Water use efficiency of sugarcane clones under rainfed condition

P D Riajaya* and F T Kadarwati

Indonesian Sweetener and Fiber Crops Research Institute (ISFCRI)
Jl. Raya Karangploso, Malang, East Java, Indonesia

Corresponding author email: primariajaya@gmail.com

Abstract. Crop water use study is necessary for crop management. The purpose of the research was to determine water use efficiency (WUE) of sugarcane clones under rainfed conditions. A field trial was carried out in rainfed at Kediri, East Java, from August 2018 to June 2020 in two seasons of plant cane (PC) and first ratoon cane (RC1). A Split-Plot Design was used for the field trial with three replications. Sub-plots consisted of five clones and one check variety. The WUE is the ratio of sugarcane yield to total crop evapotranspiration. Crop evapotranspiration was the reference evapotranspiration multiply by crop coefficients. Reference evapotranspiration needs meteorological data and relied on the FAO Penman-Monteith method. The average sugarcane crop evapotranspiration for two seasons was 1260.9 mm/year in PC and RC1, with effective rainfall of 817.6 mm and 797 mm, respectively. Average water use efficiency to produce sugarcane were 11.47 and 10.85 t/100 mm and sugar 1.085 and 0.884 t/100 mm, respectively, in PC and RC1. The WUE benefit as criteria for crop selection and to calculate the potential yield given the available water.

Keywords: sugarcane yield, sugar yield, crop evapotranspiration

1. Introduction

In recent years, sugarcane in Indonesia is generally sown under rainfed areas as one of the estate crops to produce sugar. The total sugarcane area in Indonesia is around 429 thousand hectares, with national sugar production of approximately 2.1 million tons in 2018. East Java province is the largest producer of sugar (48.19%) in dry land with smallholder sugarcane land ownership [1]. The national average sugarcane yields are around 70.72 t/ha and sugar 5.07 t/ha with a sugar content of 7.17% [2]. However, the yields fluctuate from year to year depending on climatic conditions and on-farm management. The crop is on the field for almost one year, facing the changing climatic elements in the year. Therefore, climate plays an essential role in sugarcane production.

The average rainy period in the sugarcane area of East Java is 14-20 decades shorter than the average in Sumatra (23.1 decades) [3]. Therefore, sugarcane resistance to drought is critical. In addition, we need information on clones with a high water use efficiency to produce high productivity with minimum use of water resources.

The water needs of sugarcane in rainfed land are met only from rainfall. Efficient water use of sugarcane reflected the effectiveness of water use from rain or irrigation to produce sugarcane yield per unit of water used through evapotranspiration [4]. Total evapotranspiration during sugarcane growth
was very high, ranging from 800-2000 mm [5]. As a result, sugarcane can grow in the tropics and subtropics and produce very high biomass, requiring very high plant water [6,7].

Sugarcane development on dry land depends on water availability, a limiting factor for sugarcane productivity. Globally limited water availability occurs in sugarcane areas because land expansion is usually to marginal areas with limited water availability, as in Brazil [8]. Water use efficiency is a standard measure in sugarcane: the ratio of sugarcane yield and unit of water used from planting to harvest [9]. This present study had the aims of determining the water use efficiency of sugarcane clones in rainfed land. Information on the efficient water use of sugarcane is essential and limited in Indonesia. This information is helpful as a criterion in crop selection for high resource use efficiency and yield prediction.

2. Materials and methods
The field studies were done in Janti Village, Wates, Kediri, East Java, between latitude S 7°51’20”, longitude E 112°4’19” and altitude 145 m asl during two seasons of 2018-2019 for plant cane (PC) and 2019-2020 for the first ratoon cane (RC1). The experimental site represented a typology of dry land with light-textured and well-drained soil. Sugarcane planting was done during the crop season in August 2018 and harvested in July 2019 for PC, then RC-1 started until June 2020. A Split-Plot Design was used for the field trial with three replications. Three planting systems were allocated to the main plot, namely single row (SR) with a spacing of 110 cm, double rows (DR1) with spacing 50+135 cm, and double rows (DR2) with spacing 50+170 cm. The subplots consisted of five promising clones: MLG-5, MLG-9, MLG-14, MLG-52, MLG-55, and PS-881 as a check variety. Sugarcane and sugar yields measurement were made at harvest.

The calculation of reference evapotranspiration (ETo) using the Penman-Monteith approach required meteorological data such as relative humidity, maximum and minimum air temperature, wind speed, and sunshine hours collected from the climatology station nearby. The calculation processes were related to crop water use [5,10] by running CROPWAT8.0 software for windows advanced by FAO (The Land and Water Development Division). The Penman-Monteith approach is a rational estimate of ET0 [11] and is generally used to compute ET0 using climatic data[12]. Crop evapotranspiration (ETo) was the ET0 multiply by a crop coefficient (kc) by soil water balance with ten-day periods. Crop coefficients for sugarcane were adapted from the standard FAO-56 methodology [12] that varied with plant development. That was 0.40 at the initial stage (planting to nearly 10% land coverage), 0.4 to 1.25 at the crop development stage (10% to full coverage), 1.25 at the midseason stage (full coverage to early maturity), and 1.25 to 0.25 at the late-season stage (early maturity to harvest). The monthly rainfall data were collected from the rain station near the experimental plot in Sidomulyo, Wates, Kediri, 2018-2020.

Crop water use in this study was the ratio of sugarcane yield to cumulative crop evapotranspiration from planting to harvest.

3. Results and discussion
Sugarcane and sugar that can be yielded in every unit of water used by the plant in PC and RC1 are presented in Tables 1 and 2. Sugarcane yield varied with planting arrangements and clones both in PC and RC1. The average WUE of sugarcane and sugar yields in PC was 11.47 t/100 mm and 1.085 t/100 mm, respectively (Table 1). The different planting arrangements and clones in RC1 had an average WUE of 10.85 t/100 mm and 0.884 t/100 mm for sugarcane and sugar yields (Table 2). PS-881 in PC and MLG-9 in RC1 was the most efficient in producing sugar (WUE=1.218 t/100 mm and 1.231 t/100 mm, respectively).

The promising clone for WUE was MLG-52, yielding 12.26 t/100 mm in PC and 12.54 t/100 mm in RC1. This value highlights the high ability of clone MLG-52 in converting water used into the fresh cane yield. The WUE in RC1 ranged from 10.44-11.60 t/100 mm for varying planting arrangements and 9.15-12.54 t/100 mm for several clones. The average WUE of sugarcane in RC1 was 10.85 t/100 mm (Table 2).
Table 1. Sugarcane water use efficiency (WUE) in PC.

| Treatments          | Yields of sugarcane (t/ha) | WUE in yields of sugarcane (t/100 mm) | WUE in yields of sugar (t/100 mm) |
|---------------------|---------------------------|---------------------------------------|-----------------------------------|
| Planting arrangements |                           |                                       |                                   |
| SR 110 cm           | 133.79 b*                 | 12.26 a                               | 10.61                             | 0.972                             |
| DR-1 50+135 cm      | 145.96 ab                 | 12.42 a                               | 11.58                             | 0.985                             |
| DR-2 50+170 cm      | 153.94 a                  | 13.99 a                               | 12.21                             | 1.110                             |
| Promising clones    |                           |                                       |                                   |
| MLG-5               | 143.60 ab                 | 10.59 b                               | 11.39                             | 0.840                             |
| MLG-9               | 142.26 ab                 | 14.55 a                               | 11.28                             | 1.154                             |
| MLG-14              | 126.71 b                  | 10.57 b                               | 10.05                             | 0.838                             |
| MLG-52              | 154.56 a                  | 13.55 a                               | 12.26                             | 1.075                             |
| MLG-55              | 149.22 ab                 | 12.73 ab                              | 11.83                             | 1.010                             |
| PS-881              | 151.02 a                  | 15.36 a                               | 11.98                             | 1.218                             |
| CV (%)              |                           |                                       |                                   |
| Average             | 15.14                     | 20.53                                 | 11.47                             | 1.085                             |

* Number sharing different letters in a column differ significantly by the DMRT at 5% probability.

Table 2. Sugarcane water use efficiency (WUE) in RC1.

| Treatments          | Yields of sugarcane (t/ha) | WUE in RC1 yields of sugarcane (t/100 mm) | WUE in yields of sugar (t/100 mm) |
|---------------------|---------------------------|-------------------------------------------|-----------------------------------|
| Planting arrangements |                           |                                           |                                   |
| SR 110 cm           | 146.26 a*                 | 11.93 a                                  | 11.60                             | 0.946                             |
| DR-1 50+135 cm      | 132.61 b                  | 10.83 a                                  | 10.52                             | 0.859                             |
| DR-2 50+170 cm      | 131.63 b                  | 10.68 a                                  | 10.44                             | 0.847                             |
| Promising clones    |                           |                                           |                                   |
| MLG-5               | 123.02 bc                 | 7.48 d                                   | 9.76                              | 0.593                             |
| MLG-9               | 154.26 a                  | 15.52 a                                  | 12.23                             | 1.231                             |
| MLG-14              | 149.22 ab                 | 12.73 ab                                 | 11.83                             | 1.010                             |
| MLG-52              | 158.07 a                  | 11.46 b                                  | 12.54                             | 0.909                             |
| MLG-55              | 140.46 ab                 | 11.24 b                                  | 11.14                             | 0.891                             |
| PS-881              | 132.86 bc                 | 11.69 b                                  | 10.30                             | 0.927                             |
| CV (%)              |                           |                                           |                                   |
| Average             | 10.54                     | 11.16                                    | 10.85                             | 0.884                             |

* Number sharing different letters in a column differ significantly by the DMRT at 5% probability.

WUE resulted from the present study were in line with those observed by [13] in Australia (12.21 t/ML), 4.8-12.1 t/ML in sites of Southern Africa, Hawaii, and Australia [14]. The other related studies also reported 12.6 t/100 mm of water in South Africa [4], 95.84 and 88.72 kg/ha/mm in PC and RC in Brazil [15], 71 kg/ha/mm in PC and 63 kg/ha/mm in RC in subtropical India [16], 70.2 kg/ha/mm in Brazil [17] and 5.43 kg/m³ in Iran [18]. Every 10 mm of water will produce one ton of sugarcane per hectare, and with highly efficient irrigation, the productivity increased to 1.5 t/ha [19]. The efficiency of water used under 80% of soil moisture conditions was 5-8 kg sugarcane/m³ and 0.6-1 kg sucrose/m³ [5]. There was a linear relationship between plant water use and biomass production in several crops, including sugarcane, under optimum environmental conditions of fertilizer, radiation, and temperature...
Most of the biomass in sugarcane production is in the form of stalks. High productivity and water use efficiency indicate good crop management. Increased productivity and low water use efficiency indicate the need to improve crop management. There are genetic variations in transpiration efficiency and water uptake by roots in sugarcane areas with varying rainfall [20].

Evapotranspiration of sugarcane varied with the crop phase from the initial stage, development stage to maturation (Figure 1). The mean sugarcane evapotranspiration was 1260.9 mm/year with effective rainfall of 817.6 mm for PC and 797 mm in RC1. This ETc was comparable to the mean ETc in two seasons computed by [21,22], ranging from 1399 mm/year (0% water deficit) and 1160 mm (30% water deficit) in the semiarid region. Annual sugarcane evapotranspiration was in the ranges of 1023.9 – 1068.5 mm in Brazil [23], 1231.5 mm average from nine seasons [24], 1645 mm [25], 829 mm (PC), and 685 mm (RC) in Southeast Brazil [11]. The other related researches also informed 1369.84 mm in Myanmar [26], 1450 mm in Bundaberg, Australia [13], 1100-1960 mm in many sites in Australia [19], 1542-1964 mm in Hawaii [27]. In addition, Carr and Knox (2011) [28] reported 1100-1800 mm from sugarcane plantations worldwide.

![Figure 1. Crop evapotranspiration of sugarcane throughout the sugarcane crop cycle in Kediri, E. Java.](image)

Accumulated ETc in Figure 2 at the initial stage was 35.0 mm or 2.78% from total ETc and reached 183.8 mm or 14.58% at the development stage (budding to intense tillering). During the midseason stage (growth in height), accumulated ETc was 796.6 mm or 63.19%, then turn to 245.3 mm or 19.46% at the late stage. The midseason stage of sugarcane plantation in Southeast Brazil accumulated 70% of the total ETc [29]. The midseason stage or the elongation stage of sugarcane from Nov I to Apr III consumed much water (fast crop development). Therefore, the soil moisture must be sufficient to supply crop water needs during that period. During this period, the cumulative ETc in Figure 2 continued to increase and slow down until the final phase. Sugarcane and sugar yields caused to reduce by 8.3-15% and 11.7-19.1%, respectively, when six weeks of water deficits occurred at the peak of ETc and less rainfall during the midseason [6].

Planting time is critical so that the maximum plant water need coincides with the rainy season period. The rainfall pattern in Figure 3 in PC and RC1 is slightly in line with the actual evapotranspiration pattern (Figure 1). Therefore, the peak of plant water needs coincides with the rainy season period from November to April. Starting from May (early of the dry season), the evapotranspiration decreased along with the ripening phase. During this period, the plant requires a dry period for sucrose accumulation. Therefore, the late-season phase in average weather conditions will coincide with the dry season.
Crop evapotranspiration and WUE are closely related and strongly determined by soil moisture. Yield increases with the increasing availability of water. Daily evapotranspiration and water use efficiency depend on soil water availability. Sugarcane evapotranspiration in Brazil was 2.7 mm/day under rainfed conditions to 4.2 mm/day at full irrigation[30], 4.25 - 4.32 mm estimated by Bowen ratio method in Brazil [31]. As the plant entered the maturity phase, the biomass did not increase, indicated by a slow plant growth rate and fewer water requirements. Libardi et al. (2019) [32] obtained average sugarcane evapotranspiration of 4.8 mm/day in Brazil, depending on the clones used. Momii et al. (2021) [33] calculated daily transpiration in Japan in the ranges of 3.3 - 6.6 mm/day. Each phase of plant growth has a different response to water stress. The amount of water used by plants is closely related to the level of production produced [34].

Total rainfall from planting to harvest in PC was 1242 mm and slightly less than the total observed in RC1 (1296 mm). Figure 3 shows the rainfall distribution for two seasons in PC and RC1. The rainy season period occurred from November to April-May and the dry season for the rest. The planting time was in August 2018, then the plant in PC entered the midseason stage at the rainy season. As a result, harvesting time in PC and RC1 coincided with the dry season in July 2019 and June 2020.
for irrigation. Crop water requirement in the initial phase is still relatively low and only about 200 mm of irrigation is needed to meet the total crop evapotranspiration. Furthermore, when the plant entered the rainy season the soil water conditions rise again. Soil water conditions fluctuate following the pattern of rainfall. Starting at the crop age of 80 to 170 days after planting along with the rainy season, the soil water deficit is lower, this can stimulate the growth of stem elongation. Next, when the plant entered the maturity phase, a soil water deficit was needed so that there was no need for irrigation although the soil water declined. Plants in the maturity phase coincided with the dry season.

![Figure 4. The simulated dynamic of soil moisture during the crop cycle of sugarcane growing in PC.](image)

4. Conclusion

Average sugarcane crop evapotranspiration was 1260.9 mm/year for plant cane and first ratoon cane, and effective rainfall was 817.6 mm and 797 mm, respectively. Average water use efficiency in sugarcane yield was 11.47 and 10.85 t/100 mm, and sugar yield was 1.085 and 0.884 t/100 mm, respectively, in PC and RC1. This WUE benefits as criteria for crop selection for high resource use efficiency and to calculate the potential yield given the available water.

Acknowledgments

The field study was financially supported by DIPA Balittas 2018-2020. In addition, the authors acknowledge the staff of the Experimental Station of Karangploso, Malang, for their help in the field activities and data collection.

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