.6g), followed by QĐ93-159 (46.5g), ROC16 (46.2g), ROC10 (46.1g), and VL06 (44.4g). Leaf area also varied among the sugarcane cultivars and ranged from 11.4cm^2 in VL06 to 20.1cm^2 in ROC22. A reduction in plant growth under water deficit conditions can be seen as the consequence of the decrease in cell elongation caused by the interruption of water flow from the xylem to surrounding elongation cells, the increase in cell sap concentration, and the dehydration of the protoplasm (Nonami, 1998; Larcher, 2003). Low biomass accumulation of sugarcane, when exposed to drought stress, can be explained by reductions in light interception, plant extension rate, and photosynthetic capacity (Koonjah *et al.*, 2006). The drought tolerance index (DTI) has been used as an important parameter in evaluating the tolerance ability of crops. Among the sugarcane cultivars, the highest DTI was recorded in ROC16, followed by VL06, ROC10, QĐ93-159, and ROC22, respectively.

Conclusions

Drought stress at an early growth stage (100-120 DAP) significantly affected the growth and physiological characteristics of five sugarcane cultivars. A 20-day water withholding treatment resulted in reductions in plant height, stalk diameter, and leaf number of sugarcane, in addition to reductions in photosynthetic pigment content, *Fv/Fm*, and SPAD readings at 120 DAP, and in stem, root, and leaf fresh weights, and leaf area at 150 DAP (30 days after re-watering). Furthermore, drought stress led to reductions in stomatal density and increases in stomatal length. Variation was also found among the cultivars in response to drought stress. The highest value of stem fresh weight under stressed conditions was recorded in ROC22 (50.6g), followed by QĐ93-159 (46.5g), ROC16 (46.2g), ROC10 (46.1g), and VL06 (44.4g). However, the highest DTI was recorded in ROC16, followed by VL06, ROC10, QĐ93-159, and ROC22, respectively.

Conflicts of Interest

The authors declare no conflicts of interest.

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