SIMULATING WATER BALANCE AND CROP YIELD FOR SUGARCANE PLANTATION IN PASURUAN USING AQUACROP MODEL

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ABSTRACT
Sugarcane is one of the estate crops that has been cultivated in Indonesia for a long time. Sugarcane farmers must be more adaptable and adjust their current field management as a result of water shortage caused by climate change. rip irrigation has been one of the prospectus alternatives to be implemented by farmers by altering their furrow irrigation. Before being implemented in the field, the AquaCrop model is useful to simulate the advisability of particular farm management such as irrigation. The AquaCrop model was used to simulate and analyse the water balance, crop yields, and water productivity of sugarcane in Pasuruan under two alternative field managements, i.e. conventional and enhanced practices. Results confirmed that drip irrigation requires less water for irrigation than furrow irrigation. In comparison to no mulching procedures in conventional method, improved field management decreased surface run-off by up to 95%. Farmers obtained higher crop yield and water productivity by shifting the farm management, i.e. 7-8% and 12-16%, respectively. However, there are several constraints on this analysis. Thus, advanced studies on conducting AquaCrop for more realistic conditions are still promising in future.

Keywords: AquaCrop, sugarcane, crop yield, irrigation, water productivity

Received *3 April 2022* ***Accepted*** *13 June 2022*

INTRODUCTION
Sugarcane is the one of estate crops that has been long time ago cultivated in Indonesia. It is an essential commodity for Indonesia's balance of trade since sugar national demand is partially supplied by import from other countries. However, Indonesia was the top sugarcane production country in circa 1960. The gap between supply and demand is due to: i) declining area and productivity, ii) low-yielding varieties, and iii) out-of-date facilities, small capacity, and inefficiency of existing sugar mills (Sulaiman, et al., 2019). Thus, Indonesia sugarcane production is strongly required to be enhanced by certain strategic programs especially in producing region.

Pasuruan Regency is suitable for sugarcane plantation in Indonesia. It is located in northern part of East Java Province (E 112°33'55"-113°05'37" and S 7°32'34" - 7°57'20"). Sugarcane harvested area on Pasuruan is around 3.116 ha in 2020 (Directorate-General-of-Estate-Crops, 2020) and mainly distributed at the northern part of Pasuruan Regency due to its geographical suitability.

Climate change has been impacted on agriculture over the world in recent years. Sugarcane that is facing the water scarcity due to this phenomenon drives farmers to be more adaptive and modify their current field management. Putra, et al. (2021) proposed several methods to enhance the crops yields as well as reduce the water irrigation requirement. Efficient irrigation has been one of the prospectus options to be implemented by farmers.

This improvement is also prospectus to be implemented on sugarcane plantation in Pasuruan due to many farmers still practices conventional irrigation method. However, before implement those methods in field, it is possible to simulate them by modelling software to ensure their advisability.

The simulation and analysis were conducted by AquaCrop model to compare the water balance, crop yields, as well as water productivity of sugarcane under two different field managements i.e. the conventional and the improved one. Since sugarcane cultivation in Indonesia is usually divided in two planting time based on the beginning and the end of rainy season, then the simulation was also conducted for those different planting time. The modelling results will be useful to understand which field management will give best contribution for water balance and definitely the crop yields.

RESEARCH METHODS

A. AquaCrop Model

AquaCrop model has been widely used to simulate water balance and crops yields under certain conditions, e.g. field management or climate change (Revathy and Balamurali, 2019; Alvar-Beltrán, et al., 2021). It is also useful for modelling water footprint of certain crops production (Yesilkoy and Saylan, 2020). The length of the period that can be simulated is not only in one year but even in decades (Lee and Dang, 2018).

The AquaCrop model was based on calculation of four different input components, that are climate (e.g. rain, reference evapotranspiration, and temperature), crop (e.g. growing cycle and optimal harvest index), field management (e.g. irrigation methods, weed, and mulches), and soil (e.g. soil type and groundwater condition). Those certain input conditions then are simulated step by step to determine crop development (described as green canopy cover), crop transpiration, above ground biomass and eventually the crop yield (FAO, 2018).

B. Climate Data

This simulation was using daily climate data obtained from Juanda Meteorology Weather Station located around 24km northwest from Pasuruan Regency. Due to the limitation of data availability and completeness from recent years, then daily climate data used for this simulation were from period of 2007-2011 (BMKG, 2022). Figure 1 below shows briefly the anual climate data distribution in 5 years average.

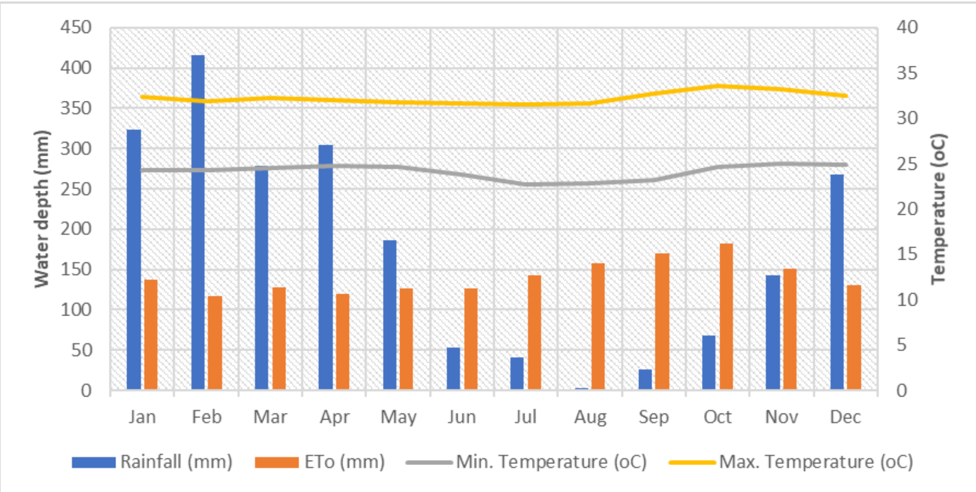

Figure 1. Monthly climate data distribution of Pasuruan Regency

C. Crop Data

Crop data mainly used sugarcane characteristic data from AquaCrop based on FAO-56 stages (FAO, 1998). Reference harvest index (HI0) was modified from default data and set to 74%

based on Kapur, et al. (2013). Planting schedule was also arranged in accordance with current sugarcane cultivation practices in Pasuruan Regency, that are Pattern A (from April to March) and Pattern B (from September to August) (Windiastika, 2019).

D. Soil Data

Previous study has been conducted to measure soil characteristic on sugarcane plantation in Pasuruan (Ranomahera, et al., 2020). In general, soils in Pasuruan is categorized as clay soils. Brief description of both soil chemical and soil physical parameters used in this simulation are described in Appendix 1.

E. Field Management Scenarios

Two different field management scenarios were simulated and compared each other. The first scenario assumed existing practices. The second one is improved field management practices. Specifically, furrow irrigation used for Scenario 1 since it is recognized as surface irrigation conventional method in Indonesia (Ranomahera and Ritzema, 2020) and drip irrigation was introduced as most water efficient method in Scenario 2 (Ranomahera, et al., 2020). Initial conditions were also conducted by differentiating soil water content at the beginning of planting month for both Pattern A and B. Thus, there were four conditions simulated in this analysis as described in Table 1.

Table 1. Field management practices of two different scenario

Practice	**Scenario 1 (Existing practices)**		**Scenario 2 (Improved practices)**	
	Pattern A	*Pattern B*	*Pattern A*	*Pattern B*
Irrigation method	Furrow	Furrow	Drip	Drip
Irrigation time	80% of TAW	80% of TAW	20% of TAW	20% of TAW
Mulches	None	None	Organic (75% covered)	Organic (75% covered)
Weed management	Good	Good	Very good	Very good
Weed cover	15%	15%	5%	5%
Planting schedule	Apr-Mar	Sept-Aug	Apr-Mar	Sept-Aug
Initial soil water content	47% (FC)	29% (10% of TAW)	47% (FC)	29% (10% of TAW)

Notes: TAW = Total Available Water; FC= Field Capacity

FINDINGS AND DISCUSSION

A. Water Balance

Information on water balance is important for agricultural use (Schulz, et al., 2021). There are many water balance components can be measured in field by direct and indirect measurements. AquaCrop model allows us to calculated water balance from input data. Water balance components described here are consisted of irrigation, precipitation, evapotranspiration, and runoff. Figure 2 shown the comparison of the water balance components between two scenarios in each planting time.

In Figure 2, drip irrigation requires less water for irrigation than furrow irrigation, since we already noticed that drip irrigation is the water-efficient irrigation method (Jha, et al., 2016). However, changing planting month does not always mean low irrigation water required in this case. Irrigation requirement (IR) in pattern B for conventional scenario are higher than pattern A, but it is opposite for improved scenario.

Field management also impact other water balance components since improved scenario implement organic mulching for covering soil surface by 75%. Actual evapotranspiration of improved method is lower than conventional method. This reduction is markedly contributed by decreasing of evaporation value. The runoff has also been decreased tremendously (up to 95%) by this field management rather than no mulches practices on conventional scenario. Other studies of the effect of mulching on soil conservation conducted by Zhang, et al. (2009) and Montenegro, et al. (2013) confirmed this finding.

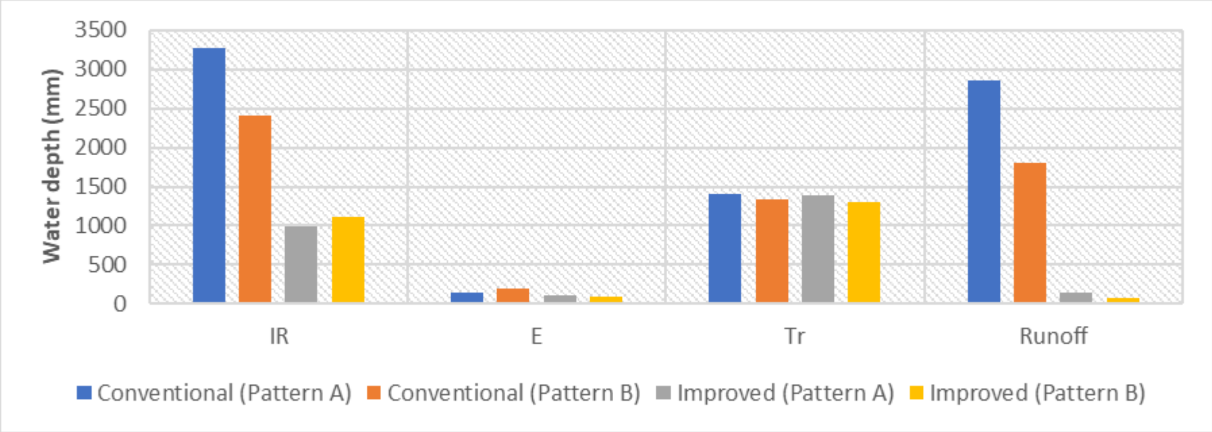

Figure 2. Water balances parameters

The organic mulch application likely also impacts the water balance by increasing the effective precipitation (Pe). This parameter per se is defined as part of rainfall that directly contribute for crop ET. Hence, on this analysis, the effective rainfall was calculated from infiltration value derived from rainfall. Figure 3 below shows that Pe in conventional scenario and improved method are 70-72% and 93-95%, respectively. However, there are many other factors also affect the Pe in field, for example preceding soil moisture, crop and soil condition, as well as climatic parameters (Ali and Mubarak, 2017).

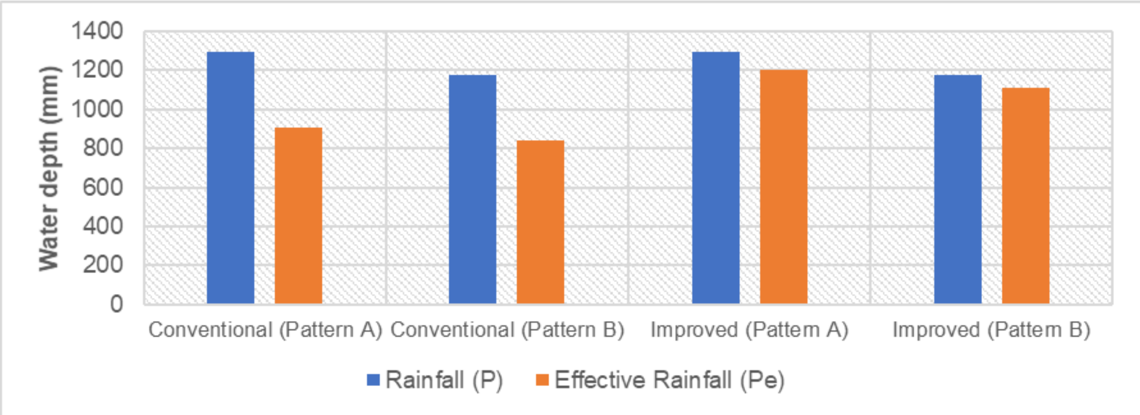

Figure 3. Rainfall (P) and effective rainfall (Pe) of two scenarios

During the growing season, there were change on soil moisture stock for all scenarios. Those can be determined by comparing the preceding soil water content (ϴi) to the final soil moisture content (ϴF). The comparisons are shown on Figure 4.

The ϴF of improved method is slightly higher than conventional method in Pattern A, despite the irrigation requirement is lower. However, ϴF of two methods show similar pattern by depth. They are also still exceeding the ϴ at field capacity (ϴFC), means there is no water stress at the end of growing season. It is occurred since the harvest time is on March when the precipitation remains considerable.

In contrast, the ϴF of two methods in Pattern B show extremely different line pattern of each other. The ϴF of improved methods in soil surface is lower than ϴFC, but increasing by depth and attained 47% at 25cm below soil surfaces. The ϴF of conventional method in soil surface is also lower than ϴFC, event than ϴ at permanent wilting point, ϴPWP. The ϴF of conventional method than is increased at 15cm soil layer, yet suddenly decreased at 25cm below soil surfaces, and increased again until attain ϴFC at 68cm below soil surfaces.

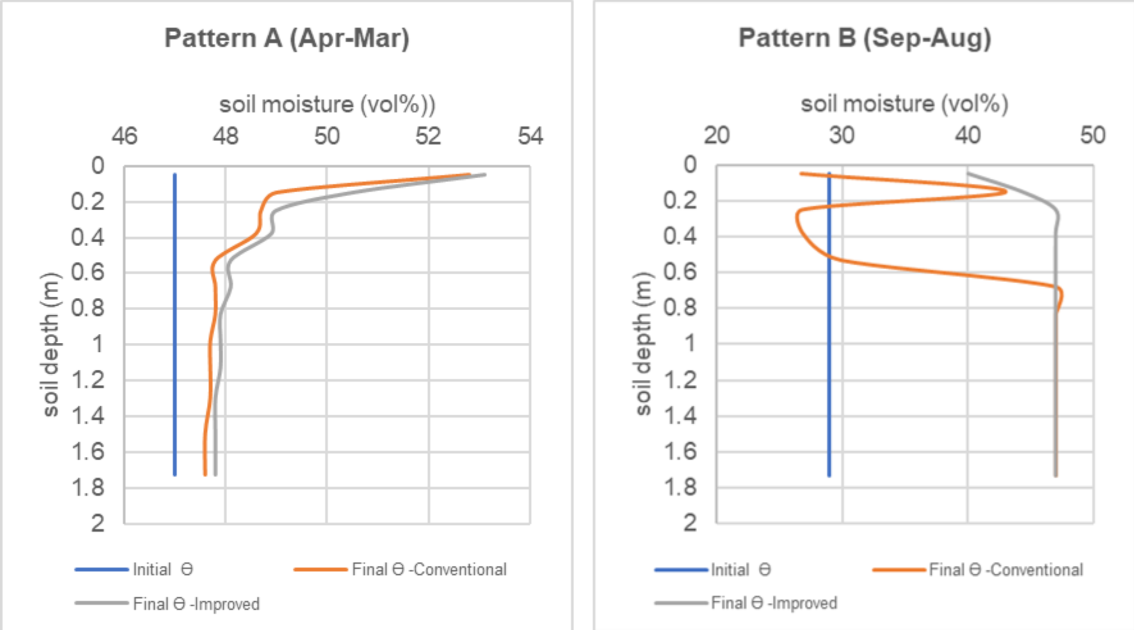

Figure 4. Soil moisture content (vol%) in water depth of two scenarios

Dynamic changing of conventional methods ϴF is likely due to several factors. Harvest time of pattern B that fell on August indicated by dry month triggered more evaporation, especially no mulch covering the soil surface. Thus, soil water at that upper layer loosed by evaporation. Irrigation water retained at 15cm soil layer due to heavy-textured and low-macro porosity clay soil is likely the explanation for increasing ϴF at that depth. At 25-53cm below soil surfaces, the ϴF are only affected by rainfall, hence the ϴF at that certain layers are decreased from beginning of dry season on March.

B. Crop Yield

Crop yield (Y) is determined by following equation (FAO, 2018):

$$Y = f_{HI}.HI_0.B$$

where f_{HI} is a multiplier which considers the stresses that adjust the Harvest Index from HI_0 that has value of 74%. Since the biomass resulted in this simulation is on dry condition, thus water content of sugarcane biomass used for calibrating the dry yield to wet yield. Average water content of sugarcane biomass applied for this simulation is 57.5% (Kaewpradap, et al., 2013).

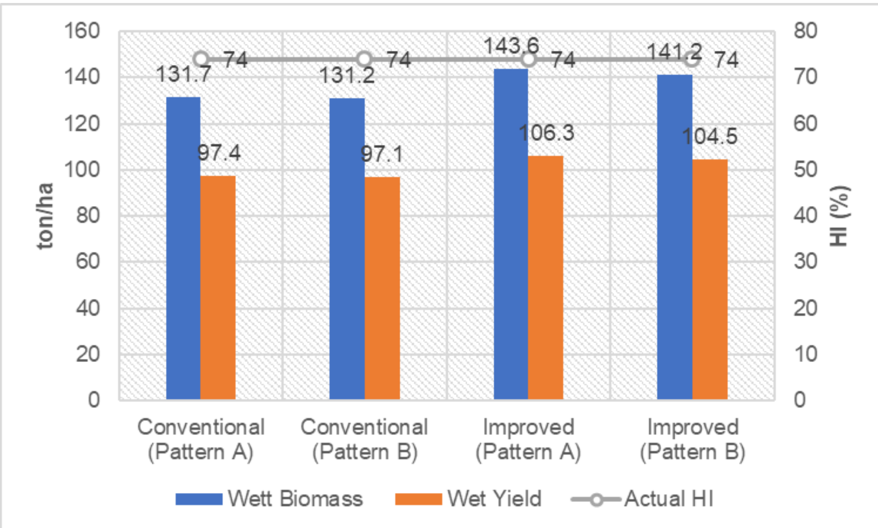

Figure 5. Wet biomass, wet yield, and actual HI of two different scenarios

Different management scenarios definitely impact to wet biomass and crop wet yield. As shown at Figure 5 below, improved scenario has higher both biomass and yield than conventional method. The difference between two methods is around 7-8%. On the other hand, there is no significant yield difference between different planting time for similar scenario. Actual Harvest Index of all scenarios somehow remain similar to HI_0 since there are no significant environmental stress including adequate water supply.

C. Water Productivity
Water productivity (WP) is determined following equation (FAO, 2018):

$$WP = \frac{B}{Tr}$$

where B is above ground biomass produced and Tr is water transpired by crops. In other way, we can also calculate WP by dividing Y over ETa.

Drip irrigation definitely results higher WP since higher Y obtained but lower ET required than furrow irrigation. Table 2 below described that improved method has 12-16% WP higher than conventional method. On the other perspective, it can be said that by lowering irrigation requirement for more efficient irrigation method can be enhancing the crop yield as well as water productivity.

Table 2. Water productivity of two different scenarios

Scenario	Pattern	ETa (mm)	Yield (ton/ha)	WP (kg.m-3)
Conventional	A	1560	75.7	3.59
	B	1528	75.5	3.65
Improved	A	1493	82.6	4.09
	B	1391	81.2	4.32

D. Discussion
The above results described vary of simulated parameters by the AquaCrop model. However, the reliability those results should be compared to other studies. It is useful to convince user that the AquaCrop model has strong correlation to direct-observed results. Thus, this model can be feasible to adopted for various field projects.

Indonesia sugarcane productivity has been declined over the years since it peaked on 1960's achieving more than 110 ton.ha-1 (Putra, et al., 2020). In last five years, Indonesia sugarcane yields only around 65-75 ton.ha-1 (Directorate-General-of-Estate-Crops, 2020).This value is lower than simulated results from AquaCrop model because there are many ecological stresses that could be inhibit plant growth and reducing crop yields. This analysis simulates certain conditions that may be more favorable than field condition. However, the simulated results remain below the potential sugarcane yield.

Field measurement of WP on sugarcane plantation has been also conducted by Rabnawaz, et al. (2015). They observed a linear relationship between sugarcane yield and irrigation water applied. The WP values were found on the range between 2.22 and 3.50 kg.m-3. Again, the higher WP values obtained by simulated model may be because the difference between both schemes. The simulated WP values were also not extremely higher than other findings.

CONCLUSION
The AquaCrop model was successfully applied to predict sugarcane yield under two different field management scenarios in this analysis. The observation on water balance parameters indicates that more efficient irrigation method uses in improved scenario will leads to lower evapotranspiration and runoff. Mulch application also enhanced this beneficial effect due to

covered soil surface. Higher effective precipitation and well-distributed soil moisture content by depth will also achieved by implementing improve scenario. Furthermore, 12-16% increase of water productivity on improved scenario seems to be contributed by less water requirement as well as more sugarcane productivity. Those above findings have been confirmed to other studies. However, there are still numerous constraints on this analysis due to both AquaCrop model and assumption made. Advanced studies on conducting AquaCrop for other crops and more realistic conditions are still promising in future.

ACKNOWLEDGEMENTS

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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APPENDIX

Appendix 1. Soil characteristics of sugarcane plantation in Pasuruan

Soil parameter		Unit	Value
pH			6.88 (neutral)
Cation Exchange Capacity		me.100g^{-1}	43.34 (very high)
Soil texture	Clay fraction	%	76.5
	Silt fraction		21.5
	Sand fraction		2
Soil moisture	pF 0	g.g^{-1}	0.54
	pF 2.5		0.47
	pF 4		0.27