Jurnal Tanah dan Iklim Vol. 44 No. 2, Desember 2020: 141-153
DOI: http://dx.doi.org/10.21082/jti.v44n2.2020.141-153

ISSN 1410-7244
E-ISSN 2722-7723

Agronomic Performance and Economic Benefits of Sugarcane (*Saccharum officinarum* L.) Under Drip Irrigation for Sandy and Clay Soils in East Java, Indonesia

Performa Agronomis dan Ekonomis Tebu dengan Irigasi Tetes pada Tanah Pasiran dan Lempung di Jawa Timur, Indonesia

Muhammad Rasyid Ridla Ranomahera[1*], Arinta Rury Puspitasari[1], Rivandi Pranandita Putra[1] ,Dias Gustomo[2], Sri Winarsih[3]

[1] Indonesian Sugar Research Institute, Jl Pahlawan No. 25, Pasuruan 67126, East Java, Indonesia
[2] PT Saraswanti Anugerah Makmur, AMG Tower Jl. Dukuh Menanggal No. 1A, Surabaya, East Java, Indonesia
[3] PT Tunas Nusantara Persada, Wisma 77 Tower II Jl. Letjend. S. Parman Kav 77 Lt. 7, Slipi, Jakarta Barat 11410, DKI Jakarta, Indonesia

INFORMASI ARTIKEL

Riwayat artikel:

Diterima: 8 Oktober 2020
Disetujui: 16 Desember 2020
Dipublikasi online: 22 Desember 2020

Kata Kunci:

Surface drip irrigation
Sub-surface drip irrigation
Conventional irrigation
Sandy soil
Clay soil

Keywords:

Irigasi tetes permukaan
Irigasi tetes bawah permukaan
Irigasi konvensional
Tanah berpasir
tanah lempung

Direview oleh:

Neneng L. Nurida, Elza Surmaini

Abstract. Sugarcane (*Saccharum officinarum* L.) growth and production are greatly affected by water availability. The lack of water availability in sugarcane cultivation can be surmounted by irrigation. In performing irrigation, it is essential to understand the sugarcane crop water requirement and soil texture as they influence the irrigation efficiency. To date, drip irrigation is considered as the most efficient type of irrigation. This study aimed to investigate both agronomic performance and economic benefits of different irrigation methods for sugarcane grown in sandy (in Kediri) and clay (in Pasuruan) soils. The irrigation treatments were surface drip irrigation, sub-surface drip irrigation, and conventional irrigation, while the conventional irrigation through drains was the control treatment. The experimental design was a Randomized Complete Block Design with three replications. In sandy soil, both surface and sub-surface drip irrigation led to better agronomical performance yet the conventional irrigation showed a contrasting result. Sugarcane productivity under surface drip irrigation, sub-surface drip irrigation, and conventional irrigation were 81.29, 110.33, and 69.25 tons ha^{-1}, respectively. Meanwhile, in clay soil, there were no prominent differences of agronomic parameters between all irrigation treatments. Sugarcane productivity under surface drip irrigation, sub-surface drip irrigation, and conventional irrigation were 79.03, 60.58, and 78.16 tons ha^{-1},respectively. The water cost used to produce one kg of sugarcane biomass under conventional irrigation, surface drip irrigation, and sub-surface drip irrigation in sandy soil were IDR 169, IDR 103, and IDR 87, while the cost in clay soil were IDR 443, IDR 218, and IDR 293, respectively.

Abstrak. Pertumbuhan dan produksi tebu (*Saccharum officinarum* L.) dipengaruhi oleh ketersediaan air. Kekurangan air dalam budidaya tebu dapat dipenuhi melalui irigasi. Dalam melakukan irigasi, penting untuk mengetahui kebutuhan air tebu dan tekstur tanah karena kedua faktor tersebut mempengaruhi efisiensi irigasi. Hingga saat ini, irigasi tetes merupakan salah satu jenis irigasi yang paling efisien dalam pertanian. Studi ini bertujuan untuk mengetahui performa agronomis serta keuntungan ekonomis berbagai metode irigasi pada tanaman tebu yang ditanam di tanah bertekstur pasir (di Kediri) dan lempung (di Pasuruan). Perlakuan irigasi pada penelitian ini yaitu irigasi tetes permukaan, irigasi tetes bawah permukaan, dan irigasi konvensional, dimana irigasi konvensional yang diberikan melalui parit menjadi perlakuan kontrol. Desain percobaan menggunakan Rancangan Acak Kelompok Lengkap, dengan tiga ulangan. Pada tanah pasir, performa agronomis tebu pada perlakuan irigasi tetes permukaan dan bawah permukaan lebih baik daripada irigasi konvensional. Produktivitas tebu pada irigasi tetes permukaan, irigasi tetes bawah permukaan, dan konvensional di tanah pasir masing-masing sebesar 81,29 ton ha^{-1}, 110,33 ton ha^{-1} dan 69,25 ton ha^{-1}. Pada lokasi percobaan di tanah lempung, tidak ada perbedaan agronomis tebu yang signifikan antar perlakuan irigasi. Produktivitas tebu pada irigasi tetes permukaan, irigasi tetes bawah permukaan, dan konvensional di tanah lempung masing-masing sebesar 79,03 ton ha^{-1}, 60,58 ton ha^{-1}, dan 78,16 ton ha^{-1}. Biaya air yang digunakan untuk memproduksi satu kilogram tebu dengan perlakuan irigasi konvensional, irigasi tetes permukaan, dan irigasi tetes bawah permukaan di tanah pasir masing-masing sebesar IDR 169, IDR 103, dan IDR 87, sedangkan di tanah lempung masing-masing sebesar IDR 443, IDR 218, dan IDR 293.

* Corresponding author: rranomahera@gmail.com

Introduction

Sugarcane (*Saccharum officinarum* L.) is one of Indonesia's strategic estate commodities. It is not merely the primary sugar producer but also the national economy booster (Sulaiman *et al*. 2019). Sugarcane production in the country fluctuates over the decades, but the trend is decreasing (Putra *et al*. 2013; Indonesian Directorate General of Estate Crops 2016; Indonesian Ministry of Agriculture 2020). Such decline may be linked with several factors, such as water availability, choice of sugarcane cultivars, cultivation practice, and sugar mill efficiency (Toharisman & Triantarti 2016; Putra *et al*. 2020). In Indonesia, sugarcane is mostly cultivated on drylands (Riajaya 2020), as well as in the future, sugarcane plantations in Indonesia have to be expanded to dryland areas, preferably outside Java Island (Hani & Mustapit 2016), as a sugarcane extensification program. Growing sugarcane in dryland areas requires a supplementary irrigation to ensure the optimum sugarcane productivity.

Sugarcane requires adequate, but not excessive water supply during its growth stage (Hunsigi 2012). Waterlogging condition may lead to a reduction of sugarcane growth and yield (Gomathi *et al*. 2015; Avivi *et al*. 2016; Jaiphong *et al*. 2017). Sugarcane crop water requirement (CWR) defined as the amount of water needed to compensate evapotranspiration process in the field (Fito *et al*. 2017). The value of sugarcane CWR during a crop cycle is within the range of 1,100-1,800 mm, depending on location (Carr & Knox 2011). Crop Water Requirement developed and diminished according the growth stage (Pawirosemadi 2011; de Oliveira 2018), and calculated using the data of crop coefficient (Kc), crop evapotranspiration (ET_0), and effective rainfall (Pe) (Ondieki & Kitheka 2017). Understanding CWR is essential to achieve irrigation efficiency (IE). However, IE is influenced by multiple factors, such as soil texture. Previous global studies revealed a difference in IE under various soil textures (Burke *et al*. 1999; Katerji & Mastrorilli 2009; Fang & Su 2019). Hence, although sugarcane does not require a special type of soil (FAO 2020), it is important to understand the difference of IE in different soil textures.

An efficient irrigation method in sugarcane cultivation, especially in drylands, shall be developed to maximize water use efficiency and minimize operational costs (Gunarathna *et al*. 2018). By far, drip irrigation is considered as the most efficient irrigation method in agriculture since the water is given directly around plant roots (Goyal 2012; Singh *et al*. 2016). The drip method uses a low discharge flow of two up to twenty liter hour^{-1} through pipelines equipped with outlets, i.e., emitter or dripper (Bajpai & Kaushal 2020). Drip irrigation leads to a higher water efficiency than other irrigation methods due to a lower evaporation, seepage, and percolation; thus, water consumption can be minimized (Yang *et al*. 2020). The timing of irrigation can also be precisely adjusted to crop needs. Although this irrigation method offers several benefits, it is not yet popular amongst sugarcane growers in Indonesia due to relatively high investment costs and the lack of technical expertise. Rather than sugarcane, drip irrigation is commonly implemented for high-value crops, such as vegetables, fruits, and flowers. The selection of the most appropriate agricultural irrigation method in a given area shall be considered based on various factors, such as soil characteristics (Sauer *et al*. 2010). The suitable irrigation system is essential to improve water use efficiency and to reduce salinity in the root zone (Zaman *et al*. 2018).

Sandy soils comprises of large particles causing low water retention, means that irrigation water given to this soil type immediately infiltrate into the bottom soil layer. On the contrary, clay soils have very a small, compact particles, and higher water retention than sandy soils. However, water flows quickly to clay soils have a potential to become run-off. This study purposed to assess both agronomic and economic attributes of sugarcane cultivation under drip irrigation over sandy and clay soil in East Java, Indonesia. Economic aspect considered in this study is intended to compare the economical benefit between drip irrigation and conventional irrigation. This is interesting to investigate the potential water saving and higher crop yields since both are often linked as the advantages of the drip irrigation, although the investment cost is high (Narayanamoorthy *et al*. 2018). This study's results can be used by sugarcane growers, sugar mills, or the other related stakeholders in Indonesian sugar industry as a consideration before implementing the drip irrigation system.

Materials and Methods

This research employed a complete drip irrigation system for 0.75 hectare in each trial site (1.5 hectare in total for both Kediri and Pasuruan), conventional irrigation equipment, soil sampler, sample ring, chemicals to perform soil analysis, insecticides, bioinsecticides (metastigma), SP-36 fertilizer, sugarcane bud setts, plastic bag, and labelling paper. Sugarcane cultivars used in the Kediri and Pasuruan trial site were PS 862 and PS 881, respectively. Both cultivars had been certified by the Indonesian Sugar Research Institute. PS 862 and PS 881 were selected as they are the popular cultivars among sugarcane growers in East Java.

Three irrigation treatments were surface drip irrigation (SDI), sub-surface drip irrigation (SSDI), and conventional irrigation (CI). SDI and SSDI were compared as previous studies reported an agronomic performance difference of various crops under both treatments (Martinez & Reca 2014; Umair *et al.* 2019; Miyazaki & Arita 2020). Water in both SDI and SSDI treatment was released through drip line (emitter), and water in the CI treatment was applied through the open canal. The experimental design was a Randomized Complete Block Design (RCBD), with three replications. The installation of the drip irrigation system fulfilled the mounting standards. In this case, the drip irrigation vendor installed the system to make it ready to use.

For each site, the experimental plot of both drip irrigation treatment (SDI and SSDI) consisted of eight double rows of 0.4 meters, with inter-row spacing of 1.8 meters. The row's length was 32 meters, so the area of each experimental plot was 620 m^2. There were 12 experimental plots for both SDI and SSDI; thus, the total area needed for the SDI and SSDI treatment was 7,449 m^2 or 0.75 hectare. There were two edge rows, *i.e.*, left and right rows, and four middle rows. There were no drains built in both SDI and SSDI experimental plots as the irrigation water was given through pipelines. As a control treatment, the CI experimental plot applied a row's length of 32 meters with a 0.5-sized drain in every 7.5 meters. At the CI plots, several perpendicular drains were built to facilitate water flow. The total plots for CI treatment were six; hence, the total area needed for the CI treatment was 1,920 m^2 or 1.92 hectares. This experimental design (Figure 1) applied for both Kediri and Pasuruan.

Soil Tillage

A preparation step before soil tillage was executed due to a substantial coverage of weed that found in Kediri trial site, so the weed were controlled first. Weed were sprayed with glyphosate-based herbicide of six litre ha^{-1} dosage. Ten days later, after the weeds started to wilt and dry, soil tillage was performed. A mechanical soil tillage was executed, started with the first and second ploughing, harrowing, and furrowing. The drip irrigation plots used a double row pattern, following the manual standard for the operational of the drip system. The furrowed experimental plots resulted in a short row of 40 cm and a long row of 140 cm, with a depth of 40 cm for each row (Figure 2). In both trial site, soil tillage was also performed mechanically using tractor.

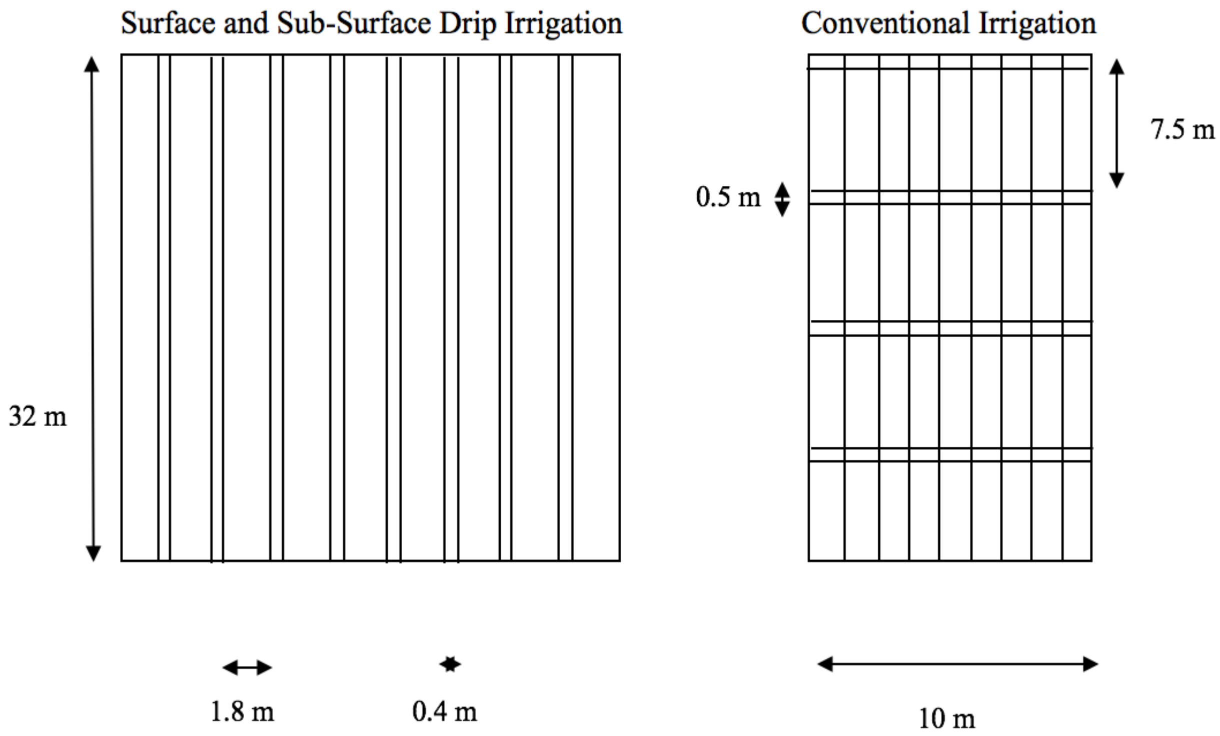

Figure 1. Detailed experimental plot design

Gambar 1. Desain rinci plot percobaan

Figure 2. Soil tillage process, creating furrowed experimental plots with a double row planting system in Kediri site

Gambar 2. Proses pengolahan tanah, membuat alur juring ganda di lahan percobaan Kediri

Plotting and Installation of Drip Irrigation Equipment

A set of drip irrigation equipment in Kediri trial site was installed according to the field situation. The installment steps were as follows: marking the dividing points of the drip lines, pre-assembling of distribution pump, casting of the main hose, digging the main hose line, and connecting the main hose. The installment of the hoses in both SDI and SSDI treatment plots was assisted with a tractor mounted with a hose roll that can be adjusted in the direction of rows. In the SSDI system, the hoses between the grid were then covered with soil at approximately 20 cm from the soil surface (Figure 3b). Meanwhile, the hoses were not backfilled with soil in the SDI system, instead placed between short rows. The way of hoses installation in the Pasuruan trial site was the same as in the Kediri trial site (Figure 3a and 3b).

(a) (b)

Figure 3. Installed (a) surface drip irrigation, (b) sub-surface drip irrigation in Kediri

Gambar 3. Pemasangan (a) irigasi tetes pemukaan, (b) irigasi tetes bawah permukaan di Kediri

(a) (b)

Figure 4. Installed (a) surface drip irrigation, and (b) sub-surface drip irrigation in Pasuruan

Gambar 4. Pemasangan (a) irigasi tetes permukaan, (b) irigasi tetes bawah permukaan di Pasuruan

(a)

(b)

Figure 5. Emitter in the drip line of the a) surface and b) sub-surface drip irrigation

Gambar 5. Emiter dari selang pada drip irigasi a) permukaan dan b) bawah permukaan

Both divider hoses which equipped for the SDI and SSDI used the same of half an inch size. Emitter, as the water outlet, was placed every 50 cm and embedded in the hoses. The hoses used in the SSDI treatment were relatively more rigid than the hoses used in the SDI treatment (Figure 5a and 5b).

Conventional Irrigation (CI)

Irrigating the CI plot at clay soil (Pasuruan) was done manually using water bucket. Each crop line (7.5 metre) was given four buckets of water. The bucket volume was measured for getting the applied irrigation value. Irrigation was applied at the furrow and if any spillover water, it flew through the drain canal perpendicular to the furrow. The drain canal size was prepared to anticipate the potential of excessive runoff during rainy season, particularly in clay soil (Pasuruan) that has low soil permeability value. In sandy soil (Kediri), the application of CI was done using a set of prevailed conventional irrigation system, consist of a medium pump (5 horsepower) and hoses with 3-inch in diameter. Water was given by directing the hose into the crop line at the furrow and let the water stream through the entire canal. This practice is based on what the local grower did. Since the very accurate water volume of CI application was very difficult to determine, the discharge from the hose was calibrated before application so each row of 32 metre was irrigated at the certain time. The irrigation requirement value was calculated by Cropwat and has different value for each location. Different soil type and climatic regime were accounted into the Cropwat calculation.

Irrigation Requirement and Application

Calculation of the crop water requirement (CWR) became a basis for determining the volume of irrigation water at both locations. This process was done by Cropwat 8.0 software, using the historical (10 years) agroclimatic inputs from each location. The inputs such as rainfall, minimum-maximum air temperature, minimum maximum air humidity, wind speed, solar radiation, day length and all those data were gained from nearby meteorological station. The Cropwat software output was the irrigation requirement volume and the irrigation interval. Each location has its specific value. The irrigation application in the field was based on this value.

Sugarcane Planting and Bioinsecticides Application

This step was undertaken after the installation of the drip irrigation equipment. The planting material used was sugarcane bud sett with two "eyes". There was a total of four bud setts in each meter. SP-36 fertilizer with a dose of 200 kg ha^{-1} was applied evenly over the rows before planting. After the bud setts planted, 100 kg ha^{-1} bioinsecticides (metastigma) was applied to all the experimental plots to prevent a white grub attack. Finally, the bud setts were covered with fine soil of a 5-10 cm thickness.

Figure 6. Manual sugarcane bud setts planting in Kediri trial site

Gambar 6. Penanaman benih secara manual di lahan percobaan Kediri

Observed Parameters

The agronomic observation parameters were: germination percentage of sugarcane at one month after planting (1 MAP), number of tillers at at 4, 6, 9, and 12 MAP, stalk height (cm) at 4, 6, 9, and 12 MAP, stalk diameter (mm) at 4, 6, 9, and 12 MAP, number of stalk per meter at at 4, 6, 9, and 12 MAP, and sugarcane weight (kg) at 12 MAP. The number of tillers was observed since 4 MAP until the maximum growth period of sugarcane to develop tillers. Sugarcane yield weighing was performed on the four middle rows of each plot during harvesting.

The irrigation and other observation parameters include: 1) water amount applied at all irrigation treatment, whereas the data for both SDI and SSDI treatment were known through flow meter attached to the main pipe, and the data for the CI treatment was set as four flushes of uniform bucket size for each grid; 2) monthly rainfall between 1995-2014; 3) monthly evapotranspiration between 1995-2014, which was obtained through the nearby automatic weather station (AWS); 4) the amount of water delivered to all irrigation treatment plots, measured through measuring device attached for the SDI and SSDI treatment; and the volume of flush buckets for the CI treatment; and 5) soil analysis of 60 cm-depth soil samples in both Kediri and Pasuruan trial site, comprises of analysis of pH, cation exchange capacity (me 100 g^{-1}), total nitrogen (%), phosphorus (P_2O_5) (Olsen) (ppm), potassium (K_2O) (ppm), organic carbon (C) (%), calcium (Ca) (me 100 g^{-1}), magnesium (Mg) (me 100 g^{-1}), sulphur (SO_4) (ppm), soil texture (%), and soil moisture (g g^{-1}) at pF 0, pF 2.5, and pF 4.

The soil analysis was conducted prior to the experiment of irrigation treatment and aimed to compare the soil chemical and physical properties in both locations. The agronomic data were analyzed using Analysis of Variance (ANOVA) and continued with Duncan's Multiple Range Test (DMRT) at the 95% confidence level (α = 0.05).

The economic analysis was performed in a simple way of Water Productivity (m^3 kg^{-1}), indicating water used to produce the harvested biomass) term and focus only on the irrigation cost. The observed parameters were the irrigation volume applied at field, the investment cost of the irrigation system, and the operational cost of running the system. The investment cost represented the total capital spent to provide the system installed and ready to use in the field. The drip irrigation system would last for maximum 5 years; therefore, the investment cost was spread evenly for each year for calculation. The operational cost consists of the labor cost during irrigation, pump fuel cost, and water fee. The water fee, for this study purpose only, was set to Indonesian Rupiah (IDR) 1,633/m3, as proposed by Wirawan *et al*. (2017). In the real field, this fee was not applied, and this calculation was for understanding purposes only, if in the future, the water regulation will force the water fee into effect. Water cost, investment cost, and operational cost regarding to irrigation was calculated proportionally to the biomass yield, resulted in IDR kg^{-1} or m^3 kg^{-1}.

Results and Discussion

Soil Chemical and Physical Properties of Experimental Sites

The soil samples in Kediri and Pasuruan was taken one time each before the trial start. Results of soil analysis indicated a difference in soil chemical characteristics in the Kediri and Pasuruan (Table 1). The chemical analysis result showed that the soil in Pasuruan is better in the term of soil fertility. The soil pH was near normal value (pH = 7) while in Kediri shows the acidity (pH < 7). The total nitrogen (N) and potassium (P) of soil in Kediri and

Table 1. Results of analysis of soil chemical and physical properties in Kediri and Pasuruan

Tabel 1. Hasil analisis sifat kimia dan fisika tanah di Kediri dan Pasuruan

Soil parameter		Unit	Trial site	
			Kediri	Pasuruan
pH			5.8 (slightly acid)	6.88 (neutral)
Cation exchange capacity		me 100 g^{-1}	4.63 (very low)	43.34 (very high)
Total nitrogen		%	0.07 (very low)	0.09 (very low)
Phosphorus (P_2O_5) (Olsen)		ppm	9.4 (low)	35.85 (very high)
Potassium (K_2O)		ppm	83 (low)	170.5 (low)
Organic carbon (C)		%	0.89 (very low)	1.32 (low)
Calcium (Ca)		me 100 g^{-1}	6 (medium)	44.735 (very high)
Magnesium (Mg)		me 100 g^{-1}	1 (low)	21.815 (very high)
Sulphur (SO_4)		ppm	70 (medium)	228.5 (high)
Soil texture	Clay fraction	%	11	76.5
	Silt fraction		33	21.5
	Sand fraction		56	2
Soil moisture	pF 0	g g^{-1}	0.45	0.54
	pF 2.5		0.11	0.47
	pF 4		0.05	0.27

Note: categorization of each value of soil chemical parameter (within bracket) is according to Prasetyo *et al.* (2009)

Pasuruan were equally categorized as very low and low, respectively. Micronutrient (Mg, Ca, SO_4) availability in Pasuruan was also higher than in Kediri. Of the most contrasting value of chemical soil parameters in both locations is cation exchange capacity (CEC), whereas Kediri and Pasuruan had very low and very high CEC, respectively. High CEC reflects a fertile soil, and vice versa. Clay soil with a high CEC can retain large amounts of cations against potential loss by leaching (Price 2006). Besides, pH of high CEC soil tends to be more stable (Nelson 2012). This is in line with the pH analysis, whereas soil pH in Pasuruan trial site is neutral.

From the analysis of soil physical properties, it was confirmed that soil type in Kediri is sandy-loam texture (56% sand fraction and 33% silt fraction), while the soil in Pasuruan is dominated by clay texture (76% clay fraction and 21% silt fraction). Each texture brings the different consequences related to irrigation and water holding capacity. In general, sandy soil in Kediri will quickly absorb the water in the surface, infiltrate to the bottom layer quickly; thus, only a small fraction of water was held in the rhizosphere. The clay soil in Pasuruan was much slower to infiltrate and penetrate water to the bottom layer. After irrigation, waterlogging occurred for a while, then it started to infiltrate to the soil. Based on this condition, the size of the drain canal in Pasuruan was larger than in Kediri, to easily drain the water. The difference in soil type also brings into the shorter irrigation interval in the sandy soil than in clay soil.

Agronomic Performance of Sugarcane

Several differences in agronomic performance of sugarcane cultivated under three different irrigation methods in both Kediri and Pasuruan were observed (Table 2).

In both Kediri and Pasuruan, the lowest germination percentage was observed under the CI treatment. On the contrary, the highest sugarcane germination percentage was under SSDI in both locations, since the SSDI provided a precise amount of water to create proper soil moisture for sugarcane buds, and the water losses through evaporation can be minimized in the system. Irrigation was performed based on the soil moisture measurement condition, instead of a fixed irrigation interval. This is to prevent excess moisture in the rhizosphere that leads to better growth environment. Under the CI treatment in Kediri, the buds may be were possibly getting insufficient soil moisture to promote germination, while there were some waterlogged points in Pasuruan. Overall, compared to Kediri, Pasuruan has a higher germination percentage. This may be linked with better water retention soil in Pasuruan, leading to the better soil moisture which fulfilling the buds' water requirement. Germination phase is a critical event of sugarcane cycle, which is highly dependent on water sufficiency (Pierre *et al.* 2014). In

Table 2. Agronomic performance of sugarcane in Kediri and Pasuruan

Tabel 2. Performa agronomis tanaman tebu di Kediri dan Pasuruan

Agronomic parameter	Months after planting (MAP)	Irrigation treatment		
		Surface drip irrigation (SDI)	Sub-surface drip irrigation (SSDI)	Conventional irrigation (CI)
Sandy loam (Kediri)				
Sugarcane bud germination (%)	1	42.28 b	55.90 a	39.93 b
Number of tillers within a clump	4	3.58 a	3.40 a	3.65 a
Number of stalks per meter	12	13 a	11 a	7 b
Stalk height (cm)	12	250.25 b	283.48 a	219.50 c
Stalk diameter (mm)	12	25.15 a	25.49 a	22.23 b
Sugarcane productivity (ton ha^{-1})	12	81.29 b	101.33 a	69.25 c
Clay (Pasuruan)				
Sugarcane bud germination (%)	1	79.99 b	88.51 a	63.90 c
Number of tillers within a clump	4	1.81 a	1.25 b	1.65 a
Number of stalks per meter	12	7.53 a	7.92 a	7.55 a
Stalk height (cm)	12	249.67 a	254.33 a	263.33 a
Stalk diameter (mm)	12	21.00 a	22.67 a	21.67 a
Sugarcane productivity (tons ha^{-1})	12	79.03 a	60.58 b	78.16 a

Note: The same letters following numbers in same raw indicate insignificant statistical difference among treatments

Kediri, low water retention of sandy soil led to rapid water infiltration, causing the soil dried up quickly so that the buds experiencing inadequate water condition to germinate. The germination percentage was observed at 1 MAP. However, sugarcane productivity is not fully determined based on the result of 1 MAP. The stalk number at 4 MAP is the moment that germination has come to its final stage (Pawirosemadi 2011). At this point, sugarcane growers can predict the maximum mill-able cane in their yield.

As the number of tillers is an essential parameter in sugarcane production, the observation showed the insignificant differences in the number of tillers within a clump between treatments in Kediri. Nevertheless, the number of tillers under SSDI treatment in the Pasuruan trial site was significantly lower than the two other treaments. This may be attributed with the slightly waterlogged conditions that occurred due to too shallow channels in the experimental plots.

The number of stalks per meter under CI treatment in Kediri was significantly less than the other treatments. This is in line with a research result by Ramesh *et al.* (2016), which observed a higher number of stalks, sugarcane height, and sugarcane productivity under drip irrigation than a conventional irrigation through furrow. This condition may be associated with direct water availability under drip irrigation to be taken up efficiently by sugarcane. In the CI treatment, the water has a great potential to lost through evaporation before it is taken up by sugarcane. In Pasuruan, there were insignificant differences between the three irrigation treatments. This can be explained that clay soil in Pasuruan kept the irrigation water to stay longer in the soil and available for sugarcane.

Sugarcane stalk, an essential part of the crop for sugar production, was also observed. There were significant differences between irrigation treatments on the stalk height of sugarcane grown in Kediri. The highest and lowest sugarcane height was under SSDI and CI treatment, respectively. Meanwhile, there were insignificant differences in sugarcane stalk height in the three irrigation treatments. Stalk diameter of sugarcane grown under CI treatment in Kediri was significantly lower than the two other treatments. This indicates a better stalk growth under drip irrigation. In Pasuruan, there were insignificant differences of stalk diameter of sugarcane among all irrigation treatments.

There was a significant difference of final sugarcane yield between the treatments in Kediri (Table 2). SSDI led to the highest sugarcane productivity, followed by SDI, and the CI treatment was the lowest. The provision of precise water in the rhizosphere by SSDI led to proper soil moisture, thus led to better growth of sugarcane. The SDI dropped the water in the soil surface, which has more potential to evaporate quickly, rather than stay as the soil moisture. The CI flew water over the furrow, which possibly to evaporate and run-off. Therefore, SSDI resulted in the highest productivity in Kediri.

An interesting result was observed in Pasuruan, where the sugarcane productivity under clay soil between SDI and CI reflects the insignificant result. In further, SSDI resulted in the lowest sugarcane productivity in Pasuruan, which is contrary to the Kediri's result. Clay soil has a high soil water retention that keeps water in the soil surface. The irrigation through SDI and the CI has the similarity *i.e.* water applied in the soil surface that may lead to waterlogging The SSDI applied water in the sub-surface at the root zone where caused adverse waterlogging in the root zone. Sugarcane prefers an adequate moisture in the soil, either not too dry or not too wet (Pawirosemadi 2011).

Measurement of agronomic parameters indicated that each irrigation method is more suitable in different soil texture. Sandy soil is more suitable using SSDI to provide better soil moisture precisely at the root zone to promote growth. While in clay soil, the CI can still be used than the SDI and SSDI, especially if there is insufficient capital to invest the irrigation system. Overall, in Kediri, it can be known that the most positive agronomic performance was under the SSDI treatment. This may be attributed to an increase in water use efficiency due to less evaporation in the SSDI treatment than the other irrigation treatments (Hamada *et al.* 2015; Umair *et al.* 2019). Miyazaki and Arita (2020) observed that when the deeper the SSDI equipment is placed, the higher the root length and branching of sugarcane.

Evapotranspiration, Effective Rainfall, and Crop Water Requirement

Crop water requirement (CWR) was calculated according to the climatic data, soil data, and crop data for each location. The monthly CWR value was then matched in pair with the effective monthly rainfall data to produce irrigation requirement (IR) value, which divided into two methods of conventional irrigation (CI) and typical drip irrigation (DI). The result is shown in Table 3.

Annual evapotranspiration value (Table 3) in Pasuruan was higher than in Kediri, but the annual precipitation in Pasuruan was lower than in Kediri. Higher evapotranspiration and lower precipitation produced higher CWR value. In Pasuruan, the CWR value almost two-fold than in Kediri, denoting that Pasuruan is a hot and humid area with low rainfall. When irrigation efficiency included in IR calculation, Pasuruan needs a

Table 3. Evapotranspiration, effective rainfall, and sugarcane crop water requirement in Kediri (K) and Pasuruan (P), average data of five years

Tabel 3. Data evapotranspirasi, curah hujan efektif, dan kebutuhan air tanaman tebu di Kediri (K) dan Pasuruan (P), rerata data 5 tahun

Month	Evapotranspiration (mm month^{-1})		Effective rainfall (mm month^{-1})		CWR (m^3 ha^{-1})		IR under CI (m^3 ha^{-1}), with an assumption of 50% efficiency		IR under DI (m^3 ha^{-1}), with an assumption of 95% efficiency	
	K	P	K	P	K	P	K	P	K	P
August	21	156	7	6	140	1,502	350	3,755	147	1,669
September	58	128	21	15	365	1,124	912	2,810	384	1,249
October	105	47	108	32	28	351	0	877	0	390
November	134	68	160	85	253	0	0	0	0	0
December	119	111	160	119	409	12	0	0	0	0
January	124	147	167	152	436	20	0	0	0	0
February	116	102	170	144	537	16	0	0	0	0
March	128	169	172	136	435	324	0	0	0	0
April	128	162	162	122	334	401	0	1,003	0	446
May	127	176	149	90	219	855	0	2,137	0	95
June	105	170	59	57	462	1,127	1,155	2,818	487	1,252
July	97	173	46	18	513	1,565	1,282	3,912	540	1,739
Total	1,262	1,609	1,381	976	4,131	7,297	3,599	17,312	1,558	6,840

Note: K= Kediri; P = Pasuruan; CWR = crop water requirement; IR = irrigation requirement; CI = conventional irrigation; DI = drip irrigation (all type); The assumption of IR efficiency is based on Shoji (1977) three times larger IR value than Kediri. The difference in soil type influenced the consideration of irrigation interval as it relates to the soil infiltration rate and field capacity point.

In Kediri, soil evaporation was higher than effective rainfall in June, July, August, and September. Irrigation at these months is required to fulfill the water demand of sugarcane. The annual CWR in the Kediri trial site was 4,131 m^3 ha^{-1}. The amount of water required for the conventional and drip irrigation method was 3,599 m^3 ha^{-1} and 1,558 m^3 ha^{-1}, respectively. Compared to Kediri, Pasuruan had less annual rainfall and more months with higher soil evaporation than the effective rainfall, *i.e.*, March, April, May, June, July, August, September, and October. At these months, irrigation is needed to achieve optimum sugarcane growth. The annual CWR was 7,297 m^3 ha^{-1}, resulting in the water required for the conventional and drip irrigation was 17,312 m^3 ha^{-1} and 6,840 m^3 ha^{-1}, respectively. Overall, it is evident that the water requirement in the conventional irrigation was higher than the drip irrigation (Table 3).

Economic Analysis

A simple economical water productivity analysis was performed based on some assumptions, such as the price (IDR) of the irrigation water used, five years of drip irrigation system operation feasibility, and one year for conventional irrigation. The price of irrigation water was assumed as IDR 1,633/m^3, as proposed by Wirawan *et al.* (2017). In Kediri, the greatest irrigation requirement (IR) was on the CI treatment, which led to a higher water cost than the two drip irrigation treatments. The low application efficiency in CI (max. 50% efficiency by FAO) means that 50% more amount of water than CWR value must be provided. That is why in CI needs much more water than drip irrigation system. Although the investment cost required in the CI treatment was much lower than the two drip irrigation treatments, the total operational cost needed to run the CI was the highest than the two drip irrigation treatments, due to its water cost. In the end, the water cost required to produce one kg of sugarcane biomass under the CI, SDI, and SSDI was IDR 169, 103, and 87, respectively (Table 4). This result suggests that the SDI and SSDI were cheaper in implementation than CI in Kediri, although the SDI and SSDI need more capital for invest. When investment on drip irrigation in Kediri also brought to a higher productivity, the capital availability of the grower is the primary consideration before implementing more water-efficient technology yet incur high investment cost (Halsema & Vincent 2012).

In Pasuruan, the greatest water consumption was on the CI treatment, which led to a significant higher water cost than the two drip irrigation treatments. The total operational cost needed to run the CI treatment was the highest than the two drip irrigation treatments. The water cost required to produce one kg of sugarcane biomass under the CI, SDI, and SSDI was IDR 443, 218, and 293, respectively (Table 4). This result indicates that the SDI was the most economical irrigation method, a promising irrigation alternative method to be applied. Nevertheless, a high investment cost to purchase, install, and maintain the SDI equipment should be taken into account (Hellegers *et al.* 2009). It should also be noted that if the water consumption for the CI in Pasuruan can be reduced, the CI method can be the cheapest amongst the two drip irrigation treatments.

For the calculation of water productivity in this study, we excluded the cost of production, such as land preparation, seed, planting, and harvesting. Kediri and Pasuruan have a different range of production cost, while this study only focused on the seasonal water irrigation cost to see how much needed to provide irrigation as the effort to improve the productivity in one crop cycle. Production cost at each location can be calculated proportionally to the corresponding yield to gain the production cost per kilogram biomass. Thus, the value of water productivity and production cost will reflect the total sugarcane cultivation cost at a certain location. Future research might incorporate this insight for a better understanding of the sugarcane production system.

Conclusions

Our study demonstrates the implication of implementing different irrigation methods for sugarcane growth over predominantly sandy and clay soil. In the sandy soil (Kediri), both the surface drip irrigation and sub-surface drip irrigation led to better agronomical performance and productivity, and vice versa for the conventional irrigation. Nevertheless, the water cost required to produce one kilogram of sugarcane biomass under the surface drip irrigation and sub-surface drip irrigation was lower than the conventional irrigation. The smaller amount of water used in surface drip irrigation and sub-surface drip irrigation corresponds to the lower water cost than the conventional irrigation system, although the investment cost for surface drip irrigation and sub-surface drip irrigation quite substantial. By a proper maintenance, the drip system would last longer, giving more economic benefit to the user. Meanwhile, in the clay soil (Pasuruan), there were insignificant differences in agronomic

Table 4. Water cost of different irrigation treatments in Kediri and Pasuruan for a crop cycle (12 months)

Tabel 4. Biaya air pada berbagai perlakuan irigasi di Kediri dan Pasuruan selama satu siklus tanaman tebu (12 bulan)

	Irrigation treatment		
	Conventional irrigation	Drip irrigation	
		Surface	Sub-surface
Kediri (sandy loam soil)			
Irrigation requirement (IR) (m^3)	3,599	1,558	1,558
Water cost (WC) (IDR 1,633 per m^3)	5,877,167	2,554,214	2,554,214
*Investment cost (IC5) (IDR) – for 5 years	2,847,586	15,693,226	17,943,226
*Investment cost (IC1) (IDR) – for 1 year	2,847,586	3,138,645	3,588,645
Operational cost (OC) (IDR)	3,000,000	2,700,000	2,700,000
Total cost (WC+IC1+OC) (IDR)	11,724,753	8,392,859	8,842,859
Sugarcane productivity (SP) in kg ha^{-1}	69,250	81,290	101,330
Water cost required to produce 1 kg of sugarcane biomass ((WC+IC1+OC)/SP) (IDR)	169	103	87
Pasuruan (clay soil)			
Irrigation requirement (IR) (m^3)	17,312	6,840	6,840
Water cost (WC) (IDR 1,633 per m^3)	28,270,496	11,169,720	11,169,720
*Investment cost (IC5) (IDR) – for 5 years	3,351,462	17,153,002	19,403,002
*Investment cost (IC1) (IDR) – for 1 year	3,351,462	3,430,600	3,880,600
Operational cost (OC) (IDR)	3,000,000	2,700,000	2,700,000
Total cost (WC+IC1+OC) (IDR)	34,621,958	17,300,320	17,750,320
Sugarcane productivity (SP) in kg ha^{-1}	78,160	79,030	60,580
Water cost required to produce 1 kg sugarcane biomass ((WC+IC1+OC)/SP) (IDR)	443	218	293

Note: *) investment cost for SDI and SSDI are for five years, yet for CI is one year only

performances between all irrigation treatments. The highest water cost required to produce one kilogram of sugarcane biomass was under the conventional irrigation treatment, and the lowest was under the surface drip irrigation treatment. The implementation of the drip irrigation system in sandy soil, as well as in clay soil, is relatively more promising than conventional, especially in the water-scarce area, since it can provide the sugarcane root zone with adequate and accurate soil moisture, reduces the amount of water used for irrigation through its high application efficiency, and uniform water distribution across the drip coverage in the sugarcane plantation. All those benefits, further supported by good operational and management of the irrigation system, the sugarcane yield and productivity will increase, and economically feasible to compensate the investment cost of the drip irrigation system.

Acknowledgement

Thank you for the funding support from the Badan Penelitian dan Pengembangan Pertanian, Kementerian Pertanian. We also would like to thank PT Daya Sentosa Rekayasa and PT Perkebunan Nusantara X for in-field support in this research.

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