RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
53 (2) 172-186, 2021

RATOONING ABILITY OF DIVERSE SUGARCANE CULTIVARS UNDER NATURAL SHORT- AND LONG-TERM WATERLOGGED FIELD CONDITIONS

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SUMMARY

The productivity of sugarcane crops, especially that of ratoon cane, is seriously limited by flooding. The objective of this study was to evaluate the ratooning ability, yield, yield components, and sugar yield of sugarcanes cultivated under natural field conditions with short- and long-term waterlogging. The first ratoon field experiments were conducted separately under short- and long-term waterlogging conditions. Plant cane in these fields experienced corresponding flooding. Each trial was arranged in a randomized complete block design with four replications, and 12 diverse sugarcane cultivars were assigned as treatments. Germination percentage was recorded 1 month after the harvest. At the final harvest of ratoon cane, millable canes, stalk weight, stalk length, stalk diameter, sugar yield, and yield were determined, and ratooning ability was then calculated. Long-term flooding but not short-term waterlogging could disturb the germination percentage of ratoon cane. Good germination with appropriate yield components in ratoon contributed to high ratooning ability and yield potential under natural waterlogging. A positive correlation between millable cane and cane yield existed, and this trait could be used as the selection criterion for high-yielding cultivars under waterlogging conditions. Stalk length could also be used as a surrogate trait under short-term waterlogging conditions for ratoon cane.

Keywords: Flooding, ratoon crop, yield components, yield potential, germination, millable cane

Key findings: Good germination with appropriate yield components in ratoon contributes to high ratooning ability and yield potential under natural waterlogging conditions. Millable cane can be used as a selection criterion for high-yielding ratoon cane cultivars under waterlogging conditions.

Manuscript received: November 17, 2020; Decision on manuscript: January 28, 2021;
Accepted: February 23, 2021.

Communicating Editor: Dr. Thilak Attanayaka

INTRODUCTION

Increasing greenhouse gas emissions and global warming significantly affect crop production by inducing variations in temperature, carbon dioxide, precipitation, and wind (FAO, 2019). At present, variations in rainfall seriously affect the growth and yield of sugarcane because some production areas face flooding conditions, which are considered as a severe problem. Many factors affect sugarcane production under normal conditions (Zulu *et al*., 2019) and yield under waterlogging conditions. These factors include genotype, the developmental stage of sugarcane, environment, and the extent and duration of waterlogging (Gomathi *et al*., 2015).

Flooding has seriously reduced the yield and yield components of sugarcane in a plant cane trial (Palachai *et al*., 2019). It has also affected morphological traits by, for example, decreasing leaf dry weight by approximately 43% (Gomathi and Chandran, 2010), decreasing stalk dry weight and stalk length (Gomathi and Chandran, 2009; Gomathi *et al*., 2015; Hidaka and Karim, 2007), and decreasing millable cane by up to 26% in plant cane and 21% in ratoon cane (Deren and Raid, 2003). In addition, adventitious roots, aerenchyma, and the central air space of the stalk increase in sugarcane in response to waterlogging environment (Gilbert *et al*., 2007). The reductions in sugarcane yield and sucrose under flooding during 10–20 days before harvest relative to those under nonflooding conditions are due to a decrement in stalk number (Glaz *et al*., 2005). Waterlogging duration is a factor that is connected to the quality of sugarcane stalk (Paul, 2003). Under natural field test conditions, (Palachai *et al*., 2019) long flooding periods (duration of 4.5 months) in lowland areas result in lower cane yield and single stalk weight than short flooding periods (duration of 3 months) in upland fields.

The yield of ratoon cane is reduced by up to 10%–30% when compared with that of the first crop (Yadav, 1991). The yield potential of ratoon cane depends on soil fertility and soil preparation. Appropriate tillage can maintain the high number of millable cane at harvest and also increases ratooning ability (Bhale, 1994). The ability of ratoon cane to maintain yield with a loss of only 25%–30% of the plant cane can help farmers reduce the cost for renewed planting (Yadav, 1991). Sugarcane ratooning can remove the cost of seed cane, soil preparation, and labor incurred in the planting process, thus leading to increased profit (Ellis and Merry, 2004). Under rainfed conditions without waterlogging, different sugarcane genotypes differ significantly in ratooning ability in terms of germination percentage and cane yield (Chumphu *et al*., 2019). The yield of ratoon cane under rainfed conditions is contributed by root length density, stomatal conductance, and photosynthesis (Chumphu *et al*., 2019).

Although many previous reports have revealed the effect of flooding on sugarcane yield and yield components, ratooning ability in frequently flooded areas remains poorly understood. Information on the ratooning ability of diverse sugarcane cultivars under natural waterlogging conditions with regard to the aspects of yield and yield components does not exist. Therefore, the objective of this study was to evaluate the ratooning ability, cane yield, millable cane, stalk weight, stalk length, and sugar yield of 12 diverse sugarcane varieties cultivated in a natural short waterlogging duration (upland) and a long waterlogging duration (lowland) to provide information on the selection of sugarcane cultivars resistant to waterlogging and to identify the adaptation potential of various yield components to waterlogging conditions.

MATERIALS AND METHODS

Experimental detail

The experimental details of the plant cane trial were reported in Palachai *et al*. (2019), with waterlogging conditions during the elongation stage in upland and lowland fields. Palachai *et al*. (2019) stated that the flooding duration was approximately 3 months in the upland trial and approximately 4.5 months in the lowland field. The current experiment was carried out in continuation with the plant cane trial to evaluate the ratooning ability of sugarcane under the effect of natural short- and long-term waterlogging conditions.

The first ratoon crop was assessed under natural field experimental conditions from December 2016 to January 2018. In upland areas, the experiment was located in the Borabue District, Maha Sara Kham Province, Thailand (16°07'21.0"N, 103°09'12.6"E) in sandy soil and often faced a natural short period of waterlogging. The field capacity, EC, and organic matter content of the soil were 22%, 0.03 dS/mm, and 0.52%, respectively. The lowland field experiment, in which a long period of waterlogging was implemented, was conducted at Mueang Maha Sarakham District, Maha Sarakham Province, Thailand (16°11'33.7"N, 103°12'43.8"E). The soil at the lowland experimental site had a clayey texture, 43% FC, 0.28 dS/m EC, and 2.28% organic matter. Each field experiment was arranged in a randomized complete block (RCB) design with four replications. The plot size was 30 m^2 and consisted of five rows with a row length of 6 m. The between-row spacing was 120 cm, and the between-plant spacing was 50 cm.

Sugarcane material

Twelve diverse sugarcane lines included in the Thailand sugarcane breeding program were used. Seven commercial sugarcane cultivars, namely, KK3, LK92-11, K88-92 K93-219, UT12, UT13, and Kps01-12, were also selected for this study. KK3, LK92-11, and K88-92 were identified by Khonghintaisong *et al*. (2018) as drought-tolerant cultivars with well-adapted rooting and physiological traits under water deficit conditions. Cultivar K93-219 was identified as a waterlogging-resistant cultivar (Office of the Cane and Sugar Board, Thailand, 2016). The UT12 cultivar used in this study has been evaluated and selected under irrigated conditions. Given that UT13 is an improved cultivar from the wild-type genotype (Office of the Cane and Sugar Board, Thailand, 2016), it might display good adaptation to environmental stress. Kps01-12 was identified as having wide adaptability, which is reflected by its high yield productivity in multiple locations. Five elite sugarcane lines, including KKU99-02, KKU99-03, KK06-501, TBy28-0941, and MPT02-458, were also used for this experiment; these sugarcane lines were selected in different evaluation stations, i.e., KKU99-02, KKU99-03, KK06-501, and MPT02-458 were evaluated in the north-eastern Thailand region (drought and sandy soil environment), and TBy28-0941 was evaluated in the central region of Thailand (wet and clay soil environment) (Palachai *et al*., 2019).

Crop management

Prior to cultivation, the fields were prepared through rough ploughing and then ploughing in regular furrows. Three node sets of each genotype were manually planted. N:P:K fertilizer was applied as basal dressing at the rate of 46.9, 46.9 and 46.9 kg ha^{-1}. It was also applied at the rate of 46.9, 46.9 and 46.9 kg ha^{-1} as top dressing with two equal split applications at the tillering stage (4 months after planting) (Palachai *et al*., 2019). Fertilizers were applied after plant cane harvesting with the top dressing of N:P:K at the rate of 46.9, 46.9 and 46.9 kg ha^{-1}. Additional N:P:K fertilizers were applied at the rates of 46.9, 46.9 and 46.9 kg ha^{-1} at the tillering stages (4 months after harvesting) for ratoon cane. Weed, pest, and disease control measures were performed as necessary to keep the plants free from pests, diseases, and weeds throughout the experimental period. Both experiments were conducted under rain-fed conditions.

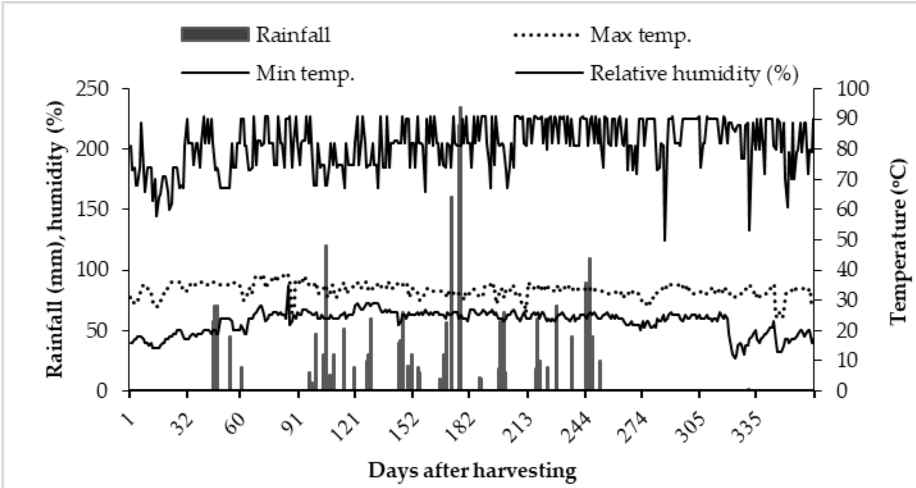

Figure 1. Rainfall (mm), maximum temperature (°C), minimum temperature (°C), and humidity (%) during the experimental period (1–365) days after harvest under short-term waterlogging conditions (SC) and long-term waterlogging conditions (LC).

Data collection

1. Determination of weather conditions

Rainfall, relative humidity, maximum and minimum temperatures, and solar radiation were recorded daily from the plant cane harvest until the ratoon harvest by a weather station located 10 km away from the experimental fields. Waterlogging was recorded every 15 days after flooding events.

The minimum daily air temperatures and the maximum temperatures ranged from 11 °C to 35 °C and 24 °C to 39 °C, respectively. Humidity ranged from 50% to 91% during the growing season of ratoon cane. Rainfall accumulation reached 2380.81 mm throughout the experimental period, and rainfall during waterlogging (45–251 days after planting) ranged from 13 mm to 235 mm (Figure 1). As a result of rainfall during these experiments, the waterlogging period in the upland area lasted for approximately 2.5 months (233–303 days after harvesting) and that in the lowland area lasted for approximately 5.5 months (151–315 days after harvesting). Natural waterlogging in lowlands and uplands in this experiment also confirmed the presence of different conditions between the two ratoon fields.

2. Determination of germination percentage, yield components, yield, sugar yield, and ratooning ability of ratoon cane

One month after the harvesting of canes, the germinated number of hills of ratoon cane in each plot was counted. The germination percentage of ratoon was then calculated as the number germinated hills of ratoon compared with the number of hills of plant cane. The germination percentage was calculated as described by (Chumphu *et al*., 2019) by using the following equation:

$$\text{Germination percentage} = \frac{\text{No. of stool germination of the first ratoon crop}}{\text{Number of stool harvested of the plant cane}} \times 100 \quad (1)$$

All canes in each plot area were harvested at final harvest. All stalk numbers were counted for the measurement of millable canes and then cut at the ground level, and stalk fresh weight per plot was recorded. A subsample of six stalks per plot was selected randomly to determine agronomic characteristics, i.e., stalk length and stalk diameter. The lengths of six representative stalks were measured by using a measuring tape. A digital Vernier caliper was used to measure the diameter of the same six stalks. The reading region was defined as one-third of the stalk length (from the base to the top). Juice was extracted from the six-stalk subsample in each plot for measurement of the commercial cane sugar (CCS). The juice was subjected to Brix and pol determination by using a refractometer (Model ATR-SW, Schmidt and Haensch, Berlin, Germany) and polarimeter (Polartronic NIR W2, Schmidt and Haensch, Berlin, Germany), respectively. Fiber content (%) was calculated from the fresh and dry weights of the remaining stalk material. CCS was calculated as described by (Klomsa-ard *et al*., 2013) by using the following equation:

$$CCS = 3/2P[1-(F+5)/100)-½ B (1-(F+3)/100] \quad (2)$$

where P = pol at 20 °C, B = Brix at 20 °C, and F = fiber content.

The sugar yield per plot was calculated on the basis of cane yield and CCS value as follows:

$$\text{Sugar yield} = \text{Cane yield} \times CCS / 100 \quad (3)$$

Ratooning ability was calculated on the basis of cane yield values between plant cane and ratoon. Ratooning ability (RA) was calculated as described by Mehareb *et al*., 2016, by using the following equation:

$$RA = (R/PC) \times 100 \quad (4)$$

where RA is ratooning ability, PC is the yield of plant cane ($t\ h^{-1}$) and R is the yield of ratoon cane ($t\ h^{-1}$).

The mean yield between plant and ratoon cane was calculated follows:

$$\text{Mean yield } (\bar{x}) = (PC + R)/2 \quad (5)$$

where $\bar{x}$ is the mean yield of the plant and ratoon cane, PC is the yield of planted cane ($t\ h^{-1}$), and R is the yield of ratoon cane ($t\ h^{-1}$)

Statistical analysis

The statistical analysis and combined analysis of variance for the trials over two locations were conducted by using Statistix 8 software program. The data were subjected to analysis of variance in accordance with a RCB design. The comparison among varieties for germination percentage, sugar yield, yield, and yield components was performed on the basis of the least significant difference (LSD) test (Gomez and Gomez 1984). Simple correlation analysis was conducted to determine the relationship between cane yield and sugar yield under the short-term waterlogging condition (SC) and cane yield under the long-term waterlogging condition (LC) and between agronomic traits and cane yield.

RESULTS

Combined analysis of variance for agronomic traits, yield components, yield, sugar yield, and CCS

The combined analysis of variance showed significant differences between environments (E) for single-stalk weight at $P \leq 0.05$, millable cane, cane yield, and sugar yield ($P \leq 0.01$) but not for stalk length, stalk diameter and CCS (Table 1). The differences in genotypes (G) were significant for almost all traits ($P \leq 0.01$) except for millable cane, which was significantly different at $P \leq 0.05$. G × E interactions were not significant for stalk length, single stalk weight, millable cane, cane yield, sugar yield and CCS, whereas a G × E interaction existed for stalk diameter ($P \leq 0.05$) (Table 1).

Table 1. Mean squares from the combined analysis of variance of agronomic traits, yield components, yield, sugar yield, and CCS of 12 sugarcane genotypes at harvest grown for two durations of waterlogging in ratoon cane.

Source of Variation	d.f.	Stalk length	Single stalk weight	Stalk diameter	Millable cane	Cane yield	Sugar yield	CCS
Environments (E)	1	22860^{ns}	1.24*	0.09^{ns}	1.39×10^{10}**	8289.8**	165.0**	0.5^{ns}
Replications (E)	2	5745	0.00	0.10	5.04×10^{7}	0.3	0.1	0.2
Genotypes (G)	11	2906**	0.40**	0.17**	2.72×10^{8}*	1047.6**	22.5**	2.1**
G × E	11	554^{ns}	0.11^{ns}	0.04*	2.11×10^{8ns}	262.5^{ns}	5.6^{ns}	1.1^{ns}
Pool error	22	412	0.10	0.00	1.10×10^{6}	217.4	4.3	0.6

ns, *, ** : Nonsignificant, significant, and highly significant at the P ≤ 0.05 and P ≤ 0.01 probability level, respectively. CCS: Commercial cane sugar.

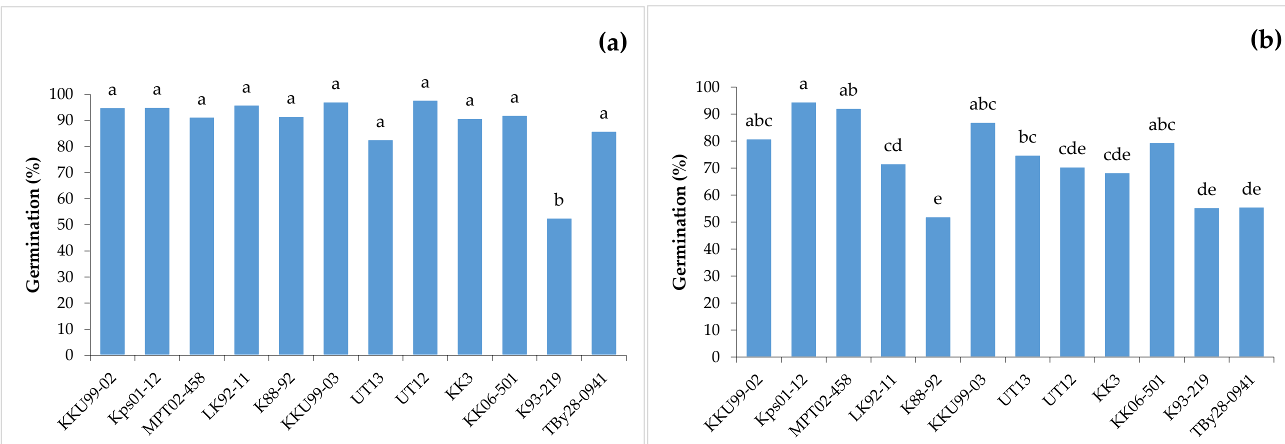

Figure 2. Germination percentage (%) in 12 varieties under SC and LC (b) in ratoon fields. *Means of columns with different letters are significantly different (P ≤ 0.05).*

Germination percentage under different waterlogging conditions

This ratoon experiment was carried out in continuation with the plant cane trial wherein the flooding duration was approximately 3 months in the short-term waterlogging trial and approximately 4.5 months in the long-term waterlogging trial. The combined analysis of variance showed significant differences between E and among G for germination percentage at $P \leq 0.01$, and a G × E interaction existed for this trait ($P \leq= 0.01$) (data not shown). Ratoon cane that experienced a short-term waterlogging period maintained a higher germination percentage than the long-term waterlogged ratoon cane (Figure 2). Under SC, the cultivar K93-219 showed a lower germination percentage than the other cultivars (Figure 2a). Under LC, only four genotypes that revealed a germination percentage greater than 80%, namely, Kps01-12, MPT02-458, KKU99-03, and KKU99-02 (Figure 2b). K88-92, K93-219, and TBy28-0941 presented a lower rate of 60% germination under LC. Apparently, long-term waterlogging in plant cane can disturb ratoon cane germination. Even though K93-219 is a waterlogging-resistant cultivar, it might not be an appropriate cultivar with respect to ratoon germination.

Ratooning ability under waterlogged conditions for cane yield and sugar yield

For ratooning ability in terms of cane yield, combined analysis of variance showed highly significant differences between environments, among genotypes, and G × E interaction (data not shown). KKU99-02, Kps01-12, and LK92-11 cultivars showed high ratooning ability under SC. However, in terms of yield potential ($\bar{x}$), KKU99-02 and Kps01-12 were identified as the two top genotypes that provided good performance in terms of mean yield (plant and ratoon canes) (Figure 3). Under LC, Kps01-12, KKU99-02 and MP02-458 were identified as the cultivars with high ratooning ability and yield potential (73.6–105.4 and 66.6–75.2 t ha^{-1}, respectively). Although UT13 provided good performance in terms of yield productivity under SC, this genotype showed a great reduction in ratoon yield. By contrast, the best ratooning ability value was found in cultivar KK06-501. However, this cultivar had a very poor yield for planted and ratoon canes (Figure 3). Hence, KKU99-02 and Kps01-12 were identified as appropriate sugarcane cultivars for areas under short- and long-term waterlogging.

The sugar yields of ratoon cane showed a similar trend with cane yields under both conditions. KKU99-02 and Kps01-12 showed good sugar yield and ratooning ability and other potential aspects under both waterlogging conditions. KKU99-02, LK92-11, and MPT02-458 showed good sugar yield and ratooning ability under SC. KK06-501, UT12, and Kps01-12 demonstrated high ratooning ability under LC (Figure 4). KKU99-02 and Kps01-12 provided higher mean sugar yields of planted and ratoon cane under SC (18.3 and 17.1 t CCS ha^{-1}, respectively) and LC (9.4 and 10.6 t CCS ha^{-1}, respectively) than other varieties (Figure 4). Moreover, plants grown under SC showed a higher sugar yield than those cultivated under LC. The lowest CCS cultivars were K88-92, KKU99-03 and UT12, whereas the top two CCS cultivars were KKU99-02 and LK92-11. CCS did not differ among sugarcane cultivars under LC (data not shown).

In general, the mean yield of the 12 genotypes explored in the ratoon trial decreased when compared with that of the plant crop. Ratoon cane revealed a higher mean yield under SC than under LC. In addition, a positive correlation (r = 0.63*) (Figure 5a) existed between the cane yields under SC and LC. This trend was similar for sugar yields (r = 0.65*) (Figure 5b). The top three cultivars of ratoon with the highest cane productivity under SC were KKU99-02, Kps01-12, and MPT02-458. Under SC, the three cultivars with the highest cane yield in ratoon were Kps01-12, UT12, and KKU99-02. Thus, KKU99-02 and Kps01-12 were the appropriate genotypes for both natural flooding conditions. In terms of sugar yield, KKU99-02, Kps01-12, and MP02-458 were suitable cultivars for both flooded fields.

Yield components of ratoon cane under waterlogged conditions

Under both conditions, the surrogate traits of sugarcane yield, such as millable cane, single stalk weight, stalk length, and stalk diameter, differed significantly among cultivars (Table 2). For ratoon, mean millable cane under LC was lower than that under SC. By contrast, single stalk weight had higher mean value under LC than under SC (Table 2).

The correlations between yield and agronomic traits showed that millable cane was the trait that contributed to cane yield under SC and LC, whereas the correlation between cane yield and stalk length only existed under SC (Figure 6). However, the cultivars that were identified with high cane yield in the ratoon experiment, namely, KKU99-02 and Kps01-12, showed high values of single stalk weight, stalk length, and stalk diameter in both flooding fields (Figure 6). In addition, Kps01-12 cultivars showed high millable cane under both conditions (Figure 6). The yield of ratoon cane likely had a direct relationship with the number

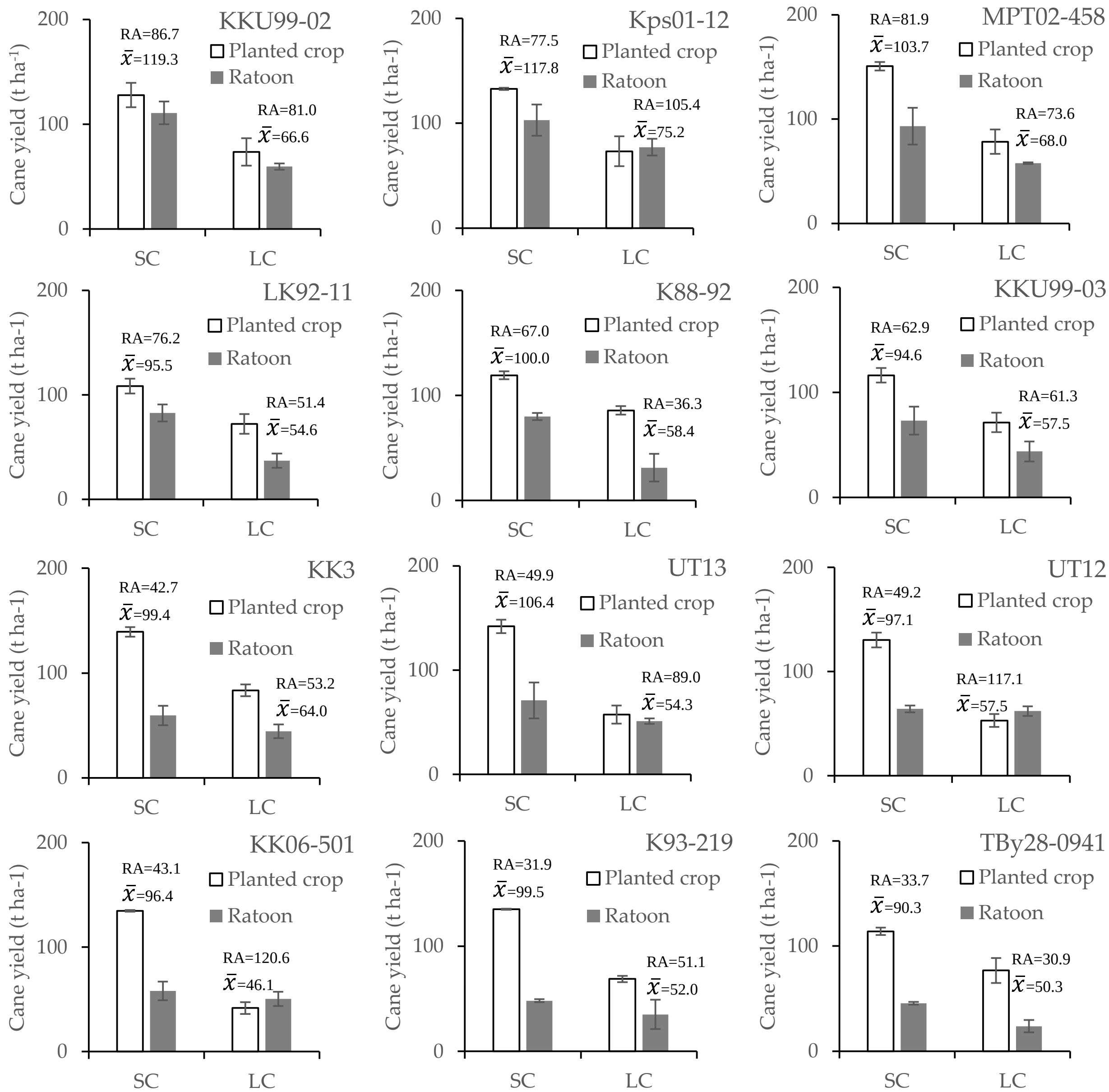

Figure 3. Cane yield of 12 varieties under SC and LC in planted and ratoon canes.
Vertical bars show the standard error of the differences between means. RA is ratooning ability in terms of cane yield.

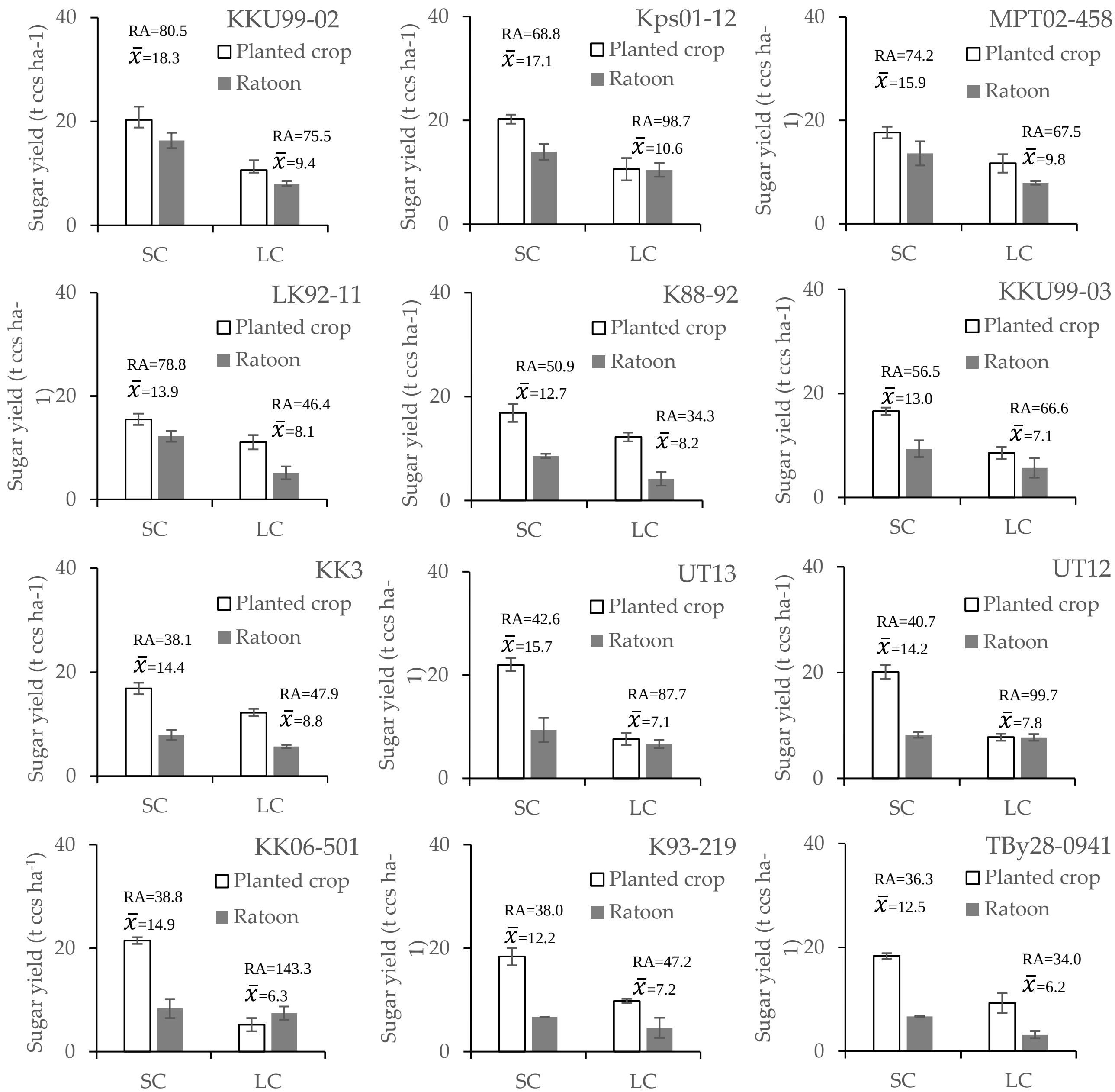

Figure 4. Sugar yield of 12 varieties under SC and LC in planted and ratoon canes.
Vertical bars show the standard error of the differences between means. RA is ratooning ability in terms of sugar yield.

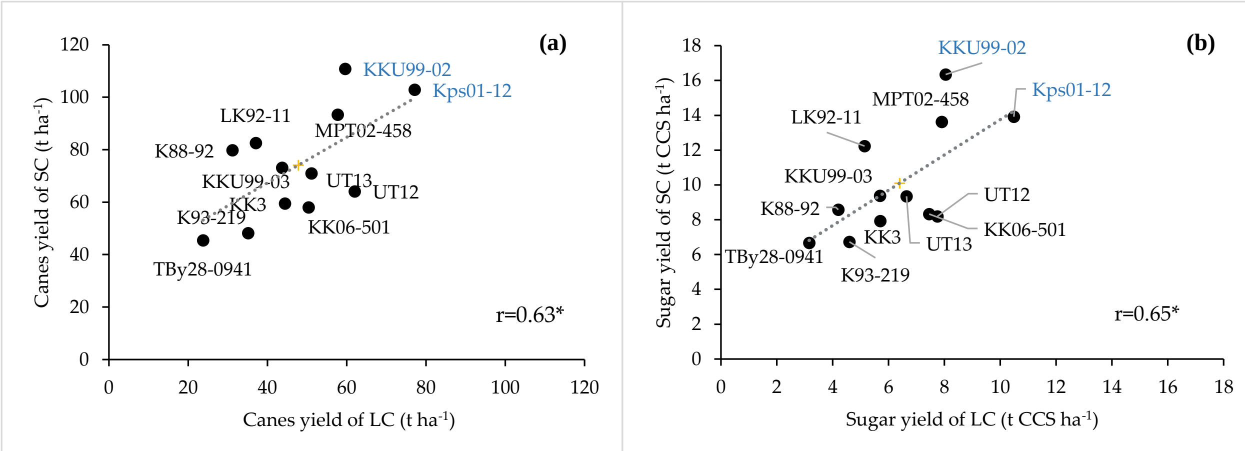

Figure 5. Correlations between cane yield under SC and LC (a) and sugar yield under SC and LC (b) of 12 sugarcane genotypes evaluated in ratoon trials.
**= significant at the P ≤ 0.05 probability level.*

Table 2. Millable cane, single stalk weight, stalk length and stalk diameter of 12 genotypes SC and LC in a ratoon field.

Genotypes	Millable canes (# ha^{-1})		Single stalk weight (kg)		Stalk length (cm)		Stalk diameter (cm)	
	SC	LC	SC	LC	LC	SC	LC	SC
KKU99-02	71818 abc	28916 abc	1.8 a	2.1 ab	213.5 abc	259.6 bcd	2.8 b	2.7 ab
Kps01-12	66012 bcd	37110 a	1.6 abc	2.1 abc	217.6 abc	253.0 bcd	2.7 bc	2.7 ab
MPT02-458	78411 ab	23477 bc	1.2 cd	2.4 a	241.3 a	305.7 a	2.9 b	2.8 a
LK92-11	78989 ab	33230 ab	0.9 d	1.2 d	169.8 def	222.0 de	2.4 de	2.6 bc
K88-92	63543 cd	22593 bc	1.3 bcd	1.4 cd	217.9 abc	205.1 e	2.7 bcd	2.4 cd
KKU99-03	81582 a	29063 abc	1.0 d	1.5 bcd	201.6 bcd	261.2 bcd	2.4 de	2.3 d
UT13	58358 d	38056 a	1.2 bcd	1.5 bcd	226.8 ab	262.7 bc	2.5 cde	2.5 bcd
UT12	54301 d	37579 a	1.7 ab	1.7 bcd	209.4 abc	271.4 ab	2.5 cde	2.7 ab
KK3	63300 cd	39147 a	1.1 d	1.1 d	188.7 cde	205.1 e	2.4 e	2.5 bcd
KK06-501	62139 cd	37133 a	0.9 d	1.4 cd	160.9 ef	211.9 e	2.5 cde	2.5 bcd
K93-219	32468 e	20426 bc	1.7 ab	1.8 a–d	193.7 b–e	234.2 b–e	3.3 a	2.8 a
TBy28-0941	59919 cd	15821 c	1.3 bcd	1.5 bcd	150.0 f	223.2 cde	2.5 cde	2.4 cd
Mean	64237	30212	1.3	1.6	199.3	242.9	2.6	2.5
F-test	**	*	**	*	**	**	**	**

* and ** = significant at *P* < 0.05 and 0.01 probability level, respectively. Means within a column with different letters are significantly different.

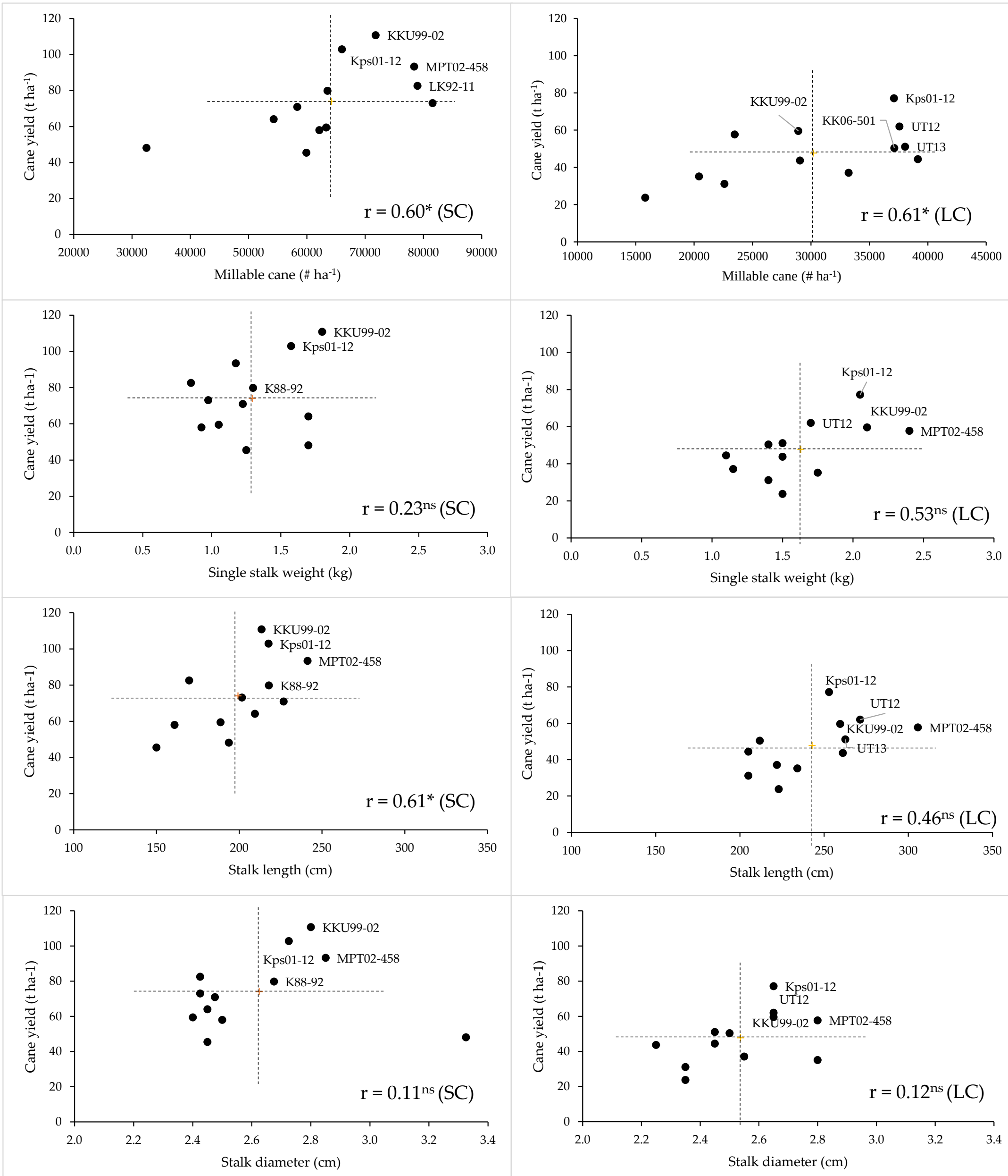

Figure 6. Correlations between cane yield and agronomic traits under SC and LC (b) of 12 sugarcane genotypes evaluated in ratoon trials.
*ns, * = nonsignificant and significant at the P ≤ 0.05 probability level, respectively.*

of active nodes as reflected by millable cane, whereas the other components of traits would have an indirect effect.

DISCUSSION

In general, sugarcane plants are cultivated through multiple ratooning cycles wherein new shoots grow from their stubbles after harvesting (Pierre *et al*., 2014). Soil aeration is a key factor in germination, which is distinguished by a considerable enhancement in respiration (Taiz and Zeiger, 2002). Moreover, excess water and O_2 deficit in the soil can cause damage to the bottom bud set under the soil and can reduce the bud vigor of ratoon. In our report, we showed that long-term waterlogging in plant canes evidently affected the germination percentage of the first ratoon cane, and the flooding duration of 4.5 months in the plant cane experiment could injure bud vigor. Emergence is a key factor in sugarcane production given that a high emergence rate provides a high population per area and consequently high cane production (Smit, 2010).

Stalk production by ratoon cane can be reduced by up to 25%–30% compared with that of plant cane (Rehman and Ullah, 2008). Cane yield usually decreases despite the selection of a good genotype and the use of advanced technology for ratoon crops, (Gomathi *et al*., 2013). In plant cane, short-term waterlogging is associated with higher yields than long periods of waterlogging (Palachai *et al*., 2019). The sugarcane genotype with flooding tolerance has higher cane yield productivity than the susceptible cultivar (Islam *et al*., 2011). Biomass production decreases when sugarcane is grown under waterlogging conditions (Palachai *et al*., 2019). Under hypoxic conditions, O_2 deficit leads to anaerobic respiration; the tricarboxylic acid cycle cannot operate, and fermentation is the only reaction available to produce energy, thus resulting in insufficient ATP energy (Taiz and Zeiger, 2002). We report that in ratoon cane, LC decreased cane yield production more than SC. Moreover, Palachai *et al*. (2019) reported that CCS among sugarcane cultivars in plant cane was different under SC but not LC. Flooding at 10 days to 20 days before harvest can decrease yield and sucrose content when compared with normal conditions and affects plant and ratoon canes (Glaz *et al*., 2007). Waterlogging in the late growth stage of sugarcane especially reduces theoretical recoverable sucrose (Glaz *et al*., 2007) and significantly reduces sucrose accumulation via changes in monosaccharide concentrations (Gomathi and Chandran, 2010). The quality of sugar from sugarcane depends on the period and depth of waterlogging (Paul, 2003). In the current report, the periods of flooding, such as short- and long-term natural waterlogging, of fields did not affect CCS likely because in both trials, waterlogging occurred at the elongation stage, and sugarcane plants begin to experience flooding at 5 and 7 months after harvesting in long- and short-term waterlogged fields, respectively. The CCS performance of diverse sugarcane lines may be mainly controlled by genetic effects, more so than by environmental ones (Saeed, 1993; Singh and Dey, 2002). Flooding-resistant cultivars can maintain high CCS and sugar yields during flooding (Islam *et al*., 2011).

Certainly, ratoon had lower yield and yield components than plant cane, including under flooding conditions. In terms of flooding duration, such as short- and long-term waterlogging, the short-term waterlogged field had a higher yield and higher value of the yield component (millable cane) than the long-term flooded field. However, the productivity of ratoon sugarcane depends on a major factor, namely, genotype (Bhatnagar *et al*., 2003). KKU99-02 and Kps01-12 showed consistently high productivity across SC and LC in ratoon fields. Obviously, these two genotypes presented good germination percentage and yield components. The collaboration between germination and yield components in ratoon contributes to high ratooning ability and yield potential under natural waterlogging. Palachai *et al*. (2019) reported that the initiation of waterlogging at 5–6 months after planting in plant cane does not disturb millable cane because they already have an established number of stalks prior to exposure to excess water. Nevertheless, for ratoon, in this study, millable cane seems to be severely affected by long periods of waterlogging as indicated by the means of millable cane between two flooding trials. This effect might be due to the influence of waterlogging in the plant cane experiment; anoxic conditions may destroy node vigor in ratoon. Even though many workers have reported an association between yield and its components in sugarcane (Chaudhary and Joshi, 2005; Tyagi and Lai, 2007; Ahmed *et al*., 2010; Palachai *et al*., 2019), information related to flooding remains lacking, especially for ratoon cane. Similarly, according to a previous report, waterlogging at 10 and 20 days prior to harvest can reduce millable cane in plant and ratoon canes (Glaz *et al*., 2005). The reductions in millable cane were 6%–26% in plant cane and 10%–21% in ratoon after over 10 days of waterlogging before harvesting (Deren and Raid, 2003). In addition, a mini core correction trial showed that under normal conditions, cane height is positively correlated with the yield of 253 accession canes (Shadmehr *et al*., 2017). In this study, which focused on flooding conditions, a positive relationship was observed between stalk length and yield under SC.

A desirable trait for use as a selection criterion in breeding programs is one with a small G × E interaction; a large interaction may lead to the failure to identify the performance of genotypes across environments (Wen and Zhu, 2005). In this report, no G × E interaction was found for stalk length, single stalk weight, and millable cane for ratoon cane. In plant cane, Palachai *et al*. (2019) reported the absence of significant G × E interaction for millable cane and stalk length under waterlogging conditions. Moreover, millable cane was the trait that contributed to cane yield under SC and LC for ratoon. Thus, in terms of ratoon, the millable cane of sugarcane can be used as selection criteria for waterlogging resistance (waterlogging period around 2.5–5.5 months after harvesting) in breeding programs.

CONCLUSIONS

Twelve sugarcane genotypes differing in terms of yield, yield components, and sugar yield under ratoon conditions were tested. In plant cane, long-term flooding can disturb the ratoon cane germination percentage, whereas short-term waterlogging had no effect on germination. KKU99-02 and Kps01-12 were identified as the top two genotypes that presented good ratooning ability and yield potential in fields under both natural flooding conditions. Good germination collaborating with the appropriate yield components in ratoon contributed to high ratooning ability and yield potential under natural waterlogging. In the ratoon field, a positive correlation between millable cane and cane yield existed. This correlation can be used as a selection criterion for the selection of high-yield cultivars under waterlogging conditions. Stalk length can also be used as a surrogate trait for ratoon cane under SC. This information will be useful in explaining the appropriate recommendation of surrogate traits for improving sugarcane genotypes in breeding programs for waterlogging under natural field conditions.

ACKNOWLEDGEMENTS

We are grateful to the Northeast Thailand Cane and Sugar Research Center, Faculty of Agriculture, Khon Kaen University, Thailand Research Fund Project no. RDG5950044 and RDG60T0165, and the Senior Research Scholar Project of Professor Dr. Sanun Jogloy (Project no. RTA6180002).

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