



ISSN: 2617-6548

URL: www.ijirss.com



Resilience and agronomic performance of promising sugarcane clone in lowland agroecosystems of Indonesia

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Abstract

Indonesia must continuously increase sugarcane productivity. This research aimed to determine the potential yields of new sugarcane clones in dryland. The research was conducted in two locations: Kediri at the end of the rainy season for Plant Cane (2018/2019) and Ratoon Cane (2019/2020), and Lamongan early in the rainy season for Plant Cane (2018/2019). Eleven promising clones and two check varieties were planted using bud chips, with five rows per treatment and each row spanning 9 m. The results of this research showed that the clones tested did not produce a sugar yield higher than the two check varieties of PS 881 (12.47 ton/ha) and Bululawang (11.66 ton/ha). However, four clones yielded sugar (11.71-12.40 ton/ha) which was comparable to the check varieties. Among these clones (CW 6535, CW 6222, 386 Soff 1118, and 400 Soff 1132), only CW 6535 and CW 6222 were deemed stable while the other two were labeled as unstable. Before introducing these selected clones as new commercial varieties, it is crucial to verify their performance in diverse agroecosystems.

Keywords: Promising clones, Stability, Sugarcane, Yield.

DOI: 10.53894/ijirss.v9i10.11957

Funding: This study received no specific financial support.

History: Received: 11 August 2026 / **Revised:** 1 October 2026 / **Accepted:** 5 October 2026 / **Published:** 26 October 2026

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Competing Interests: The authors declare that they have no competing interests.

Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Acknowledgements: The authors acknowledge the support of the Indonesian Sweetener and Fiber Crops Research Institute in funding this work through the state budget, KTM Sugar Mill for providing facilities, and IP2TP Karangploso for assistance during the field work.

Publisher: Innovative Research Publishing

1. Introduction

Sugarcane is a crucial crop used as the primary material for sugar production worldwide, including Indonesia. Badan Pusat Statistik (BPS) [1] that Indonesia had 449 thousand hectares of sugarcane in 2021, producing 2.35 million tons of

sugar with an average sugar yield of 5.23 t/ha. Intensification and extensification outside of Java are implemented to increase sugarcane productivity and sugar yield while meeting national demand.

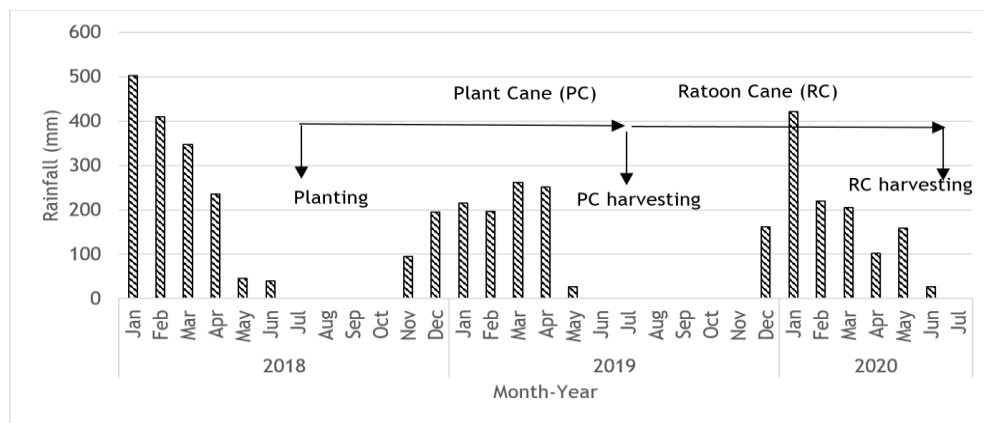
The use of new high-yielding sugarcane varieties with appropriate cultivation practices can boost the productivity of both sugarcane and sugar. The expansion of land usage is limited by the availability of land. Sugarcane in Indonesia is mainly grown on drylands in East Java with two planting seasons: one at the beginning of the rainy season and a second one that partly occurs at the end of the rainy season, with the aid of supplemental irrigation. Various factors affect the growth and productivity of sugarcane varieties including genotypic interaction with the environment where the crops grow [2-4].

It is important to keep working on enhancing sugarcane and sugar production by utilizing breeding techniques. New promising clones with high sugar yield have been established through selection. The cane farmers expect high cane yield, sugar content, drought tolerance, and good ratooning ability [4]. Sugar content is greatly influenced by genetic factors. One way to boost productivity is by creating high-yielding varieties. Promising clones established must undergo testing in diverse dryland agroecosystems. This research aimed to determine the potential yields of new sugarcane clones in dryland. The clones selected must undertake further field trials before release as new commercial varieties.

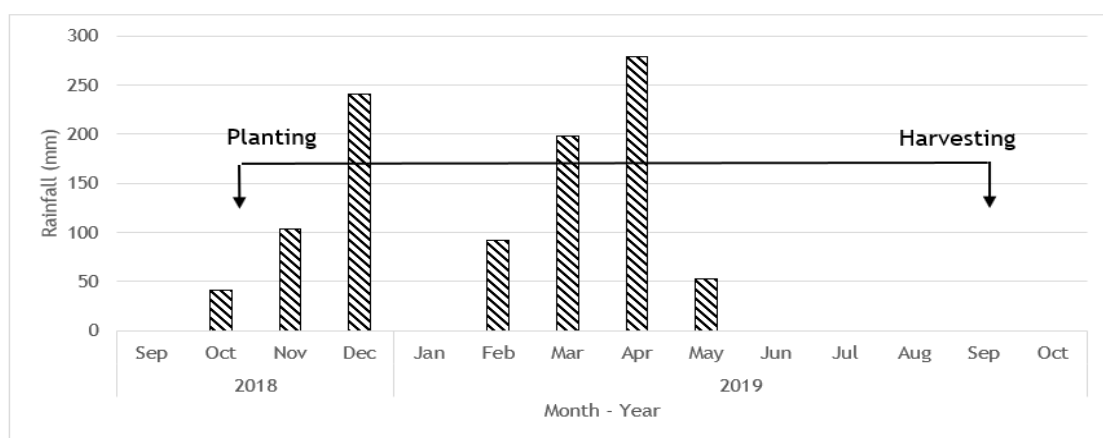
2. Research Methods

2.1. Study Site

The research was conducted on dryland in Kediri Regency in the 2018/2019 planting season (Plant Cane) and 2019/2020 for Ratoon Cane and in Lamongan Regency in the 2018/2019 planting season (plant Cane). Rainfall distribution during research is presented in Figure 1. The planting materials used were budchip seeds from eleven sugarcane clones which come from crossbreeding and exploration and two check varieties (early maturity of PS 881 and middle-late maturity of Bululawang). Other research materials include inorganic fertilizers, manure, pesticides, and herbicides. The tools used include calipers, refractometers, measuring devices, and sprayers.



(a)



(b)

Figure 1.

Rainfall during research in (a) Kediri Regency and (b) Lamongan Regency.

2.2. Experiment Design and Culture Practices

The research was conducted using a Randomized Block Design with three replications. The experiment included 11 sugarcane clones with high sugar yield (MLG 19, MLG 75, PBG 2, KDI 11, 386 Soft 1118, 400 Soft 1132, CW 6535, CW 6222, CW 6243, CW 3702, and Uthong 5) and 2 check varieties (PS 881 and Bululawang). Bululawang (BL) is the most dominant variety in Indonesia. It was officially released in 2004 and PS 881 is still commercially used and widely planted [4].

Planting was carried out in East Java in July 2018 in Kediri Regency and in October 2018 in Lamongan Regency. The planting distance was 110 cm from center to center with 50 cm between plants in rows. Each treatment consisted of 5 rows with a length of 9 m each row. Fertilizer was applied twice: first at 3-4 weeks (750 kg of NPK compound fertilizer (Phonska) and then again at 2-3 months after planting (625 kg of Ammonium Sulfate). Cultivation practices involved pulling up the soil twice around the planting bed after fertilization. Supplemental irrigation was applied based on plant needs and in times of irregular rainfall or dry preceding fertilization. Pest and disease control was adapted to the conditions of attack. Harvesting sugarcane is done when the brix values of the upper and lower stems are relatively the same, indicating physiological maturity. Stubble shaving and off-barring were implemented in Kediri Regency after harvest to improve the sugarcane root system and aid in the growth of Ratoon Cane (RC).

2.3. Plant Growth and Yield Variables Measurement

At harvest, measurements were taken for plant growth (stem length, diameter, weight, and stems/ha), sugarcane and sugar yields, and sugar content. When the plants were 12 months old (July 2019 for PC and July 2020 for RC in Kediri Regency and October 2019 in Lamongan Regency) harvest was taken by cutting down all the sugar cane stalks in the second, third, and fourth rows. Harvested stems were cleaned of leaf midribs and shoots.

The number of millable canes (NM) and sugarcane productivity (TC) were measured by counting all the stems harvested per plot (NMP) and weighing them to obtain the stem weight per plot (CP). NM and TC are calculated by Equation 1-2.

$$NM = \frac{NMP * 8100}{3 * 9} \quad (\text{stem/ha}) \quad (1)$$

$$TC = \frac{CP * 8100}{3 * 9} \quad (\text{t/ha}) \quad (2)$$

where 8100 is the total length of rows per hectare, 3 and 9 are the number and length of the harvested rows. Ten harvested samples per row were measured for stem length, diameter, and weight. Each stem was individually measured. The weight of the stem is measured by weighing all the sample stems.

Sugar content was measured by crushing ten stem samples and extracting their juice using a press machine. The crushing factor (JF) is the ratio of juice weight to stem weight. The juice was measured for Brix value with a refractometer and pol using a saccharometer. The formula in Equation 3-5 is used to calculate juice value (JV), sugar content (SC), and sugar yield (TS).

$$JV = Pol - (0.4 (Brix - Pol)) \quad (3)$$

$$SC = JF * JV \quad (\%) \quad (4)$$

$$TS = TC * SC \quad (\text{t ha}^{-1}) \quad (5)$$

2.4. Data Analysis

The growth and yield data were analyzed using R studio software with a combined variance and Tukey test at a 5% level. If there was an interaction between the clone and location in the analysis of variance, a stability analysis was performed using [5] method. If the regression coefficient value (bi) is not different from one and the standard deviation (S^2d) is not different from zero, then the clone/variety is considered stable. However, if one of the conditions is not met, the clone/variety is unstable. To determine the contribution of stem length and diameter on stem weight, as well as the number of stems and stem weight on sugarcane productivity, a stepwise regression analysis was used. The correlation coefficient value was then multiplied by 100% to express the total contribution of these variables on stem weight, sugarcane productivity, and sugar yield. A backward stepwise analysis was done to determine the contribution of each variable component to stem weight, sugarcane productivity, and sugar yield.

3. Results and Discussion

3.1. Plant Growth and Yield

The growth variables of sugarcane plants, such as stem length, diameter, weight, and millable canes per hectare, were affected by the interaction between the clones and their location (Table 1-4). The plants with the longest stem at Kediri in PC (302.60 - 322.84 cm) were CW 6222, Uthong 5, PS 881, and Bululawang, as well as CW 6535. In RC (315.90 - 324.50 cm), the longest stems were CW 6535, CW 6222, CW 6243, CW 3702, and PS 881. The longest stem (260.37 cm) in Lamongan was achieved by MLG 19 (Table 2).

The stem length of the PS 881 check variety was longer in Kediri for both PC (322.13 cm) and RC (315.90 cm) compared to Lamongan's PC (228.70 cm). The clone MLG 19 grown in Lamongan had a stem length of 260.37 cm, longer than that of PS 881. The MLG 75 in Kediri (RC) and MLG 19 in Lamongan had longer stems than Bululawang at three different locations. However, in Kediri (PC), there was no clone longer than the Bululawang variety. Clones of MLG 75, CW 6535, CW 6222, CW 6243, and Uthong 5 in Kediri (PC), MLG 75 in Kediri (RC), as well as MLG 75, PBG 2, CW 6535, CW 6222, and CW 6243 in Lamongan have the same stem lengths as those of Bululawang.

Table 1.

Stem length of promising sugarcane clones and check varieties at three study sites.

Clones/varieties	Stem length (cm)		
	Kediri PC	Kediri RC	Lamongan
MLG 19	285.00 e-i	285.85 e-h	260.37 jk
MLG 75	295.70 d-h	278.95 f-k	220.83 m
PBG 2	286.33 e-h	296.55 c-h	212.60 m-o
KDI 11	261.00 j-k	296.95 c-g	190.19 o
386 Soff 1118	275.93 g-k	279.85 e-j	196.77 no
400 Soff 1132	273.53 h-k	298.40 c-g	194.60 no
CW 6535	302.60 a-e	321.80 ab	225.50 m
CW 6222	302.63 a-e	324.50 a	215.07 mn
CW 6243	299.63 b-f	319.70 a-c	220.33 m
CW 3702	262.30 i-k	324.70 a	161.60 p
Uthong 5	311.93 a-d	283.70 e-j	196.13 no
PS 881	322.13 a-b	315.90 a-d	228.70 m
Bululawang	317.13 a-d	255.95 kl	235.33 lm

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level.

The largest stem diameter was obtained by Uthong 5 in Kediri PC (2.92 cm), CW 6535 in RC (3.18 cm), and Uthong 5 in Lamongan (3.05 cm) as seen in Table 2. There were no clone had a stem diameter greater than PS 881 in both Kediri PC and Lamongan and three clones in Kediri (RC) namely PBG 2, 386 Soff 1118, and CW 6535 had a larger stem diameter than PS 881. Clone of CW 6535 in Kediri RC and Uthong 5 in Lamongan had a larger stem diameter, while in Kediri PC no clones with a diameter larger than Bululawang.

Table 2.

Stem diameter of promising sugarcane clones and check varieties at three research sites.

Clones/Varieties	Stem diameter (cm)		
	Kediri PC	Kediri RC	Lamongan
MLG 19	2.41 j-n	2.35 k-o	2.72 c-h
MLG 75	2.55 f-k	2.28 l-o	2.48 h-n
PBG 2	2.73 c-h	2.88 b-d	2.72 c-h
KDI 11	2.25 m-o	2.10 o	2.22 no
386 Soff 1118	2.79 b-f	2.89 b-d	2.89 b-d
400 Soff 1132	2.52 g-l	2.50 g-m	2.72 c-h
CW 6535	2.72 c-h	3.18 a	2.70 c-h
CW 6222	2.57 e-k	2.55 f-k	2.75 c-g
CW 6243	2.83 b-e	2.41 j-n	2.76 c-g
CW 3702	2.72 c-h	2.43 i-n	2.86 b-d
Uthong 5	2.92 a-c	2.68 c-i	3.05 ab
PS 881	2.76 c-g	2.58 e-k	2.89 b-d
Bululawang	2.66 c-j	2.91 bc	2.63 d-j

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level.

Clones of CW 6243, Uthong, and PS 881 produced the highest stem weights (ranging from 1.678 to 2.367 kg per stem) in Kediri PC, PBG 2 in Kediri RC, and MLG 19 in Lamongan, respectively (Table 3). The clone of PBG 2 in Kediri RC and MLG 19 in Lamongan had heavier stem weights, while in Kediri PC no clone had a stem weight heavier than PS 881. The stem weights of Bululawang, PBG 2, CW 6243, and Uthong 5 Kediri PC were not significantly different. The weight of Bululawang stems at each location ranged from 1.275 to 1.855 kg/stem. Clones of Uthong 5 in Kediri PC, PBG 2 in Kediri RC, and MLG 19 in Lamongan had heavier stem weights compared to Bululawang.

Table 3.

Stem weight of promising sugarcane clones and check varieties at three research sites.

Clones/varieties	Stem weight (kg/stem)		
	Kediri PC	Kediri RC	Lamongan
MLG 19	1.487 i-n	1.352 k-p	1.678 f-j
MLG 75	1.715 e-i	1.292 m-p	1.138 op
PBG 2	2.020 b-d	2.347 a	1.265 n-p
KDI 11	1.143 op	1.093 pq	0.813 q
386 Soff 1118	1.987 c-e	1.940 c-f	1.282 n-p
400 Soff 1132	1.632 g-k	1.621 g-l	1.290 m-p
CW 6535	1.968 c-f	1.982 c-e	1.315 m-p
CW 6222	1.878 c-g	1.833 c-h	1.327 l-p
CW 6243	2.085 a-c	1.588 g-m	1.393 j-o
CW 3702	1.805 c-h	1.876 c-g	1.063 pq
Uthong 5	2.367 a	1.732 d-i	1.467 i-n
PS 881	2.287 ab	1.805 c-h	1.537 h-n
Bululawang	1.855 c-g	1.689 e-j	1.275 n-p

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level

The clones of MLG 19 and KDI 11 in Kediri PC produced the highest number of millable canes (91,320-93,120 stems/ha), MLG 19, MLG 75, KDI 11, 400 Soff 1132, PS 881, and Bululawang in Kediri RC (87,440-102,101 stems/ha), and 400 Soff 1132 in Lamongan by 84,150 stems/ha (Table 4).

Clones of MLG 19, MLG 75, KDI 11, and CW 6535 in Kediri PC, MLG 75, 400 Soff 1132, and CW 6535 in Lamongan had more millable canes, whereas in Kediri RC no clone was found with more stems than PS 881. The clones other than PBG 2, CW 6243, and Uthong 5 in Kediri RC had millable canes that were not different from PS 881. Compare to Bululawang only 400 Soff 1132 in Lamongan with more stems, whereas in the other two locations no clone with more stems than Bululawang. The clones other than 386 Soff 1132, CW 3702, and Uthong 5 in Kediri PC and clones other than PBG 2, CW 6243, and Uthong 5 in Kediri RC had number of stems that were not different from Bululawang

Table 4.

Number of millable canes per ha of promising sugarcane clones and check varieties at three research sites.

Clones/Varieties	Number of millable canes (stems/ha)		
	Kediri PC	Kediri RC	Lamongan
MLG 19	91320 a-d	102101 a	57870 j-k
MLG 75	79680 d-h	98253 ab	81720 d-g
PBG 2	72960 e-j	52326 k	71280 f-j
KDI 11	93120 a-d	101088 a	64620 h-k
386 Soff 1118	60780 i-k	83700 b-e	71100 f-j
400 Soff 1132	71280 f-j	97322 a-c	84150 b-e
CW 6535	78900 d-h	82256 c-g	80640 d-g
CW 6222	74700 e-i	78327 d-h	74970 e-i
CW 6243	71880 f-j	69417 f-j	74070 e-i
CW 3702	65040 h-k	81608 d-g	72990 e-j
Uthong 5	53880 k	70713 f-j	72810 e-j
PS 881	60360 i-k	91449 a-d	60390 i-k
Bululawang	82380 c-g	87440 a-e	67320 g-k

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level.

Sugarcane yields including sugarcane productivity, sugar content, and sugar yield are influenced by the interaction between location and the clones used (Table 5-7). The highest sugarcane productivity in Kediri PC (140.39-155.22 t/ha) was obtained by PBG 2, CW 6535, CW 6222, CW 6243, and Bululawang, where in Kediri RC (138.49-162.99 t/ha) by MLG 19, 386 Soff 1118, 400 Soff 1132, CW 6535, CW 6222, CW 3702, PS 881, and Bululawang, while in Lamongan (105.25-108.58 t/ha) by 400 Soff 1132, CW 6535, and Uthong 5 (Table 5).

By comparing the sugarcane productivity of PS 881 (137.16, 163.75, and 92.39 t/ha) and Bululawang (152.44, 148.19, and 85.44 t/ha) at each location, there was no clone with greater sugarcane productivity significantly than both check varieties at all locations. Clones other than KDI 11 in Kediri PC, MLG 75, PBG 2, KDI 11, CW 6243, and Uthong 5 in Kediri RC, as well as KDI 11 in Lamongan have sugarcane productivity that were not different from PS 881. Clones other than KDI 11, 386 Soff 1118, 400 Soff 1132, and CW 3702 in Kediri PC, KDI 2, KDI 11, CW 6243, and Uthong 5 in Kediri RC, as well as KDI 11 had sugarcane productivity which were not different from Bululawang.

Table 5.

Sugarcane productivity of promising sugarcane clones and check varieties at three research sites.

Clones/Varieties	Sugarcane productivity (t/ha)		
	Kediri PC	Kediri RC	Lamongan
MLG 19	135.32 b-g	138.49 a-f	96.68 i-n
MLG 75	137.37 b-f	127.16 d-h	92.08 k-n
PBG 2	148.10 a-d	121.96 e-i	90.18 mn
KDI 11	106.10 h-m	110.81 g-m	53.63 o
386 Soff 1118	120.83 e-j	157.80 ab	91.12 l-n
400 Soff 1132	116.49 f-l	157.93 ab	108.58 h-m
CW 6535	155.22 ab	162.99 a	105.25 h-m
CW 6222	140.39 a-f	143.82 a-e	101.06 i-n
CW 6243	150.04 a-d	110.72 g-m	96.49 j-n
CW 3702	117.48 f-k	153.13 a-c	77.81 no
Uthong 5	128.00 c-h	119.65 e-j	106.62 h-m
PS 881	137.16 b-f	163.75 a	92.39 k-n
Bululawang	152.44 a-d	148.19 a-d	85.44 mn

Note: Numbers accompanied by the same letter are not significantly different at the Tukey test at the 5% level.

The CW 3702 clone produced the highest sugar content (11%) in Kediri PC, Bululawang (10.14%) in Kediri RC, and 386 Soff 1118, 400 Soff 1132, and CW 3702 (10.28-11.09%) in Lamongan (Table 6). The CW 3702 clone in Kediri PC and 400 Soff 1132 and CW 3702 in Lamongan produced higher sugar content than PS 81, whereas in Kediri RC no clone was obtained higher than PS 81, and sugar content of 386 Soff 1118 was not different from PS 881. Clones other than KDI 11 and Uthong 5 in Kediri PC and 386 Soff 1118, 400 Soff 1132, CW 6243, and CW 3702 had higher sugar content than Bululawang, whereas in Kediri RC no clone with higher sugar content and only 386 Soff 1118 had a sugar content that was not different from Bululawang.

Table 6.

Sugar content of promising clones of sugar cane along with check varieties at three research sites.

Clones/varieties	Sugar content (%)		
	Kediri PC	Kediri RC	Lamongan
MLG 19	9.34 d-i	8.13 k-o	8.99 f-j
MLG 75	9.23 e-i	9.13 e-j	9.39 d-i
PBG 2	9.80 c-f	8.90 h-l	8.75 i-m
KDI 11	6.79 pq	8.94 g-k	9.59 c-h
386 Soff 1118	10.11 cd	9.58 c-i	10.28 a-c
400 Soff 1132	9.55 c-i	8.82 h-m	10.96 ab
CW 6535	9.55 c-i	7.41 op	9.75 c-g
CW 6222	9.75 c-g	8.30 j-n	9.42 d-i
CW 6243	9.89 c-e	6.31 q	9.88 c-e
CW 3702	11.00 a	7.49 n-p	11.09 a
Uthong 5	7.79 no	9.01 f-j	8.08 l-o
PS 881	9.36 d-i	9.38 d-i	9.93 c-e
Bululawang	8.06 m-o	10.14 b-d	9.01 f-j

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level.

The highest sugar yield in Kediri PC (12.89-14.80 t/ha) was obtained by PBG 2, CW 6535, CW 6222, CW 6243, CW 3702, and PS 881, in Kediri RC (13.84-15.35 t/ha) obtained by 386 Soff 1118, 400 Soff 1132, PS 881, and Bululawang, while in Lamongan (11.91 t/ha) obtained by 400 Soff 1132 (Table 7). In comparison with the sugar yields of PS 881 (12.89, 15.35, and 9.17 t/ha) and Bululawang (12.30, 14.99, and 7.71 t/ha) at each location, only 400 Soff 1132 in Lamongan obtained higher sugar yields, whereas in the other two locations no clone with higher sugar yield than the two check varieties. The clones other than KDI 11 in Kediri PC and clones of 386 Soff 1118 and 400 Soff 1132 in Kediri RC had no different sugar yield from the two check varieties.

Table 7.

Sugar yields of promising clones of sugarcane and check varieties at three research sites.

Clones/varieties	Sugar yield (t ha ⁻¹)		
	Kediri PC	Kediri RC	Lamongan
MLG 19	12.69 b-f	11.31 e-i	8.66 j-m
MLG 75	12.63 b-f	11.54 e-i	8.66 j-m
PBG 2	14.44 a-d	10.86 f-j	7.88 k-m
KDI 11	7.19 l-n	9.89 g-k	5.16 n
386 Soff 1118	12.20 c-g	15.12 ab	9.36 i-m
400 Soff 1132	11.00 f-j	13.84 a-e	11.91 d-h
CW 6535	14.80 a-c	12.08 d-h	10.32 f-k
CW 6222	13.67 a-e	11.92 d-h	9.55 h-l
CW 6243	14.79 a-c	6.83 mn	9.55 h-l
CW 3702	12.93 a-f	11.47 e-i	8.63 j-m
Uthong 5	9.94 g-k	10.73 f-j	8.62 j-m
PS 881	12.89 a-f	15.35 a	9.17 i-m
Bululawang	12.30 c-g	14.99 ab	7.71 k-m

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level.

3.2. Stability of Sugarcane Clones/Varieties Based on Growth and Yield

Based on the stem length of each clone/variety, there were six clones/varieties (MLG 19, MLG 75, CW 6535, CW 6222, Uthong 5, and Bululawang) classified as stable and the rest were classified as unstable (Table 8). Of the stable clones, there were two clones (CW 6535 and CW 6222) with the longest stem length (280.73-283.30 cm). Similarly, among the unstable clones/varieties, there were two clones/varieties (CW 6243 and PS 881) having the longest stem (279.89-288.91 cm). Based on stem diameter, there were two clones (MLG 19 and CW 6222) classified as stable and the others were unstable (Table 9). None of the two stable clones had the largest diameter, while the four unstable clones/varieties (PBG 2, 386 Soff 1118, CW 6535, and Uthong 5) had the largest diameter (2.77-2.88 cm).

Table 8.

Mean stem length, regression coefficient, standard deviation and stability of promising sugarcane clones and check varieties.

Clones/varieties	Stem length (cm)	bi	S ² _d	Stability
MLG 19	277.07 bc	0.700 ^{ns}	53.439 ^{ns}	Stable
MLG 75	265.16 de	0.783 ^{ns}	88.819 ^{ns}	Stable
PBG 2	265.16 de	0.951 ^{ns}	146.630*	Unstable
KDI 11	249.38 f	1.088 ^{ns}	358.957**	Unstable
386 Soff 1118	250.85 f	0.973 ^{ns}	150.736*	Unstable
400 Soff 1132	255.51 ef	1.111 ^{ns}	198.640*	Unstable
CW 6535	283.30 ab	1.051 ^{ns}	20.307 ^{ns}	Stable
CW 6222	280.73 ab	1.194 ^{ns}	42.684 ^{ns}	Stable
CW 6243	279.89 a-c	1.083 ^{ns}	178.492*	Unstable
CW 3702	249.53 f	1.623 ^{ns}	1280.810**	Unstable
Uthong 5	263.92 de	1.196 ^{ns}	55.473 ^{ns}	Stable
PS 881	288.91 a	1.076 ^{ns}	186.494*	Unstable
Bululawang	269.47 cd	0.569 ^{ns}	67.666 ^{ns}	Stable

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level. bi: regression coefficient; S²_d: standard deviation; *, ** and ns: significantly different, very significantly different, and not significantly different based on the t-test for bi and F-test for S²_d.**Table 9.**

Mean stem diameter, regression coefficient, standard deviation and stability of promising sugarcane clones and check varieties.

Clones/varieties	Stem diameter (cm)	bi	S ² _d	Stability
MLG 19	2.49 fg	1.010 ^{ns}	0.000 ^{ns}	Stable
MLG 75	2.43 g	1.403 ^{ns}	0.019*	Unstable
PBG 2	2.77 a-c	2.209**	0.000 ^{ns}	Unstable
KDI 11	2.19 h	0.879 ^{ns}	0.012*	Unstable
386 Soff 1118	2.86 ab	0.103**	0.003 ^{ns}	Unstable
400 Soff 1132	2.58 ef	1.767**	0.001 ^{ns}	Unstable
CW 6535	2.87 a	3.587**	0.041**	Unstable
CW 6222	2.62 de	1.217 ^{ns}	0.002 ^{ns}	Stable
CW 6243	2.67 c-e	2.520**	0.043**	Unstable
CW 3702	2.67 c-e	3.322**	0.003 ^{ns}	Unstable
Uthong 5	2.88 a	2.837**	0.001 ^{ns}	Unstable
PS 881	2.74 b-d	2.397**	0.002 ^{ns}	Unstable
Bululawang	2.73 cd	2.057**	0.008 ^{ns}	Unstable

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level. bi: regression coefficient; S²_d: standard deviation; *, ** and ns: significantly different, very significantly different, and not significantly different based on the t-test for bi and F-test for S²_d.

Based on the stem weight of each clone/variety, there were six clones/varieties (MLG 19, MLG 75, CW 6535, CW 6222, Uthong 5, and Bululawang) classified as stable, however the others were classified as unstable (Table 10). Two clones (CW 6535 and Uthong 5) from the stable clones/varieties had the heaviest stem weight (1.755-1.855 kg/stem). Similarly, out of unstable clones/varieties there were three clones (PBG 2, 386 Soff 1118, and PS 881) with the heaviest stem (1.736-1.877 kg/stem).

Based on the millable canes per ha, three clones (KDI 11, 386 Soff 1118, and 400 Soff 1132) were classified as unstable and 10 other clones/varieties were classified as stable (Table 11). Two clones (KDI 11 and 400 Soff 1132) from unstable clones had the highest number of millable canes (83,764-86,276 stems/ha), as well as the three clones (MLG 19, MLG 75, and CW 6535) from stable clones with millable canes of 80,599-86,551 stems/ha.

Table 10.

Average stem weight, regression coefficient, standard deviation and stability of promising sugarcane clones and check varieties.

Clones/varieties	Stem weight (kg/stem)	bi	S ² _d	Stability
MLG 19	1.506 ef	0.872 ^{ns}	0.001 ^{ns}	Stable
MLG 75	1.382 f	0.889 ^{ns}	0.016 ^{ns}	Stable
PBG 2	1.877 a	1.589 ^{ns}	0.176 ^{**}	Unstable
KDI 11	1.016 g	0.601 [*]	0.005 ^{ns}	Unstable
386 Soff 1118	1.736 a-c	1.314 ^{ns}	0.048 [*]	Unstable
400 Soff 1132	1.514 ef	0.643 [*]	0.002 ^{ns}	Unstable
CW 6535	1.755 ab	1.246 ^{ns}	0.018 ^{ns}	Stable
CW 6222	1.679 b-d	1.024 ^{ns}	0.001 ^{ns}	Stable
CW 6243	1.689 b-d	1.072 ^{ns}	0.051 ^{**}	Unstable
CW 3702	1.582 de	1.441 ^{ns}	0.043 ^{**}	Unstable
Uthong 5	1.855 a	1.400 ^{ns}	0.015 ^{ns}	Stable
PS 881	1.876 a	1.190 ^{ns}	0.040 [*]	Unstable
Bululawang	1.606 c-e	1.020 ^{ns}	0.006 ^{ns}	Stable

Note: Numbers accompanied by the same letter mean were not significantly different at the Tukey test at the 5% level. bi: regression coefficient; S²_d: standard deviation; *, ** and ns: significantly different, very significantly different, and not significantly different based on the t-test for bi and F-test for S²_d.

Table 11.

Average number of millable canes per ha, regression coefficient, standard deviation and stability of promising sugarcane clones and check varieties.

Clones/varieties	Number of millable canes (stems/ha)	bi	S ² _d	Stability
MLG 19	83764 ab	1.646 ^{ns}	56489666 ^{ns}	Stable
MLG 75	86551 a	1.469 ^{ns}	17407828 ^{ns}	Stable
PBG 2	65522 f	1.662 ^{ns}	17535556 ^{ns}	Stable
KDI 11	86276 ab	2.152 ^{ns}	284607571 ^{**}	Unstable
386 Soff 1118	71860 d-f	1.408 ^{ns}	74503322 [*]	Unstable
400 Soff 1132	84251 ab	1.541 ^{ns}	94398945 [*]	Unstable
CW 6535	80599 a-c	0.194 ^{ns}	25811862 ^{ns}	Stable
CW 6222	75999 c-e	0.293 ^{ns}	27693186 ^{ns}	Stable
CW 6243	71789 d-f	0.322 ^{ns}	26637646 ^{ns}	Stable
CW 3702	73213 de	0.992 ^{ns}	19391130 ^{ns}	Stable
Uthong 5	65801 f	0.446 ^{ns}	19184451 ^{ns}	Stable
PS 881	70733 ef	1.634 ^{ns}	17441066 ^{ns}	Stable
Bululawang	79047 b-d	1.209 ^{ns}	57650118 ^{ns}	Stable

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level. bi: regression coefficient; S²_d: standard deviation; *, ** and ns: significantly different, very significantly different, and not significantly different based on the t-test for bi and F-test for S²_d.

Based on sugarcane productivity, there were six clones (PBG 2, KDI 11, 386 Soff 1118, 400 Soff 1132, CW 6243, and CW 3702) classified as unstable and the others were classified as stable (Table 12). Two stable clones/varieties (CW 6535 and PS 881) had the highest sugarcane productivity (131.10-141.15 t ha⁻¹), while none of the unstable clones had the highest sugarcane productivity. Based on the sugar yield, PS 881 was classified as a stable variety and 12 other clones/varieties were classified as unstable (Table 13). Three unstable clones (386 Soff 1118, 400 Soff 1132, and CW 3702) had the highest yield, while none of the stable clones had the highest sugar content.

Table 12.

Average sugarcane productivity, regression coefficient, standard deviation and stability of promising sugarcane clones check varieties.

Clones/varieties	Sugarcane productivity (t/ha)	bi	S ² _d	Stability
MLG 19	123.50 b-d	0.893 ^{ns}	99.973 ^{ns}	Stable
MLG 75	118.87 cd	0.865 ^{ns}	11.714 ^{ns}	Stable
PBG 2	120.08 b-d	0.936 ^{ns}	393.355*	Unstable
KDI 11	90.18 e	1.218 ^{ns}	199.520*	Unstable
386 Soff 1118	123.25 b-d	1.137 ^{ns}	375.648*	Unstable
400 Soff 1132	127.66 b-d	0.715 ^{ns}	609.802*	Unstable
CW 6535	141.15 a	1.202 ^{ns}	100.832 ^{ns}	Stable
CW 6222	128.43 bc	0.911 ^{ns}	100.243 ^{ns}	Stable
CW 6243	119.08 b-d	0.667 ^{ns}	832.895**	Unstable
CW 3702	116.14 d	1.339 ^{ns}	303.182*	Unstable
Uthong 5	118.09 cd	0.362 ^{ns}	47.487 ^{ns}	Stable
PS 881	131.10 ab	1.333 ^{ns}	86.109 ^{ns}	Stable
Bululawang	128.69 bc	1.421 ^{ns}	27.976 ^{ns}	Stable

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level. Bi: regression coefficient; S²_d: standard deviation; *, ** and ns: significantly different, very significantly different, and not significantly different based on the t-test for bi and F-test for S²_d.

Table 13.

Average sugar yield, regression coefficient, standard deviation and stability of promising sugarcane clones and check varieties.

Clones/varieties	Sugar content (%)	bi	S ² _d	Stability
MLG 19	8.82 e-g	0.932 ^{ns}	0.238*	Unstable
MLG 75	9.25 cd	0.240**	0.048 ^{ns}	Unstable
PBG 2	9.15 de	0.028**	0.586**	Unstable
KDI 11	8.44 gh	0.174 ^{ns}	4.229**	Unstable
386 Soff 1118	9.99 a	0.681*	0.047 ^{ns}	Unstable
400 Soff 1132	9.78 ab	1.938*	0.207*	Unstable
CW 6535	8.90 d-f	2.359**	0.216*	Unstable
CW 6222	9.16 c-e	1.198 ^{ns}	0.294*	Unstable
CW 6243	8.69 f-h	3.640**	1.049**	Unstable
CW 3702	9.86 ab	3.659**	0.903**	Unstable
Uthong 5	8.29 h	0.994 ^{ns}	0.205*	Unstable
PS 881	9.56 bc	0.966 ^{ns}	0.037 ^{ns}	Stable
Bululawang	9.07 d-f	1.320 ^{ns}	1.149**	Unstable

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level. bi: regression coefficient; S²_d: standard deviation; *, ** and ns: significantly different, very significantly different, and not significantly different based on the t-test for bi and F-test for S²_d.

Based on the sugar yield, there were six clones (PBG 2, KDI 11, 386 Soff 1118, 400 Soff 1132, CW 6243, and CW 3702) classified as unstable, and seven clones/varieties were classified as stable (Table 14). Two unstable clones (386 Soff 1118 and 400 Soff 1132) had high sugar yield (12.22-12.25 t/ha), as well as four stable clones/varieties (CW 6535, CW 6222, PS 881, and Bululawang) with high sugar yield (11.66-12.47 t/ha).

Table 14.

Average sugar yield, regression coefficient, standard deviation and stability of promising sugarcane clones and check varieties.

Clones/varieties	Sugar yield (t/ha)	bi	S ² _d	Stability
MLG 19	10.89 c-e	1.022 ^{ns}	0.309 ^{ns}	Stable
MLG 75	10.94 c-e	1.043 ^{ns}	0.549 ^{ns}	Stable
PBG 2	11.06 b-d	1.510 ^{ns}	3.618*	Unstable
KDI 11	7.41 f	0.921 ^{ns}	4.080*	Unstable
386 Soff 1118	12.22 ab	1.187 ^{ns}	5.201**	Unstable
400 Soff 1132	12.25 ab	0.069*	3.420*	Unstable
CW 6535	12.40 a	0.999 ^{ns}	0.914 ^{ns}	Stable
CW 6222	11.71 a-c	1.008 ^{ns}	0.121 ^{ns}	Stable
CW 6243	10.39 de	0.596*	29.336**	Unstable
CW 3702	11.01 b-e	1.095 ^{ns}	2.256*	Unstable
Uthong 5	9.76 e	0.485	0.252 ^{ns}	Stable
PS 881	12.47 a	1.390 ^{ns}	0.942 ^{ns}	Stable
Bululawang	11.66 a-c	1.676 ^{ns}	0.120 ^{ns}	Stable

Note: Numbers accompanied by the same letter were not significantly different at the Tukey test at the 5% level. bi: regression coefficient; S²_d: standard deviation; *, ** and ns: significantly different, very significantly different, and not significantly different based on the t-test for bi and F-test for S²_d.

4. Discussion

4.1. Plant Growth and Yield

Each variety has a different photosynthesis rate [6-8] influenced by the plant's growing environment [9-11]. The rate of photosynthesis determines the amount of carbohydrates available for plant growth [12]. Hence, the amount of carbohydrates available for plant growth is influenced by the interaction of the clone/variety and its growing environment. Sugarcane clones/varieties also require different amounts of available carbohydrates to form stem tissue [7] and are influenced by environmental conditions [13]. Therefore, the formation of sugarcane plant tissue is influenced by the interaction of the clone/variety with its growing environment. These conditions caused stem length and diameter in Table 1-2 were also determined by clones/varieties and environmental condition as also reported by Schultz, et al. [14] in sugarcane stem length [15, 16] and in stem diameter [17, 18].

Stem length and diameter are growth components closely related to stem weight [19]. In this study, a relationship was gained between stem weight and stem length and diameter, with a total contribution of both components 93.3-100.0% depending on the clone/variety used (Table 15). The MLG 19 stem weight was more dominantly influenced by stem diameter (70.95%), while other clones/varieties were more dominantly influenced by stem length (58.65-93.08%). Supriyono, et al. [20] reported that stem length and stem diameter of clones from polycross showed almost similar contribution (44.7-44.8%) to stem weight. Similarly, Side, et al. [21] using variety of Bululawang and Alam, et al. [22] using nine exotic clones found that stem diameter dominance (51.18 and 54.7%) in influencing stem weight. Because stem length and diameter are influenced by the interaction between the clone/variety and the growing environment, the stem weight is also influenced by this interaction [23].

Table 15.

The relationship between stem weight (SW) and diameter (SD) and stem length (SL) in each clone/variety along with the contribution.

Clones/varieties	Formula	Contribution (%)		
		SD	SL	Total
MLG 19	$SW1 = 3.0051 SD1 + 2.7723 SL1 - 4.0359$	70.95	29.05	100.0
MLG 75	$SW2 = 1.7023 SD2 + 0.9443 SL2 - 1.4721$	23.65	75.75	99.4
PBG 2	$SW3 = 1.7303 SD3 + 1.4160 SL3 - 1.8470$	6.62	93.08	99.9
KDI 11	$SW4 = 1.5901 SD4 + 0.6068 SL4 - 1.1236$	6.92	87.48	94.4
386 Soff 1118	$SW5 = 0.7797 SD5 + 1.2158 SL5 - 0.8902$	1.78	96.92	98.7
400 Soff 1132	$SW6 = 0.7079 SD6 + 0.6983 SL6 - 0.4718$	29.97	64.13	94.1
CW 6535	$SW7 = -0.2630 SD7 + 1.0569 SL7 + 0.0768$	0.13	98.47	98.6
CW 6222	$SW8 = 1.4472 SD8 + 1.0097 SL8 - 1.3382$	10.89	85.31	96.2
CW 6243	$SW9 = 2.1046 SD9 + 1.0350 SL9 - 1.9224$	40.55	58.65	99.2
CW 3702	$SW10 = 1.8174 SD10 + 1.2031 SL10 - 1.7668$	18.19	81.31	99.5
Uthong 5	$SW11 = 1.8775 SD11 + 1.2508 SL11 - 1.9078$	12.36	87.14	99.5
PS 881	$SW12 = 2.6611 SD12 + 1.1821 SL12 - 2.4975$	14.12	79.18	93.3
Bululawang	$SW13 = 1.2121 SD14 + 0.9116 SL14 - 1.1009$	15.82	83.78	99.6

The number of harvested stems is the result of the number of tillers that can grow into productive stems. Tillers can grow into productive stems if they are supported by the available carbohydrates for growth that depends on the rate of photosynthesis [24]. The number of shoots formed, the rate of plant photosynthesis, and the number of harvested stems are influenced by the interaction of the clone/variety with its growing environment [25-27]. Stem weight and number of harvested sugarcane stalks are two growth variables that influence sugarcane productivity Side, et al. [21]. Moraes, et al. [25] stated that sugarcane productivity is influenced by the interaction of clones with their growing environment.

In this research, a relationship was obtained between sugarcane productivity and stem weight and the number of harvested stems with a total contribution of 97.4-100% depending on the clone/variety used (Table 16). The MLG 19, KDI 11, 400 Soff 1132, and PS 881 clones were more dominantly influenced by the number of stems (64.97-81.58%), while the other clones/varieties were more dominantly influenced by stem weight (63.93-99.38%). The research results of Shikanda, et al. [28] using 22 introduced sugarcane clones showed that the number of stems was more dominant in influencing sugarcane productivity. Natarajan, et al. [29] also found that stalk number was a significant component of cane yield under rainfed. However, using radiation- mutant sugarcane clones found that stem weight was more dominant (50.82%) in influencing sugarcane productivity [21].

Table 16.

Relationship between sugarcane productivity (TC) and number millable canes (NM) and stem weight (SW) in each clone/variety and the contribution.

Clones/varieties	Formula	Contribution (%)		
		NM	SW	Total
MLG 19	$TC1 = 1.0802 NM1 + 1.6283 SW1 - 1.2223$	81.58	18.42	100.0
MLG 75	$TC2 = 0.8374 NM2 + 1.0451 SW2 - 0.6538$	16.39	83.31	99.7
PBG 2	$TC3 = 1.1530 NM3 + 0.9013 SW3 - 0.7860$	20.42	76.98	97.4
KDI 11	$TC4 = 0.6334 NM4 + 0.7832 SW4 - 0.3647$	72.10	27.90	100.0
386 Soff 1118	$TC5 = 0.9942 NM5 + 0.8418 SW5 - 0.6244$	33.44	66.46	99.9
400 Soff 1132	$TC6 = 0.9185 NM6 + 1.0407 SW6 - 0.7056$	64.97	34.93	99.9
CW 6535	$TC7 = 1.0602 NM7 + 1.0464 SW7 - 0.8200$	0.62	99.38	100.0
CW 6222	$TC8 = 0.9023 NM8 + 0.9376 SW8 - 0.6201$	1.94	97.96	99.9
CW 6243	$TC9 = 0.5513 NM9 + 0.9868 SW9 - 0.4341$	0.62	98.88	99.5
CW 3702	$TC10 = 1.1279 NM10 + 0.9143 SW10 - 0.7663$	13.86	85.84	99.7
Uthong 5	$TC11 = 1.2345 NM11 + 0.8887 SW11 - 0.8248$	30.33	69.67	100.0
PS 881	$TC12 = 1.2879 NM12 + 1.0829 SW12 - 1.0461$	70.32	29.08	99.4
Bululawang	$TC13 = 8.7073 NM14 + 9.8572 SW14 - 0.6239$	36.07	63.93	100.0

Sugar content is the sucrose content in sugarcane stems that depends on the amount of sucrose and the weight of the sugarcane stalk. The sucrose in sugarcane stems is the result of the accumulation of stored carbohydrates produced by photosynthesis during the ripening phase. Stem weight, photosynthesis rate, and length of the ripening phase are influenced by the interaction of the clone/variety with its growing environment [30, 31].

Sugarcane productivity and sugar content are two production components that influence sugar yield [19]. In this study, a relationship was obtained between sugar yield and sugarcane productivity and sugar content with a total influence of 98.8-100.0% depending on the clone/variety used (Table 17). All clones/varieties were more dominantly influenced by sugarcane productivity (56.43-99.32%) than sugar content (2.86-42.37%). The research results of Side, et al. [21] show the dominance of sugarcane productivity in influencing sugar yield. Considering that sugarcane productivity and sugar content are influenced by the interaction of the clone/variety with the growing environment, the sugar yield is also influenced by their interactions [32]. Sugar yield was influenced by the interaction of clones with their growing environment [33, 34].

Table 17.

The relationship between sugar yield (TS) and sugarcane productivity (TC) and sugar content (SC) for each clone/variety along with the contribution.

Clones/varieties	Formula	Contribution (%)		
		TC	SC	Total
MLG 19	$TS1 = 1.0092 TC1 + 0.9126 SC1 - 0.7487$	91.34	8.66	100.0
MLG 75	$TS2 = 1.0282 TC2 + 0.9534 SC2 - 0.8016$	99.32	0.68	100.0
PBG 2	$TS3 = 1.0276 TC3 + 0.7449 SC3 - 0.62038$	90.35	9.65	100.0
KDI 11	$TS4 = 1.0519 TC4 + 0.7017 SC4 - 0.6026$	86.32	13.77	100.0
386 Soff 1118	$TS5 = 1.1786 TC5 + 1.2800 SC5 - 1.20703$	96.32	3.68	100.0
400 Soff 1132	$TS6 = 1.0276 TC6 + 0.8104 SC6 - 0.6907$	81.60	18.20	99.8
CW 6535	$TS7 = 1.0674 TC7 + 1.0400 SC7 - 0.9095$	77.67	22.67	99.7
CW 6222	$TS8 = 1.0320 TC8 + 0.9481 SC8 - 0.7993$	87.29	12.71	100.0
CW 6243	$TS9 = 1.0770 TC9 + 0.7655 SC9 - 0.6716$	57.16	42.84	100.0
CW 3702	$TS10 = 1.1800 TC10 + 0.9574 SC10 - 0.9297$	78.25	21.05	99.3
Uthong 5	$TS11 = 1.0148 TC11 + 0.6964 SC11 - 0.5852$	56.43	42.37	98.8
PS 881	$TS12 = 0.9690 TC12 + 0.7983 SC12 - 0.6277$	96.84	2.86	99.7
Bululawang	$TS13 = 0.9699 TC14 + 0.9173 SC14 - 0.7250$	86.60	13.20	99.8

4.2. Stability of Sugarcane Clones/Varieties Based on Growth and Sugar Yield

Sugar yield depends on sugarcane productivity and sugar content, both individually and combined depending on the clone/variety used [35]. In this research, the stability of clones based on sugar yield depends on the clones used such as unstable clones of PBG 2, KDI 11, 386 Soff 1118, 400 Soff 1132, CW 6243, and CW 3702 (Table 14), unstable clones based on sugarcane productivity (Table 12) and sugar content (Table 13). This also applies to stable clones (MLG 19, MLG 75, CW 6535, CW 6222, Uthong 5, PS 881, and Bululawang) based on sugar yield (Table 14) and sugarcane productivity. Sugarcane productivity is determined by the number of harvested stems and weight, both individually and combined depending on the clone/variety used [36]. In this study, six clones were classified as unstable based on sugarcane productivity (Table 12), of which three clones (KDI 11, 386 Soff 1118, and 400 Soff 1132) based on the number of stems (Table 11) and stem weight (Table 10) and three other clones (PBG 2, CW 6243, and CW 3702) based on stem weight. Seven clones/varieties were classified as stable based on sugarcane productivity, and six clones/varieties (MLG 19, MLG 75, CW 6535, CW 6222, Uthong 5, and Bululawang) were based on the number of stems and stem weight, while PS 881 variety was based only on the number of stems.

Stem weight is determined by the length and diameter of the stem, both individually and combined depending on the clone/variety used [35]. In this study, seven clones/varieties were unstable (PBG 2, KDI 11, 386 Soff 1118, 400 Soff 1132,

CW 6243, CW 3702, and PS 881), based on stem weight (Table 10), based on length (Table 8), and diameter (Table 9). There were six clones/varieties classified as stable, two of which (MLG 19 and CW 6222) were based on stem length and diameter, while the other four clones/varieties (MLG 75, CW 6535, Uthong 5, and BL) were based on stem length.

5. Conclusion

Among the 11 sugarcane clones tested, none produced a sugar yield higher than PS 881 (12.47 t ha⁻¹) or Bululawang (11.66 t ha⁻¹). However, four clones achieved sugar yields ranging from 11.71 to 12.40 t ha⁻¹, which were statistically comparable to the two check varieties. Two clones (CW 6535 and CW 6222) were classified as stable, while the other two (386 Soff 1118 and 400 Soff 1132) were identified as unstable. These selected clones require further evaluation across diverse agroecosystems before being considered for release as new commercial varieties.

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