ISSN : 1812-5379 (Print) ISSN : 1812-5417 (Online) http://ansijournals.com/ja

JOURNAL OF



Asian Network for Scientific Information 308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy

ISSN 1812-5379 DOI: 10.3923/ja.2020.1.13



Research Article Performances of Elite Sugarcane Genotypes for Agro-physiological Traits in Relation to Yield Potential and Ratooning Ability under Rain-fed Conditions

^{1,2}Patcharin Songsri, ¹Jiraporn Nata, ²Nam-aoi Bootprom and ^{1,2}Nuntawoot Jongrungklang

¹Department of Agronomy, Faculty of Agriculture, Khon Kaen University, 40002 Khon Kaen, Thailand ²Northeast Thailand Cane and Sugar Research Center, Khon Kaen University, Khon Kaen, Thailand

Abstract

Background and Objective: Poor ratooning ability in sugarcane can limit crop productivity and profitability for sugarcane growers. The objective of this study was to investigate the agronomic and physiological performances of elite sugarcane genotypes in relation to yield potential and ratooning ability under rain-fed conditions. **Materials and Methods:** Thirty-nine sugarcane genotypes were evaluated in a randomized complete block design with 3 replications, in 2 separate crops, consisting of a planted crop and first ratoon crop from December, 2015 to December, 2017; at Khan Kaen University's, Faculty of Agriculture. The sugarcane genotypes were planted in 4-row plots, 8 m in length, spaced 1.5×0.5 m. Sixteen coupled plants were placed two cane pieces/row. Combined analysis of variance indicated significant effects of crop and genotype (C×G) interaction within the agronomic traits; i.e., stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield, millable cane and sugar yield; the physiological traits, i.e., SPAD chlorophyll meter reading (SCMR) and relative water content (RWC) at the drought stress period (90 DAP), the recovery period (180 DAP) and at harvest (12 months after planting) in the planted and first ratoon crops. **Results:** Kps01-12, KK3 and K88-92 were identified as the most superior clones for cane and sugar yields. Stalk length, single stalk weight and millable cane were associated with cane yields of the planted crop and first ratoon crop and may therefore, be used as surrogate traits for improved yield and ratooning ability. **Conclusion:** The association between the agronomic and physiological parameters with cane yield will determine the ratooning potential of planted and first ratoon crops.

Key words: Millable cane, photosynthetic efficiency, planted crop, ratoon crop, Saccharum spp.

Citation: Patcharin Songsri, Jiraporn Nata, Nam-aoi Bootprom and Nuntawoot Jongrungklang, 2020. Performances of elite sugarcane genotypes for agro-physiological traits in relation to yield potential and ratooning ability under rain-fed conditions. J. Agron., 19: 1-13.

Corresponding Author: Patcharin Songsri, Department of Agronomy, Faculty of Agriculture, Khon Kaen University, 40002 Khon Kaen, Thailand Tel: +66 43 364 637 Fax: +66 43 364 637

Copyright: © 2020 Patcharin Songsri *et al.* This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Profitability of sugarcane production in the rainfed areas is dependent on ratooning ability of the crop in which the crop can be harvested more years before it is discarded for planting of new crop. Sugarcane (*Saccharum* spp.) has the capability to serve human needs for both food and fuel¹. It is largely grown under rain-fed conditions in arid and semi-arid tropical regions. Drought stress is the most detrimental factor which reduces the ratooning ability and yield of sugarcane. As a ratoon crop, sugarcane can be harvested several times in each planting. The profits of sugarcane growers are therefore, dependent on the ratooning ability of sugarcane, as high ratooning verities require a low frequency of planting.

Direct selection for high ratoon yield increases ratooning ability. As a target trait for selection, ratoon yield, cane yield and the ability of a crop to be harvested several times must be taken into consideration in crop evaluation. According to Panhwar *et al.*² cane yield was closely related to stalk number, stalk diameter, stalk length and stalk weight. These traits have been suggested for use as surrogate traits for cane yield³. Stability analysis of these traits may shed light on the adaptive behaviors of the tested genotypes and may provide some indication for the possibility of their use for indirect selection for improved yield and ratooning ability.

Evaluation of crop performance in a wide range of environments is necessary to determine genotypes superior in yield and yield stability. For ratoon crops such as sugarcane, sugarcane genotypes with good ratooning ability are desirable for sustaining yield. As a ratoon crop, the profitability of sugarcane production is dependent on the ability of the crop to be harvested more years. Ratooning ability is a complex traits that is associated with other traits and highly dependent on environmental conditions and crop management practices. Selection of physiological traits associated with ratooning ability may help sugarcane breeders to identify the high yielding genotypes⁴. Physiological traits related to photosynthesis, such as photosystem II (PSII) photochemical efficiency (Fv/Fm), stomatal conductance, transpiration, SPAD (Soil Plant Analysis Development) index and water potential, were identified as the traits promoting photosynthesis in sugarcane³. The research on physiological traits related to ratooning ability of sugarcane is worth attempting⁴. The objective of this study was therefore, to investigate the agronomic and physiological performances of elite sugarcane genotypes in relation to yield potential and ratooning ability under rain-fed conditions.

MATERIALS AND METHODS

Plant materials and experiment design: Thirty-nine elite sugarcane clones (CSB06-2-21, CSB07-79, CSB06-2-15, CSB06-4-162, CSB06-5-20, CSB07-219, KK06-501, KK07-037, KK07-050, KK07-478, KK07-680, KKU99-01, KKU99-02, KKU99-03, KKU99-06, MPT05-187, MPT02-458, MPT03-166, MPT03-320, NSUT08-22-3-13, Q229, RT2004-085, TPJ04-229, TBy27-0590, TBy27-1385, TBy28-0348, TBy28-1211, TP06-419, U12, UT07-317, UT07-381, UT13, TBy28-0941, 91-2-527, K88-92, Kps01-12, LK92-11, KK3 and TPJ03-452) from several sugarcane breeding programs in Thailand were evaluated within this study. The genotypes were assigned in a randomized complete block design with 3 replications at the Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand.

The sugarcane genotypes were planted in 4-row plots, 8 m in length, spaced 1.5 m between rows and 0.5 m between plants within rows. Two stem cuttings 25 cm in length were buried horizontally in each hill. A basal fertilizer formula (15-15-15 of N-P₂O₅-KO₂) (Thai Central Chemical Public Company Limited, Pra Nakhon Si Ayuthaya, Thailand) at the rate of 312.5 kg ha⁻¹ was applied immediately to each plot after planting and a top-dressing fertilizer of the same formula was again applied (312.5 kg ha⁻¹) at 4 months after planting. A chemical fertilizer formula (15-15-15 of N-P₂O₅-KO₂) was applied to the ratoon crop in 2 splits at a rate of 312.5 kg ha⁻¹ at 4 months after the planted crop harvest. Weeds, insects and diseases were controlled for optimum crop growth. Weed control was carried out manually at four months after harvest in 2016 and 2017, for both the planted and the first ratoon crop, respectively. Crops were harvested manually by cutting the stalks at ground level and discarding the tops.

Data collection

Physiological traits: Data were recorded for chlorophyll fluorescence, SPAD chlorophyll meter reading (SCMR) and relative water content (RWC) from the upper two-thirds of the fully expanded leaf from the top of the main stem at 90 and 180 days after planting (DAP) in planted crop and at 90 and 180 days after harvest (DAH) in the first ratoon crop. Chlorophyll fluorescence was measured using a chlorophyll fluorescence meter (PAM-2000, Heinz Walz GmbH, Germany) with the method described by Maxwell and Johnson, 2000. The leaf samples were dark-adapted for 15 min using leaf clips (FL-DC, Opti-Science) before chlorophyll fluorescence

was measured. SCMR was determined using a SPAD-502 chlorophyll meter (Minolta SPAD-502 m, Tokyo, Japan) daily, between 9:00 AM and 12:00 AM. The RWC was calculated from the following equation with minor modifications⁵:

$$RWC = \left[\frac{Wf - Wd}{Wt - Wd}\right] \times 100$$
(1)

Leaf disc fresh weight (Wf) was determined within 2 h of excision. Turgid weight (Wt) was obtained after hydration in deionized water for 24 h in darkness at room temperature. Leaf discs were quickly blotted and oven-dried for 72 h at 80°C before recording the dry weight (Wd).

Yield and yield components: Data were recorded for stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, millable cane, cane yield, sugar yield and commercial cane sugar (CCS) for the planted crop at harvest (12 months after planting) and the first ratoon crop. The number of millable stalks was counted within each plot. Stalk length was measured from 6 stalks in the plot via a measuring tape and the number of internodes/stalk was measured from 6 randomly selected stalks in each plot. A vernier caliper was used to measure the diameter of the same 6 stalks in which the reading region was defined as one-third of the stalk length (from the base to the top). Then, the 6 stalks were weighed and the mean weight was obtained. Cane yield (t ha⁻¹) was calculated from the weight of all millable canes per plot within the harvest area. Lastly, juice was extracted from these 6 stalks to determine commercial cane sugar (CCS) through the following equation⁶:

$$CCS = 3P/2 \left[1 - (F+5/100)\right] - B/2 \left[(1 - (F+3)/100)\right]$$
(2)

where, P is the pol at 20°C, B is the brix at 20°C and F is the fiber (%).

Sugar yield was calculated based on cane yield and CCS value, through the following equation⁶:

Sugar yield =
$$(CCS \times Cane yield)/100$$
 (3)

Statistical analysis: Data for cane yield, yield components and physiological traits were analyzed statistically according to a randomized complete block design⁷. Analysis of variance was performed using Statistic-8

software and the least significant difference (LSD) was used to compare the mean differences at 0.05 probability level. Correlation coefficients among cane yield, yield components and physiological traits were calculated based on treatment means.

RESULTS

Meteorological conditions: Maximum temperature, minimum temperature, rainfall and relative humidity were recorded at a weather station located 100 m from the experiment area in the growing seasons of 2015 and 2017 (Fig. 1). In the planted crop from December, 2015 to December, 2016, minimum air temperatures ranged from 22.4-26.4°C and maximum temperatures ranged from 36.8-40.5°C. The highest relative humidity (87.3%) was recorded in May, 2016 and the lowest relative humidity (76.0%) was recorded in April 2016. The highest rainfall at the drought period (90 DAP) was 81.1 mm in April, 2016. At the recovery period (180 DAP) from June to August, 2016, minimum air temperatures ranged from 24.5-25.3 °C and maximum temperatures ranged from 33.0-35.0°C. The highest relative humidity (90.9%) was recorded in July, 2016 and the lowest relative humidity (89.1%) was recorded in June, 2016. August, 2016 had the highest rainfall of 196.1 mm.

In first ratoon crop from December, 2016 to December, 2017, minimum air temperatures ranged from 21.9-24.2°C and maximum temperatures ranged from 34.2-36.0°C. The highest relative humidity (93.3%) was recorded in May, 2017 and the lowest relative humidity (88.6%) was recorded in April, 2017. The highest rainfall at the drought stress period (90 DAP) was 172.2 mm in May, 2017. At the recovery period (180 DAP) from June to August, 2017, minimum air temperatures ranged from 24.1-24.5°C and maximum temperatures ranged from 31.5-33.7°C. The highest relative humidity (95.4%) was recorded in August, 2017 and the lowest relative humidity (93.3%) was recorded in June, 2017. August in 2016 had the least amount of rainfall (196.1 mm), whereas, July and August, 2017 had the highest rainfall (319.7 mm). The experiment received rainfall in all months, except in December, 2015 and 2016.

Combined analysis for agronomic traits

Variations in crops: Thirty-nine sugarcane genotypes were evaluated in both the planted crop and first ratoon crop for stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight,



Fig. 1: Rainfall (mm), maximum temperature (°C), minimum temperature (°C) and relative humidity (%) during the experiment period

Table 1: Mean squares for diameter, stalk length, number of internodes/stalk, number of stalks/stool and single stalk weight of the 39 sugarcane genotypes evaluated in the planted crop and first ration crop

Source of variance	df	Stalk diameter (cm)	Stalk length (cm)	No. of internodes/stalk	No. of stalks/stool	Single stalk weight (kg/stalk)
Crop (C)	1	0.06 ^{ns}	35037.00**	239.82**	78.45**	4.56**
Rep. within C	4	0.02	596.60	4.09	0.68	0.03
Genotypes (G)	39	0.30**	4142.60**	28.84**	1.81**	0.67**
C×G	39	0.09**	1078.40*	7.10*	1.73**	0.21**
Pool error	156	0.03	630.00	4.39	0.57	0.09
CV (%)		6.11	7.07	9.44	14.16	13.47

^{ns}Non-significant, *p<u><</u>0.05, **p<u><</u>0.01

Table 2: Mean squares for cane	yield, millable cane, CCS a	nd sugar yield of the	e 39 sugarcane genotypes e	valuated in the planted	d crop and first ratoon crop
	· · ·	<i>J ,</i>	5 5 71		

Source of variance	df	Cane yield (t ha ⁻¹)	Millable cane	CCS	Sugar yield
Crop (C)	1	57692.80**	1.70×10 ^{9*}	0.15 ^{ns}	821.72**
Rep. within C	4	316.40	8.57×10 ⁷	4.27	11.54
Genotypes (G)	39	855.70**	3.17×10 ^{8**}	20.21**	25.98**
C×G	39	538.60**	2.26×10 ^{8**}	1.61 ^{ns}	9.92**
Pool error	156	99.00	3.99×10 ⁷	2.42	3.52
CV (%)		7.79	10.56	12.96	15.05
CV (%)	× 0.01	7.79	10.56	12.96	

nsNon-significant, *p<0.05, **p<0.01

cane yield, millable cane, CCS and sugar yield. Significant differences ($p \le 0.05$ or 0.01) between crops were observed for stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield, millable cane and sugar yield; whereas the differences between crops for stalk diameter and CCS were not significant (Table 1, 2). Large differences were observed between crops for stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield

and sugar `yield; whereas, the difference for millable cane, while low, was also significant.

Genotypic variability: Genotypes were significantly different ($p \le 0.01$) for stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield, millable cane, CCS and sugar yield (Table 1, 2). The data indicated that genotypes were important sources of variations for all traits.

Source of variance	Fv/Fm		SCMR		RWC	
	3 months	6 months	3 months	6 months	3 months	6 months
Crop (C)	0.001 ^{ns}	0.002 ^{ns}	964.09**	0.82 ^{ns}	2119.88**	548.54**
Rep. within C	0.004	0.001	10.31	4.61	14.00	14.00
Genotypes (G)	0.001 ^{ns}	0.001 ^{ns}	7.87**	16.51**	17.02 ^{ns}	21.17**
C×G	0.001 ^{ns}	0.001 ^{ns}	6.83**	7.77**	25.40**	19.75**
Pool error	0.001	0.001	3.84	2.62	11.65	6.17
CV (%)	4.25	2.17	6.23	3.49	4.83	3.67

J. Agron., 19 (1): 1-13, 2020

Table 3: Mean squares for Fv/Fm, SCMR and RWC of the 39 sugarcane genotypes at 3 and 6 months in the planted crop and first ration crop

^{ns}Non-significant, **p<0.01

C×G interaction: The interactions between crop and genotype were significant ($p \le 0.05$ or 0.01) for stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield, millable cane and sugar yield, however, interaction was not significant for CCS (Table 1, 2). The highest interactions were found for stalk diameter, number of stalks/stool, single stalk weight, cane yield, millable cane and sugar yield, millable cane and sugar yield. The significant interactions between sugarcane genotype and crop demonstrated the varied responses for cane yield, as well as other traits.

Combined analysis for physiological traits

Variations between crops: Thirty-nine sugarcane genotypes were evaluated in the planted crop and first ratoon crop for Fv/Fm, SCMR and RWC at the drought stress period (90 DAP) and at the recovery period (180 DAP). Differences between crops were significant ($p \le 0.01$) for SCMR at 3 months and RWC at the drought stress period (90 DAP) and recovery period (180 DAP), though not significant for Fv/Fm at the drought stress period (90 DAP) and recovery period (180 DAP), or SCMR at the recovery period (180 DAP) (Table 3).

Variations among genotypes were highly significant for SCMR at the drought stress period (90 DAP) and recovery period (180 DAP), as well as RWC at the recovery period (180 DAP) (Table 3). The interactions between crop and genotype were significant ($P \le 0.01$) for SCMR and RWC at the drought stress period (90 DAP) and at the recovery period (180 DAP), but were not significant for Fv/Fm (Table 3).

Yield performances of sugarcane genotypes for the planted crop and first ratoon crop: The K88-92 produced high cane yield, stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, millable cane and sugar yield in the planted crop. MPT02-458 also had high cane yield and KK3 had high sugar yield in both the planted and ratoon crops (Table 4). The UT07-381 and NSUT08-22-3-13 had the lowest percentages of reduction in cane yield (increase 3.55 and 3.45%, respectively); whereas, CSB06-2-15 had the highest percentage of reduction in cane yield (64.22%). The NSUT08-22-3-13 and Kps01-12 had the lowest percentages of reduction in sugar yield (increase 3.44 and 3.08%, respectively) and CSB06-2-15 had the highest percentage of reduction in sugar yield (66.08%) (Table 4). Kps01-12, KKU99-01, KK07-680, MPT02-458 and K88-92 had high cane yield, sugar yield and CCS in planted crop and first ratoon crop, but the correlation coefficient between planted crop and ratoon crop was not significant for cane yield, although it was positive (r = 0.30) (Fig. 2a). CSB06-2-15 showed low cane yield and sugar yield and TPJ04-229 had low CCS, whereas, NSUT08-22-3-13 had high CCS in planted crop and first ratoon crop. The Kps01-12, LK92-11, KKU99-01 and KK3 had high sugar yield in the planted crop and first ratoon crop and the correlation coefficient between planted crop and ratoon crop was significant (r = 0.47^{**}) for sugar yield (Fig. 2b). The KK3, NSUT08-22-3-13 and LK92-11 had high CCS and the correlation coefficient between planted crop and ratoon crop was significant ($r = 0.86^{**}$) for CCS (Fig. 2c).

Contribution of yield components to cane yield: In the planted crop, K88-92 had high cane yield, stalk length, single stalk weight, millable cane and sugar yield, indicating that vield components, such as stalk length and single stalk weight contributed to the yields. The CSB06-2-21, however, had low stalk length, single stalk weight, millable cane and sugar yield. The results showed that cane yield was positively and significantly correlated with stalk length, single stalk weight, millable cane and sugar yield, but not correlated with stalk diameter, number of internodes/stalk or number of stalks/stool. The correlations between cane yield and other yield components in planted crop were reported in Fig. 3. Cane yield was positively and significantly correlated with stalk length (0.45**) (Fig. 3b), single stalk weight (0.35*) (Fig. 3e), millable cane (0.33*) (Fig. 3f) and sugar yield (0.64**) (Fig. 3h), but it was not significantly correlated with stalk diameter (Fig. 3a), stalk internodes (Fig. 3c), number of stalk stools (Fig. 3d) and CCS (Fig. 3g).

J. Agron.,	19 (1):	1-13,	2020
------------	---------	-------	------

Table 4: Cane	vield, sugar	vield and reduction	percentage of	the 39 sugarcar	ie aenotypes e	valuated in the	planted crop and	d ratoon crop
	, , <u>.</u> .							

	Cane yield (t ha ⁻¹)		Sugar yield (t)			
Genotypes	Planted crop	Ratoon crop	Reduction (%)	 Planted crop	Ratoon crop	Reduction (%)
CSB06-2-21	67.63 ^p	58.08 ^{j-r}	14.11	8.31 ^p	7.59 ^{e-l}	8.77
CSB 07-79	115.13 ^{bcd}	49.56 ^{qrs}	56.96	13.67 ^{b-f}	4.77 ^{mno}	65.08
CSB06-2-15	98.20 ^{h-l}	35.14s	64.22	9.72 ^{j-p}	3.30°	66.08
CSB06-4-162	96.75 ^{h-l}	64.33 ^{h-q}	33.51	13.64 ^{b-f}	9.05 ^{c-h}	33.66
CSB06-5-20	99.65 ^{f-l}	42.45 ^{rs}	57.40	12.95 ^{c-i}	5.69 ^{j-}	56.05
CSB07-219	107.88 ^{b-h}	86.25 ^{a-f}	20.05	12.23 ^{c-l}	9.26 ^{c-g}	24.31
K88-92	128.13ª	83.50 ^{a-g}	34.83	14.97 ^{abc}	9.99 ^{b-f}	33.31
KK3	111.27 ^{b-g}	76.50 ^{c-k}	31.25	16.37 ^{ab}	11.82 ^{abc}	27.81
KK06-501	97.29 ^{h-l}	84.44 ^{a-g}	13.21	11.89 ^{d-n}	9.62 ^{c-g}	19.08
KK07-037	113.08 ^{b-e}	87.73 ^{a-e}	22.42	12.17 ¹	7.20 ^{f-m}	40.85
KK07-050	107.00 ^{b-h}	70.22 ^{e-o}	34.37	11.98 ^{d-m}	6.94 ^{g-m}	42.10
KK07-478	93.67 ^{i-m}	51.64°-s	44.87	14.20 ^{b-e}	7.34 ^{f-m}	48.29
KK07-680	114.93 ^{bcd}	91.41 ^{abc}	20.47	11.49 ^{e-o}	8.71 ^{d-i}	24.15
KKU 99-01	107.04 ^{b-h}	96.72 ^{ab}	9.64	12.66 ^{c-j}	12.54 ^{ab}	0.97
KKU 99-02	96.17 ^{h-l}	76.65 ^{c-j}	20.30	10.43 ^{h-p}	8.84 ^{d-h}	15.23
KKU 99-03	117.32 ^{abc}	70.98 ^{e-n}	39.50	13.53 ^{b-g}	8.95 ^{d-h}	33.88
KKU 99-06	112.50 ^{b-f}	75.44 ^{c-l}	32.94	13.49 ^{b-g}	9.85 ^{b-f}	26.99
Kps01-12	113.03 ^{b-e}	100.28ª	11.28	13.16 ^{c-h}	13.57ª	-3.08
LK92-11	96.71 ^{h-l}	89.88 ^{a-d}	7.06	13.67 ^{b-f}	13.17ª	3.64
MP05-187	107.46 ^{b-h}	68.93 ^{f-p}	35.86	14.75 ^{a-d}	9.41 ^{c-g}	36.17
MPT02-458	119.17 ^{ab}	90.56 ^{abc}	24.01	13.61 ^{b-g}	11.33ª-d	16.71
MPT03-166	92.28 ^{j-n}	51.25 ^{p-s}	44.46	8.96 ^{nop}	5.35 ^{k-o}	40.28
MPT03-320	88.96 ^{k-o}	57.19 [⊩] r	35.72	8.18 ^p	4.89 ¹⁻⁰	40.26
NSUT08-22-3-13	80.63 ^{no}	83.41 ^{a-g}	-3.45	12.10 ^{c-l}	12.52ªb	-3.44
0229	91.35 ^{j-n}	56.11 ^{m-r}	38.58	10.64 ^{g-p}	6.36 ^{h-n}	40.23
RT2004-085	102.56 ^{d-j}	49.64 ^{qrs}	51.60	14.42 ^{b-e}	5.90 ^{i-o}	59.09
TPJ04-229	106.81 ^{b-h}	57.77 ^{k-r}	45.91	8.66°P	3.71 ^{no}	57.15
TBv27-0590	114.58 ^{b-e}	79.31 ^{b-i}	30.79	13.63 ^{b-f}	9.71 ^{c-g}	28.78
TBv27-1385	98.82 ^{g-l}	71.35 ^{d-n}	27.80	12.41 ^{c-k}	8.99 ^{d-h}	27.57
TBv28-0348	109.04 ^{b-h}	66.83 ^{g-q}	38.71	13.46 ^{b-g}	9.28 ^{c-g}	31.07
TBv28-1211	87.89 ¹⁻⁰	58.34 ^{j-r}	33.62	12.58 ^{-j}	8.16 ^{e-k}	35.18
TBv28-0941	106.28 ^{b-i}	71.75 ^{d-n}	32.49	10.07 ^{i-p}	6.36 ^{h-n}	36.83
TP06-419	78.25 ^{op}	63.01 ^{i-q}	19.48	9.41 ^{I-p}	7.69 ^{e-l}	18.23
TP 103-452	102.92 ^{d-j}	84.25 ^{a-g}	18.14	10 77 ^{f-p}	8.93 ^{d-h}	17.06
UT84-12	83.00 ^{mno}	66.83 ^{g-q}	19.48	9.06 ^{m-p}	8.47 ^{e-j}	6.49
UT07-317	118.75 ^{ab}	53.74 ^{n-s}	54.74	17.57ª	7.57 ^{e-m}	56.92
UT07-381	79.53 ^{nop}	82.35 ^{a-h}	-3.55	9.45 ^{k-p}	8.19 ^{e-k}	13 39
UT84-13	105.69 ^{c-i}	80.58 ^{b-i}	23.76	13.22 ^{c-h}	10.19 ^{b-e}	22.93
91-2-527	101.76 ^{e-k}	73.86 ^{c-m}	25.7 5	12 37 ^{c-l}	8.47 ^{e-j}	31.57
Mean	101.77	70 72	27.12	12.37	8.45	51.57
F-test	**	**		**	**	

** $p \le 0.01$, means followed by different letters in the same column are significantly different at $p \le 0.01$ probability level by least significant difference (LSD), -: Increase in yield

In first ration crop, cane yield was positively and significantly correlated with stalk length ($r = 0.36^*$) (Fig. 4b), single stalk weight ($r = 0.40^*$) (Fig. 4e) and millable cane ($r = 0.55^{**}$) (Fig. 4f), whereas, the correlations were not significant for cane yield with stalk diameter (Fig. 4a), number of internodes/stalk (Fig. 4c), number of stalks/stool (Fig. 4d), CCS (Fig. 4g) and sugar yield (Fig. 4h). The Kps01-12 had high cane yield, stalk length, single stalk weight, millable cane and sugar yield, whereas, CSB06-2-15 had low cane yield, stalk length, single stalk weight, millable cane and sugar yield. The strong correlation coefficients between cane yield and yield

components indicated that stalk length, single stalk weight, millable cane and sugar yield were the main components contributing to cane yield in the first ratoon crop.

Contribution of physiological traits to cane yield: In response to drought, the 39 sugarcane genotypes were evaluated for Fv/Fm, RWC and SCMR in the drought stress period (90 DAP) and recovery period (180 DAP) in the planted and first ratoon crops. The correlation coefficients were investigated for physiological traits in the drought stress (90 DAP) and recovery (180 DAP) periods.

J. Agron., 19 (1): 1-13, 2020



Fig. 2(a-c): Relationship between the plant crop and first ratoon crop on (a) cane yield, sugar yield and (c) CCS among 39 sugarcane genotypes

^{ns}Non-significant, **p<u><</u>0.01

Positive and significant correlation coefficients between the planted crop and first ratoon crop were observed for Fv/Fm ($r = 0.34^*$) at the drought stress period (90 DAP) (Fig. 5a) and SCMR at the recovery period (180 DAP) ($r = 0.36^*$) (Fig. 5f), but the correlations were not significant for Fv/Fm at the recovery period (180 DAP) (Fig. 5b), RWC at the drought stress period (90 DAP) (Fig. 5c), RWC at recovery period (180 DAP) (Fig.5d) and SCMR at the drought stress period (90 DAP) (Fig. 5e) at the recovery period (180 DAP). At the drought stress period (90 DAP), CSB07-219 had high Fv/Fm, whereas, KK07-478 had low Fv/Fm. At the recovery period (180 DAP), TBy28-0941 had high SCMR; however, KK3 had low SCMR.

The correlation coefficients between the drought stress period (90 DAP) and recovery period (180 DAP) were

investigated for physiological traits in the planted and first ratoon crops (Fig. 6). The Fv/Fm at 90 DAP and at 180 DAP were positively and significantly correlated ($r = 0.41^*$) in the planted crop (Fig. 6a) and demonstrated a similar relationship in the first ratoon crop ($r = 0.78^{**}$) (Fig. 6b). The correlation of RWC at the drought stress period (90 DAP) and recovery period (180 DAP) was also positively and significant ($r = 0.51^*$) in the planted crop (Fig. 6c), but it was not significant in the first ratoon crops (Fig. 6d). The SCMR at the drought stress period (90 DAP) and recovery period (180 DAP) were positively and significantly correlated in both the planted crop ($r = 0.38^*$) (Fig. 6e) and first ratoon crop ($r = 0.68^{**}$) (Fig. 6f). The KK3 had lower RWC and SCMR at 90 DAP and lower RWC at 180 DAP in the planted and first ratoon crops.



Fig. 3(a-h): Relationships between (a) Cane yield and stalk diameter, (b) Stalk length, (c) Number of internodes/stalk, (d) Number of stalks/stool, (e) Single stalk weight, (f) Millable cane, (g) CCS and (h) Sugar yield of the planted crop among the 39 sugarcane genotypes [™]Non-significant, *p≤0.05, **p≤0.01



Fig. 4(a-h): Relationships between (a) Cane yield and stalk diameter, (b) Stalk length, (c) Number of internodes/stalk, (d) Number of stalks/stool, (e) Single stalk weight, (f) Millable cane, (g) CCS and (h) Sugar yield of the first ration crop among the 39 sugarcane genotypes "Non-significant, *p<0.05



Fig. 5(a-f): Relationships between physiological traits including (a) Fv/Fm at 3 months, (b) 6 months, (c) RWC at 3 months, (d) 6 months, (e) SCMR at 3 months and (f) 6 months of the planted crop and first ration crop among the 39 sugarcane genotypes "Non-significant, *p<0.05

In the planted crop, at both the drought stress period and recovery period, MPT02-258 had high Fv/Fm, MPT03-166 had low Fv/Fm, TBy27-1385 had high RWC, KK3 had low RWC and SCMR and TBy28-0941 had high SCMR. In first ratoon crop, CSB07-79 had high Fv/Fm, whereas, NSUT08-22-3-13 had low Fv/Fm and TBy28-1211 had high SCMR, but UT84-12 had low SCMR.



Fig. 6(a-f): Relationships between physiological traits including (a) Fv/Fm at 3 and 6 months of the planted crop, (b) First ratoon crop, (c) RWC at 3 and 6 months of the planted crop, (d) First ratoon crop and (e) SCMR at 3 and 6 months of the planted crop and (f) First ratoon crop among the 39 sugarcane genotypes "Non-significant, *p<0.05, **p<0.01

DISCUSSION

In this study, the G×C interactions were significant for stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield, millable cane and sugar yield. However, the interaction was not significant for CCS. The results in this study were similar to those in the previous study of Klomsa-Ard *et al.*⁸

which showed that variations due to crop-classes (C) were significant for sugar yield and cane yield, but not for CCS.

Crop variations shared the largest proportion of total variations for stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield, millable cane and sugar yield, yet did not have a significant effect on stalk diameter or CCS. Variations in genotype also had significant effects on stalk diameter, stalk length, number of internodes/stalk, number of stalks/stool, single stalk weight, cane yield, millable cane, CCS and sugar yield. The considerable genotypic variations to all traits in this study indicated that the tested sugarcane genotypes differed in their genetic potential for yield and yield components.

The wide coverage of the tested environments, as reflected by the greatest share of variation due to each location, also suggested that the $G \times C$ interactions obtained for all these traits may represent the patterns and magnitude of the $G \times C$ interactions encountered in different production environments in Thailand. Thus, the present study provided such conditions for a valid evaluation of the performance and stability of the sugarcane genotypes.

Within the drought stress period and recovery period, the G×C interactions were significant for SCMR and RWC in the planted crop and first ratoon crop among the 39 sugarcane genotypes, yet were not significant for Fv/Fm. Therefore, the differences in the associations between the physiological parameters and yield in the planted and ratoon crops will ultimately decide the crop's ratooning potential. Identification of the physiological traits (i.e., SCMR and RWC, that create greater ratooning ability) therefore, helps the breeder to screen a large number of clones for better ratooning types. Moreover, different sugarcane genotypes have varied physiological responses. Variations, such as gradual or rapid duration; mild, moderate or severe drought intensity and stress levels within the development stage, such as tillering, stalk elongation and maturity phases; had different responses for both morphology and physiology^{1,9-11}. The responses of the physiological traits and the partitioning and assimilation during the stress and recovery periods may importantly control the performance of the biomass within these conditions¹².

The associations between the planted crop and first ratoon crop were intermediate and positive for sugar yield and high and positive for CCS. However, the planted crop was not associated with the first ratoon crop for cane yield. Klomsa-Ard *et al.*⁸ reported that the correlations between cane yield and sugar yield were high in both planted crops and ratoon crops and determined that KK3 was the most superior genotype for sugar yield, having consistent performance and stability of sugar yield across two crop-classes and also ranking high in CCS. These results showed that, in both the planted crop and first ratoon crop, K88-92 was the most superior clone for cane yield, whereas KK3 was the most superior clone for sugar yield and CCS. Based on the associations between crops for these parameters, CCS was the most important parameter in determining the superiority of sugarcane genotypes, followed by sugar yield. Sugar yield and CCS could therefore, be used as indicators for the selection for high cane yield in both planted crops and first ratoon crops.

Several components, such as tiller, millable cane, stalk length and stalk diameter contribute to cane yield. Although cane yield and sugar yield have been reported to be correlated with stalk number, stalk weight, stalk length and stalk diameter,^{2,3,8} only stalk length, single stalk weight and millable cane were found to have significant correlations with cane yield in both planted and first ratoon crops. This was confirmed in our study by the positive and significant correlations of cane yield with stalk length, single stalk weight and millable cane.

Although the individual genotypes might have achieved cane yield superiority through different yield component traits, K88-92 proved to be superior for cane yield due to its high stalk length, single stalk weight and millable cane in the planted crop. The Kps01-12 was found to be superior for cane yield based on high stalk length, single stalk weight and millable cane in the first ratoon crop. The results suggested that stalk length, single stalk weight and millable cane could be used as indicators for high and stable cane yield in both planted crops and first ratoon crops. Thus, stalk length, single stalk weight and millable cane should be targeted for selection of sugarcane varieties for high and stable cane yield in planted and first ratoon crops.

The responses of the physiological traits of the 39 sugarcane cultivars differed at the drought stress and recovery periods in both the planted and first ratoon crops, in which the relationships were positive and significant for Fv/Fm at the drought stress period (90 DAP) and for SCMR at the recovery period (180 DAP).

In this study, KK3 reduced RWC and SCMR at the drought stress periods in the planted and first ratoon crops. Jangpromma *et al.*¹³ previously stated that early season drought significantly reduces SCMR in sugarcane. The SCMR is an indicator of the photo-synthetically active light-transmittance characteristics of a leaf, which is dependent on the unit number of chlorophyll/unit leaf area (chlorophyll density)^{14,15} and is closely related to chlorophyll content¹⁶. Any differences were accountable to the varied plant ages, plant genotypes and drought duration and severity.

CONCLUSION

In this study, Kps01-12, KK3 and K88-92 were identified as the most superior clones for cane yields and sugar yields in planted crop and first ratoon crop. Stalk length, single stalk weight and millable cane were associated with cane yield of in planted crop and first ratoon crop and may be used as surrogate traits for improving yield and ratooning ability. The association between the agronomic and physiological parameters with cane yield will determine the ratooning potential of planted and first ratoon crops.

SIGNIFICANCE STATEMENT

In this study, Kps01-12, KK3 and K88-92 were identified as the most promising clones for cane yield and sugar yield. These genotypes will be further evaluated at higher levels. The study also found the associations of cane yield and yield components such as stalk length, single stalk weight and millable cane in planted crop and first ratoon crop. The traits may be useful for sugarcane breeders as indirect selection tools for cane yield and sugar yield.

ACKNOWLEDGMENTS

The research project was funded by the Northeast Thailand Cane and Sugar Research Center, Faculty of Agriculture, Khon Kaen University and the Thailand Research Fund (TRF). Grateful acknowledgment is also extended to the manuscript preparation project under Khon Kaen University's Faculty of Agriculture and the Thailand Research Fund (TRF).

REFERENCES

- Ferreira, T.H., M.S. Tsunada, D. Bassi, P. Araujo and L. Mattiello *et al.*, 2017. Sugarcane water stress tolerance mechanisms and its implications on developing biotechnology solutions. Front. Plant Sci., Vol. 8. 10.3389/fpls.2017.01077.
- Panhwar, R.N., H.K. Keerio, M.A. Khan, M.A. Rajpute and G.S. Unar *et al.* 2003. Realtionship between yield and yield contributing traits in sugarcane (*Saccharum officinarum* L.). J. Applied Sci., 3: 97-99.
- Chumphu, S., N. Jongrungklang and P. Songsri, 2019. Association of physiological responses and root distribution patterns of ratooning ability and yield of the second ratoon cane in sugarcane elite clones. Agronomy, Vol. 9, No. 4. 10.3390/agronomy9040200.

- Gomathi, R., P.N.G. Rao, P. Rakkiyappan, B.P. Sundara and S. Shiyamala, 2013. Physiological studies on ratoonability of sugarcane varieties under tropical Indian condition. Am. J. Plant Sci., 4: 274-281.
- 5. Matin, M.A., J.H. Brown and H. Ferguson, 1989. Leaf water potential, relative water content and diffusive resistance as screening techniques for drought resistance in Barley. Agron. J., 81: 100-105.
- 6. Ehsanullah, K.J., M. Jamil and A. Ghafar, 2011. Optimizing the row spacing and seeding density to improve yield and quality of sugarcane. Crop Environ., 2: 1-5.
- Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley Sons, New York, USA., ISBN: 978-0-471-87092-0, Pages: 704.
- 8. Klomsa-Ard, P., P. Jaisil and A. Patanothai, 2013. Performance and stability for yield and component traits of elite sugarcane genotypes across production environments in Thailand. Sugar Tech, 15: 354-364.
- 9. Bartels, D. and R. Sunkar, 2005. Drought and salt tolerance in plants. Crit. Rev. Plant Sci., 24: 23-58.
- 10. Inman-Bamber, N.G., P. Lakshmanan and S. Park, 2012. Sugarcane for water-limited environments: Theoretical assessment of suitable traits. Field Crops Res., 134: 95-104.
- 11. Silva, M.D.A., J.L. Jifon, J.A.G. de Silva and V. Sharma, 2007. Use of physiological parameters as fast tools to screen for drought tolerance in sugarcane. Braz. J. Plant. Physiol., 9: 193-201.
- Khonghintaisong, J., P. Songsri, B. Toomsan and N. Jongrungklang, 2018. Rooting and physiological trait responses to early drought stress of sugarcane cultivars. Sugar Tech, 20: 396-406.
- Jangpromma, N., P. Songsri, S. Thammasirirak and P. Jaisil, 2010. Rapid assessment of chlorophyll content in sugarcane using a SPAD chlorophyll meter across different water stress conditions. Asian J. Plant Sci., 9: 368-374.
- Arunyanark, A., S. Jogloy, C. Akkasaeng, N. Vorasoot and T. Kesmala *et al.*, 2008. Chlorophyll stability is an indicator of drought tolerance in peanut. J. Agron. Crop Sci., 194: 113-125.
- 15. Richardson, A.D., S.P. Duigan and G.P. Berlyn, 2002. An evaluation of noninvasive methods to estimate foliar chlorophyll content. New Phytol., 153: 185-194.
- Bunphan, D., P. Jaisil, J. Sanitchon, J.E. Knoll and W.F. Anderson, 2018. Association of chlorophyll content and spad chlorophyll in diverse sweet sorghum cultivars under different environments. Khon Kaen Agr. J., 46: 155-162.