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Growth and Yield Potential of New Sugarcane Varieties during Plant and First Ratoon Crops

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Abstract: Newly released sugarcane varieties need to be adapted to various environments. This research was aimed at examining the growth and yield potential of newly released varieties of sugarcane in the first year as plant cane (PC) and the second year as first ratoon cane (RC1) on dry land. The research was carried out at Wedarijaksa station, Trangkil Sugar Mill area, Pati, Central Java in 2019–2021. Four sugarcane varieties were grown using a double rows system, AAS Agribun, ASA Agribun, AMS Agribun, and CMG Agribun and one commercial variety, PSJK 922. Measurements of crop growth were made periodically: yield components at harvest in PC-RC1, and physiological characteristics 5 months after planting. The results indicate that mean tonnes of cane and sugar per hectare between PC and RC1 decreased by 22.7% and 21.0%, respectively, for AAS Agribun, ASA Agribun, and CMG Agribun due to decreased stem weights. AMS Agribun showed the smallest decrease in tonnes of cane (4%) and increase in tonnes of sugar per hectare (2%) from PC to RC1. The highest number of tonnes of sugar in PC was achieved by ASA Agribun (12.8 t ha^{-1}), slightly above PSJK 922 (12.69 t ha^{-1}). The decline in tonnes of cane and sugar needs to be reduced by the continuously improving cultivation techniques. The mean photosynthetic water use efficiency of tested new varieties was 7.46 µmol CO_2 mol H_2O^{-1}. These research findings provide information on crop performance and can be used as a basis for selecting varieties to be developed in the region. Further studies will be required to test these new sugarcane varieties in a wide range of agroecological zones in Indonesia.

Keywords: plant cane; ratoon cane; sugarcane; yield potential

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1. Introduction

Sugarcane as a sugar-producing plant continues to receive attention from the Indonesian government because the need for sugar is increasing along with population and industry growth. National sugar production in 2019 reached 2.227 million tonnes, which was below the average national demand of 5.7 million tonnes [1]. Increasing sugar production toward self-sufficiency is essential to reduce the country's dependence on imports.

A program to increase sugarcane productivity requires the use of new high-yielding varieties and appropriate cultivation technology. Sucrose yield is influenced by plant genetics and the growing environment through genetic engineering, environmental engineering, or both simultaneously [2] and is determined by sugarcane productivity and sucrose content [3,4]. The interaction between plant genetics and the growing environment in improving sugarcane growth and production has been widely reported by Panhwar et al., Junejo et al., and Gomathi et al. [2,5,6].

The Indonesian Agency for Agricultural Research and Development released four new mid- to -late-maturing varieties of sugarcane in 2017. These varieties needed to be tested for their suitability in various ecosystems of sugarcane areas in Indonesia. The five largest

areas of sugarcane in Indonesia are East Java, Lampung, Central Java, South Sumatra, and West Java. The adaptation of these new varieties needs to be intensified so that they are known and utilized, then supported by appropriate cultivation technology.

The yield potential of sugarcane is strongly influenced by the growing environment in addition to its genetic potential. The environment for growing sugarcane in Indonesia is predominantly dry land with erratic climate conditions, so productivity varies with time and space. The aim of this study was to obtain the growth and potential yield components of four sugarcane varieties.

2. Materials and Methods

Two field trials were conducted in the Trangkil Sugarmill region, Pati, Central Java, Indonesia (latitude 6°40′14″ S and longitude 111°4′3.17″ E, altitude of 50.4 m asl) during the 2019–2020 (plant cane) and 2020-2021 (first ratoon cane) seasons. The region has an Oldeman D3 climate type, tropical with average annual rainfall of 1614 mm and mean temperature of 27.4 °C. The soil was classified as clay texture, with 40% clay, 37% silt, 23% sand, and 1.15% organic carbon. Sugarcane varieties were planted in the third week of July 2019 and harvested in 2020 (PC), then the first ratoon was started in 2020 and harvested in 2021(RC1). The cane seed rate was 12 buds per meter of row. Sugarcane varieties tested included four new varieties (AAS Agribun, ASA Agribun, AMS Agribun, and CMG Agribun) and one commercial variety (PSJK 922). The total land used was 1 ha and each variety occupied 0.2 ha. Irrigation was applied when required, especially after planting, for setting establishment with limited water resources at the location site.

Agronomic practices included a double-row planting system with row spacing of 50–170 cm, application of biochar 2 weeks before planting (5 t ha^{-1}), planting of *Crotalaria juncea* (3 rows) between rows and applied as fertilizer cover in line with the second fertilization, and fertilizer for the double-row system, which was 1.4 times the recommended dose for a single row. The recommended dose of fertilizer for the location site is 800 kg of ZA and 400 kg of compound fertilizer NPK (Phonska). Plant maintenance consisted of weeding, cleaning out or trashing dry leaves, and renewing and repairing the drainage system.

Data were recorded for plant height growths 4–12 months after planting (MAP) and 3–10 months after harvest (MAH) of ratoon cane. Plant population, length, diameter, and stem weight were measured before harvesting. A sample of 20 randomly chosen stalks was taken from each plot (variety) to determine sucrose content in the laboratory using a saccharimeter. Photosynthesis and transpiration rates as well as stomatal conduction of PC plants were recorded 5 months after planting using the LCpro-SD portable photosynthesis system by ADC Bioscientific. Monthly rainfall data for 2019–2021 were collected from the nearby weather station.

3. Results and Discussion

3.1. Environmental Factors

The rainfall distribution in the location site during PC and RC1 in 2019–2021 is presented in Figure 1. The total amount of rainfall from planting to harvest was 1417 mm during the PC period and 1303 mm during RC1, with different distributions. The location site suffered from a water deficit or a long dry period with no significant rainfall from germination to tiller formation (after planting in July 2019). Tiller formation (tillering to early grand growth) is a very important component that affects the final yield by a storage sink [7] and is critical to water requirements. The onset of the 2019–2020 rainy season was delayed until late December 2019 or early 2020. The prolonged dry season in 2019 occurred in several regions of Indonesia, where it was extremely dry until the end of December, and limited rainfall in November was insufficient to compensate for the prolonged water deficit at this site. This condition caused a delay in germination. Optimum soil moisture during the initial stage is very important for root development and germination [8]. These new sugarcane varieties are reasonably tolerant to drought and can withstand drought stress conditions. The sugarcane reacted to the water deficit by rolling the leaves to reduce the

surface area exposed to radiation; this is a defense mechanism described by Dinh et al. [9]. Heavy rainfall occurred in January–February 2020, supporting sugarcane stem elongation. During stem elongation, there is maximum crop development, stem size, weight, and leaf production [10]. Sugarcane is susceptible to water stress during tillering and elongation phases [11].

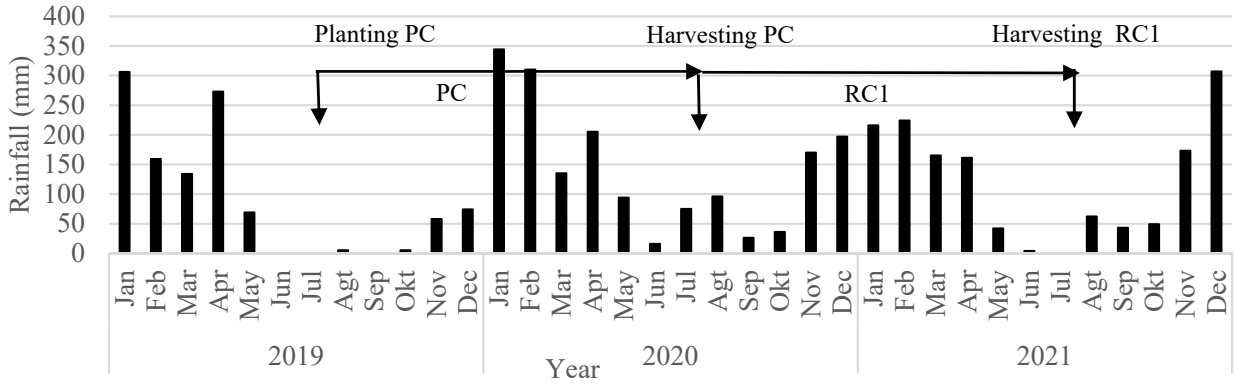


Figure 1. Rainfall distribution at study site in 2019–2021 from planting to harvesting of plant cane (PC) and first ratoon cane (RC1).

The total amount of rainfall during the PC growth period (planting to April 2020) was 1136 mm and during the maturing period was 281 mm (dry season from May to August 2020). Rainfall during the RC1 growth period (September 2020 to April 2021) was 1195 mm and during the maturing period (May to August 2021) was 108 mm. Rainfall during the PC and RC1 growth periods meet the water requirement of sugarcane. Rainfall during the dry season (PC maturing phase) was evenly distributed and the amount was higher in PC than RC1. Soil moisture and temperature both influence the sugarcane ripening process [12–14]. More frequent and intense extreme climate events are a major threat to global crop production, including sugarcane, therefore, sugarcane varieties that are tolerant to water stress are highly needed in the future [15,16] to minimize yield loss [17]. Water deficit will be the main factor affecting rainfed sugarcane yield, as in the future climate will be highly variable and uncertain around the world [18]. Climatic factors including rainfall and maximum and minimum temperature significantly affect sugarcane yield and could be a serious threat [19].

3.2. Sugarcane Growth Components

The growth components of plant height at various ages in PC (Figure 2a) showed nearly the same pattern for all varieties tested and had lower values than the commercial PSJK 922. A similar pattern was also found for the height of ratoon cane (Figure 2b). The tested sugarcane varieties reached the maximum plant height before harvest, ranging from 271–315 cm and 351 cm in commercial varieties. AAS Agribun and ASA Agribun reached a height of 315 cm before harvest, and AMS Agribun and CMG Agribun showed lower plant height of 270–280 cm in PC. Additionally, AAS Agribun in RC1 reached the same height as PSJK 922 (323.6 cm) at 10 MAH (Figure 2b), and the other varieties reached 288 cm. The RC sugarcane reached its maximum height at 10 MAH.

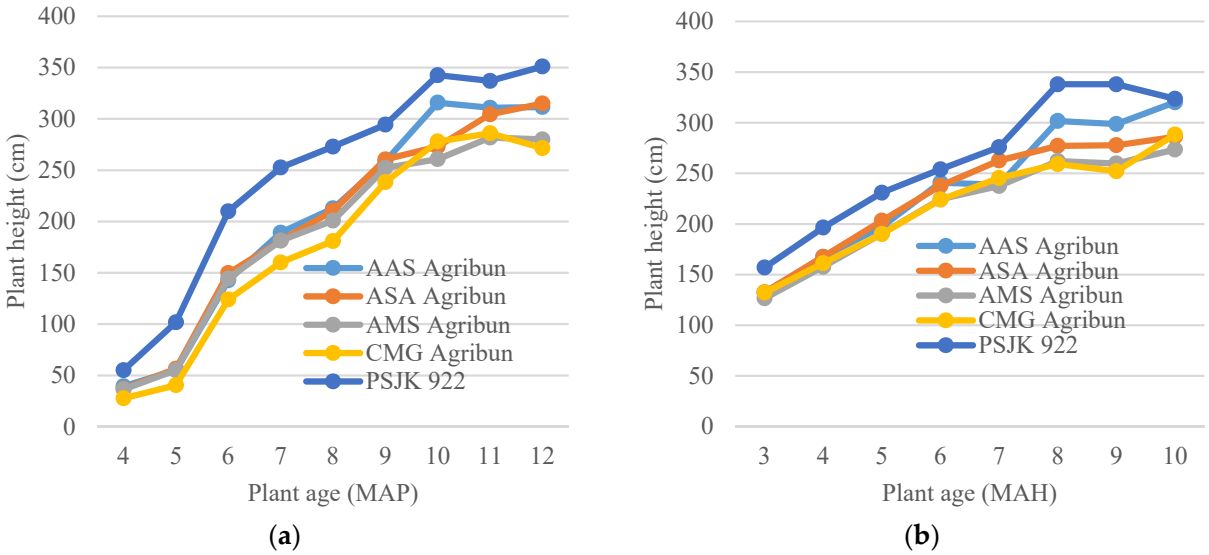


Figure 2. Plant height by age in (**a**) plant cane (PC) (month after planting, MAP) and (**b**) first ratoon cane (RC1) (month after harvesting, MAH).

Plant height and plant population (stem number) before harvest are very significant yield components determining yield gain. Figure 3a shows that peak plant heights in PC and RC1 did not differ much, reaching 281–310 cm in PC and 273–320 cm in RC1. AAS Agribun reached a plant height of 310 and 320 cm, respectively, in PC and RC1. AMS Agribun and CMG Agribun reached the same height in PC and RC1. Figure 3b shows that the plant population was in the range of 7.39–10.78 stems m^{-1} in PC and 8.22–10.94 stems m^{-1} in RC1. ASA Agribun produced very nearly the same population between PC and RC1, 10.78–10.94 stems m^{-1}, which was practically the same as PSJK 922, with a population of 10.07–10.34 stems m^{-1} in PC and RC1. CMG Agribun had the lowest population in PC and RC1 (7.39–8.22 stems m^{-1}). Higher tiller production determined the final number of stems at harvest [20].

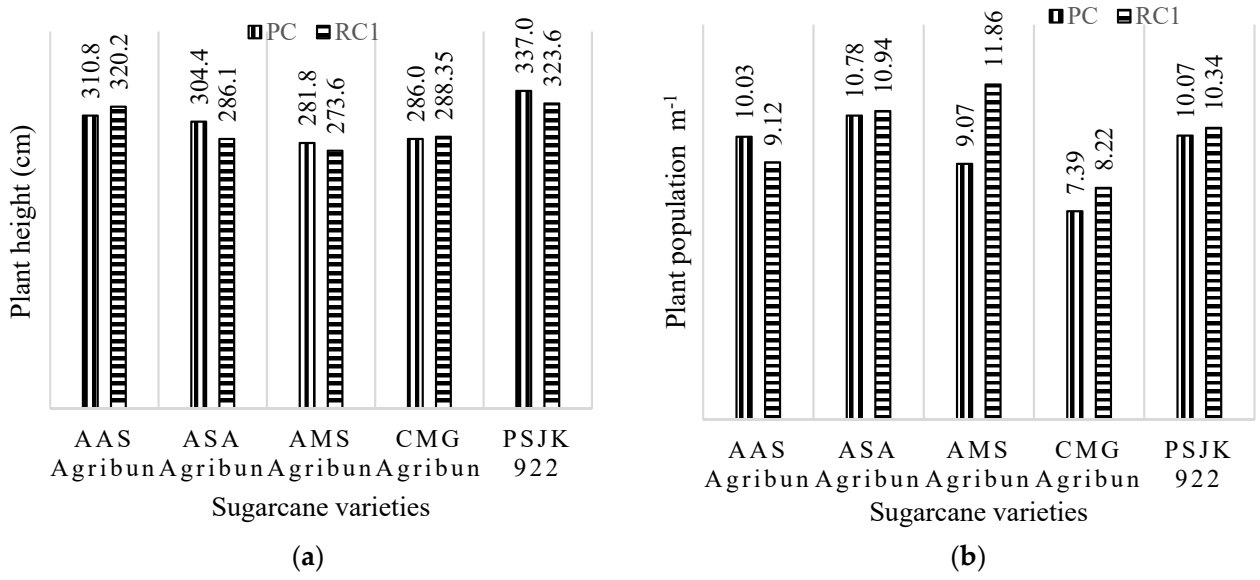


Figure 3. (**a**) Plant height and (**b**) population per meter row of tested sugarcane varieties before harvesting of plant cane (PC) and first ratoon cane (RC1).

3.3. Sugarcane Yield Potentials

The stem length of AAS Agribun was 267–276 cm in PC and RC1, and the other varieties had decreased stem length, from 255–265 cm to 236–247 cm in PC and RC1, as shown in Figure 4a. The stem length of PSJK 922 was 278–283 cm in PC and RC1, longer than the new varieties tested. As shown in Figure 4b, stem diameter decreased in all tested varieties, ranging from 27.56–30.11 mm to 22.94–24.94 mm in PC and RC1. CMG Agribun had the shortest stem length (Figure 4b) but the largest stem diameter (Figure 4b) in both PC and RC1. PSJK 922 had the largest stem length and diameter. The stem diameter of AAS Agribun decreased between PC and RC1, though its length increased.

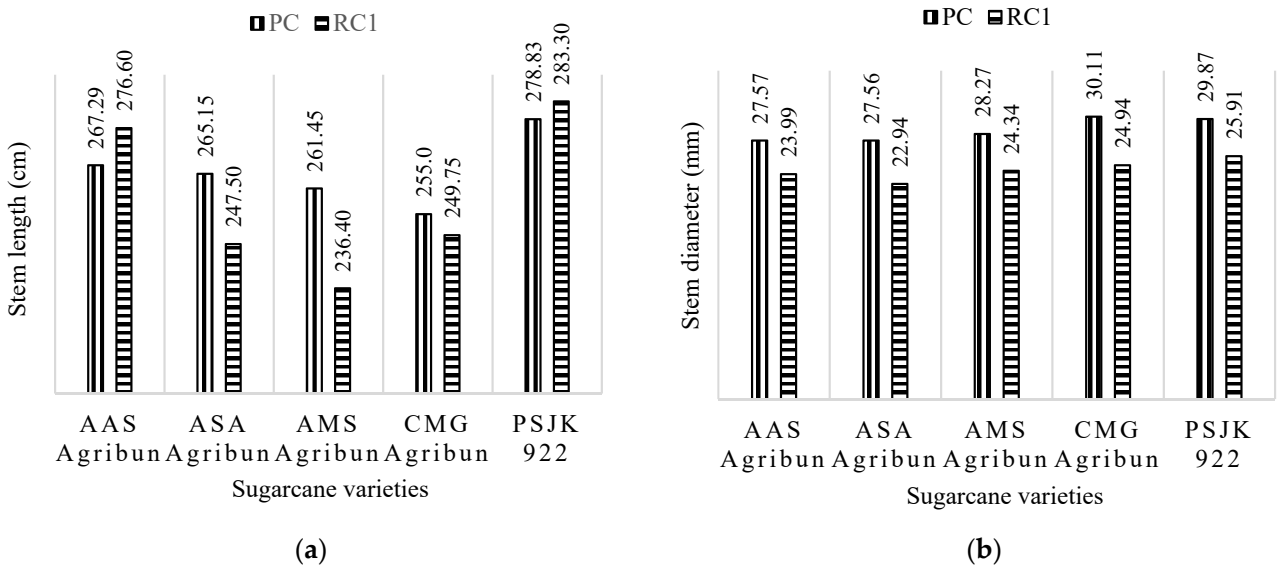


Figure 4. (**a**) Stem length and (**b**) stem diameter in plant cane (PC) and first ratoon cane (RC1) of tested sugarcane varieties before harvesting.

The decrease in the stem length and diameter between PC and RC1 caused a decrease in the stem weight (Figure 5a). Silva et al. [21] reported a close relationship between stem diameter and weight. Maintaining the sugarcane population at an optimum density and increased stalk weight is important to increase sugarcane yield [22]. The stem weight ranged from 0.61–0.82 kg m^{-1} in PC and 0.48–0.59 kg m^{-1} in RC1. The variety CMG Agribun had the highest stem diameter and weight but relatively short stem length. Another yield component is sucrose content (Figure 5b). The sucrose content between PC and RC1 increased in AAS Agribun and AMS Agribun, was relatively stable in ASA Agribun, and decreased in CMG Agribun. The sucrose content of the varieties tested in PC was higher than that of PSJK 922 in RC1, except for CMG Agribun. The range of sucrose content was 7.22–8.9% in PC and 6.75–8.44% in RC1. The sucrose content of PSJK 922 was 6.48 and 7.53% in PC and RC1, respectively. The sucrose content determines tonnes of sucrose per hectare (TSH). Sucrose content is affected by variety; our results agree with those obtained by Ahmed and Awadalla [23], and are lower than those obtained by Urgesa and Keyata [24] at a harvest age of 12 months in Ethiopia.

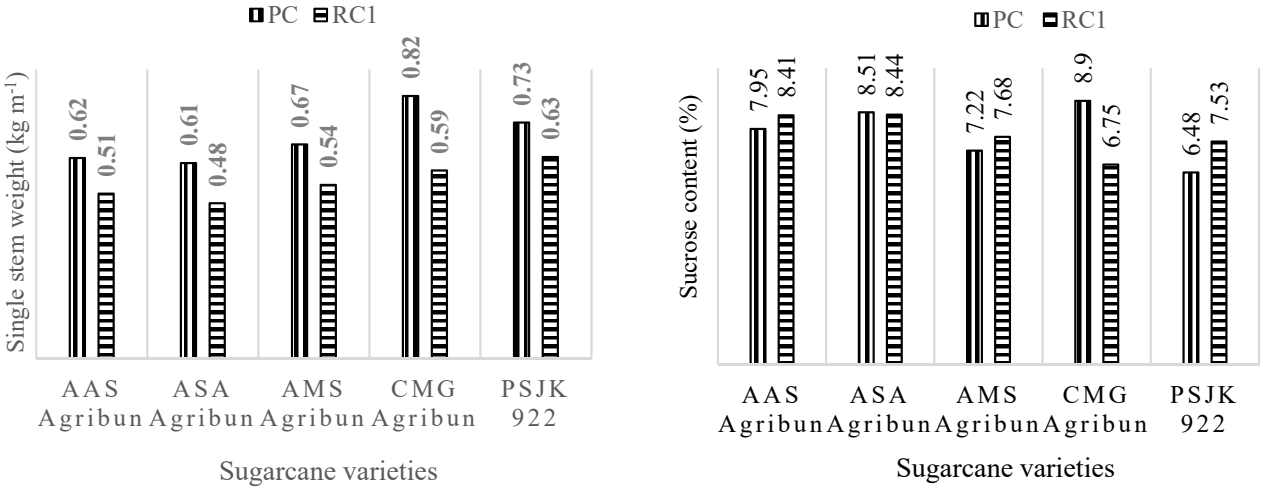


Figure 5. (**a**) Stem weight and (**b**) sucrose content of tested sugarcane varieties in plant cane (PC) and first ratoon cane (RC1) before harvesting.

The length and weight of the sugarcane stem determine the tonnes of cane per hectare (TCH). There is a linear relationship between stalk height and cane yield [20]. Stalk number, diameter, length, and weight influence sugarcane yield [25]. The TCH of the tested varieties is presented in Figure 6a, with a range of 133–150 t ha^{-1} in PC and 105–131 t ha^{-1} in RC1. The TCH of ASA Agribun between PC and RC1 decreased by 25%, from 150.34 t ha^{-1} to 113 t ha^{-1}; by 22% for AAS Agribun, from 144.54 t ha^{-1} to 112.29 t ha^{-1}; and by 21% for CMG Agribun, from 133.05 t ha^{-1} to 105 t ha^{-1}, or an average reduction of 22.7% for the three varieties. The lowest decrease in TCH was 4% for AMS Agribun, from 136.6 t ha^{-1} to 131.79 t ha^{-1}. PSJK 922 showed a 10% decrease in TCH from 176.62 t ha^{-1} to 158.44 t ha^{-1}. AMS Agribun, which exhibited a low percent reduction in TCH, can be used in future evaluations in limited water conditions. The potential cane yield of the new varieties tested was higher than that obtained from other commercial varieties surrounding the Trangkil Sugar Mill (72 t ha^{-1}) and the national productivity level in 2019 (67.39 t ha^{-1}), and values reported by Priya et al., Dlamini and Zhou, and Singh et al. [8,26,27].

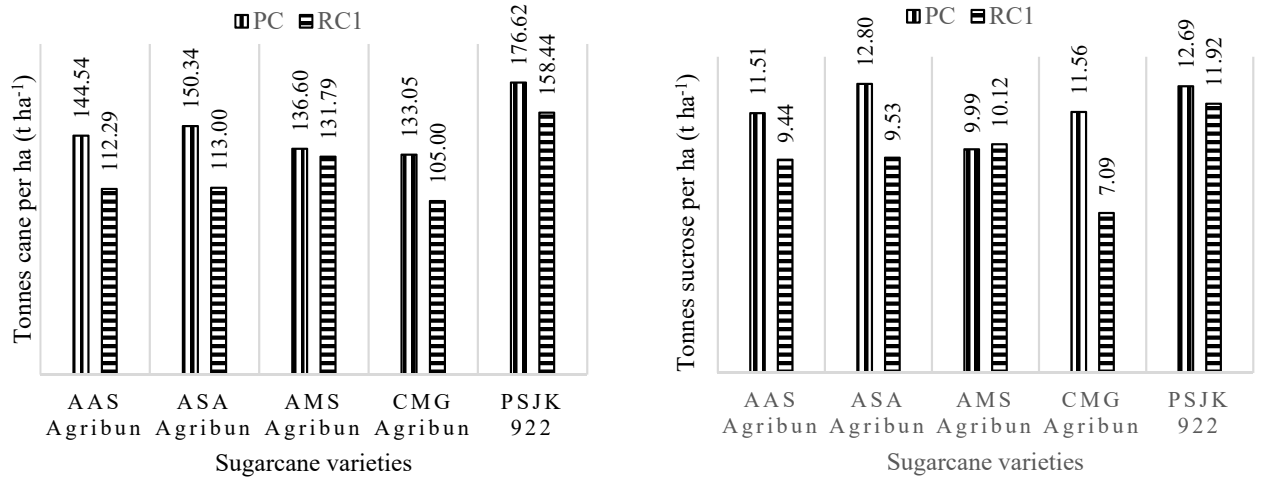


Figure 6. (**a**) Tonnes of cane per ha and (**b**) tons of sucrose per ha of tested sugarcane varieties in plant cane (PC) and first ratoon cane (RC1).

Tonnes of sugar per hectare is calculated by multiplying sucrose content (Figure 5b) by TCH (Figure 6a), as shown in Figure 6b. The TSH range was 9.99–12.80 t ha^{-1} in PC and 7.09–10.12 t ha^{-1} in RC1. The highest TSH in PC was achieved by ASA Agribun (12.8 t ha^{-1}), which was slightly above PSJK 922 (12.69 t ha^{-1}) and higher than the values obtained by Sanghera and Bhatt [28] under normal conditions. Generally, the TSH in RC1 decreased, except AMS Agribun was relatively stable between PC (9.99 t ha^{-1}) and RC1 (10.12 t ha^{-1}). Dumont et al. [29], in a study of Reunion Island, proposed that breeding program should select for high sugar yield through cane tonnage and sugar content for sustainable cane production. Variations in sucrose yield were mostly influenced by cane yield rather than sucrose concentration (POL%). Decreased cane yield depends on the environment, and there is greater decline with poor soil quality.

3.4. Physiological Characteristics

Based on the variance analysis, there was an interaction between the rate of transpiration (x) and photosynthesis (y) of the four high-yielding sugarcane varieties tested (Figure 7a; expressed by the linear equation y = 6.8632x + 2.003 with R^2 = 0.737 (R = 0.858). The higher the transpiration rate, the higher the photosynthesis rate. Photosynthetic water use efficiency (PWUE) was calculated by the ratio of photosynthetic rate to transpiration rate [9]. The average photosynthesis rate of the four varieties was 15.06 ± 3.09 mol m^{-2} s^{-1} and the transpiration rate was 2.02 ± 0.45 mol m^{-2} s^{-1}, so the average PWUE was 7.46 mol CO_2 mol H_2O^{-1}. This value is higher than the average obtained by Dinh et al. [9] at various nitrogen levels and soil moisture conditions (6.3–6.7 mol CO_2 mol H_2O^{-1}) in a greenhouse in Japan, the value reported by Riajaya et al. [30] from promising sugarcane clones under different planting systems (4.0 µmol CO_2 mol H_2O^{-1}), and the value reported by Endres et al. [31] in Brazil (4.4 µmol CO_2 mol H_2O^{-1}, depending on the variety). Water use efficiency in some plants can be considered as a characteristic for the selection of sugarcane clones in limited-water conditions in the tropics or sub-tropics, as suggested by Inman-Bamber et al. [32]. C4 plants, including sugarcane, are very efficient at water use, with more carbon is absorbed per unit of water released than C3 [33].

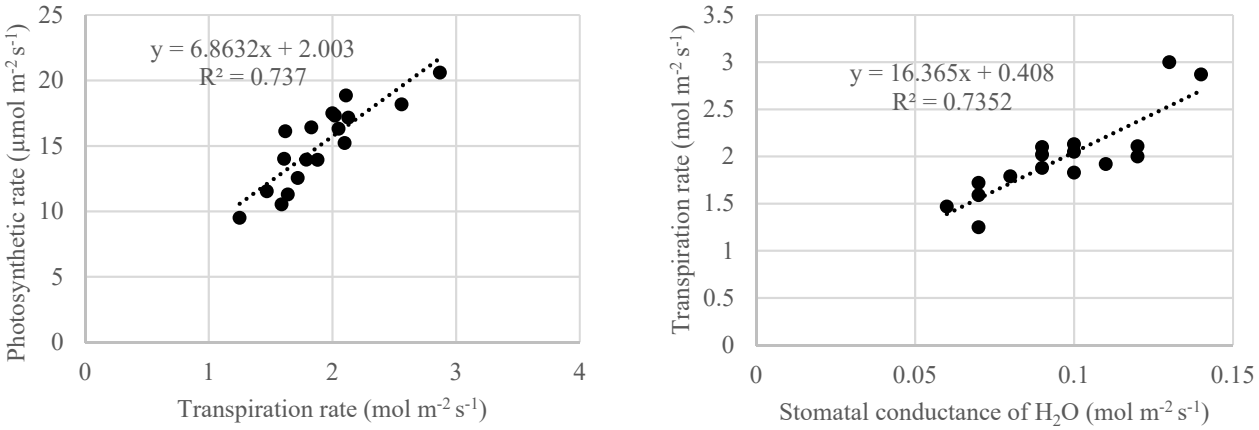


Figure 7. Relationships of (**a**) photosynthesis and transpiration rate and (**b**) transpiration rate and stomatal conductance of tested sugarcane varieties in plant cane (PC).

The stomatal conductance (x) and transpiration rate (y) of sugarcane have a positive relationship, expressed by the linear equation y = 16.365x + 0.408 with R^2 = 0.7352 (R = 0.857), as shown in Figure 7b. The mean stomatal conduction was 0.10 ± 0.02 mol m^{-2} s^{-1}. Silva et al. [34] observed a positive correlation between stomatal conductance and photosynthesis in genotypes tested in Texas. A combination of sugarcane yield and transpiration rate should be considered in clone selection in areas where water availability is a limiting factor [35].

A decline in the availability of water reduces stomatal conduction; resulting in a decrease in the photosynthesis rate due to the reduced internal carbon content. Stomatal closing decreases the transpiration rate and increases leaf temperature. Silva et al. [34] also found a positive relationship between stomatal conduction and transpiration in response to low water availability.

4. Conclusions

Growth and yield potentials varied in the tested varieties in plant cane and first ratoon cane. The growth potential of plant height showed the same pattern in both, reaching a peak of 281–310 cm in plant cane and 273–320 cm in first ratoon cane, and was lower than the commercial variety PSJK 922. Plant population was in the range of 7.39–10.78 stems m^{-1} in plant cane and 8.22–10.94 stems m^{-1} in ratoon cane. The sugarcane yield potential showed that mean tonnes of cane decreased by 22.7 and 21.0% for tonnes of sugar per hectare between plant cane and ratoon cane for AAS Agribun, ASA Agribun, and CMG Agribun due to decreased stem weight. AMS Agribun showed the lowest decrease in tonnes of cane (4%) and increase in tonnes of sugar per hectare (2%) between plant cane and first ratoon cane. The highest number of tonnes of sugar in plant cane was achieved by ASA Agribun (12.8 t ha^{-1}), which was slightly above PSJK 922 (12.69 t ha^{-1}). The declines in tonnes of cane and sugar need to be reduced by the continuous improvement of cultivation techniques. The mean photosynthetic water use efficiency of the tested new varieties was 7.46 µmol CO_2 mol H_2O^{-1}. The new sugarcane varieties need to be tested in a wide range of agroecological zones in Indonesia. This study is important for researchers to know the potential yields of new varieties and utilize them on a broad scale in sugarcane development areas, and they can be alternatives when selecting high-yielding mid- to -late-maturity sugarcane varieties.

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