Real Water Savings of Simulated Irrigation Methods and Farm Managements in Sugarcane: Case Study in Malang Regency

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Abstract**—** Water scarcity problem in East Java threatens Indonesia's sugarcane production. Various water conservation techniques are carried out to reduce water use and achieve optimal production. This study aimed to analyse the real water savings of various irrigation methods and farm managements commonly used by farmers to respond to water drought and increase crop production in Malang Regency. AquaCrop modelling software and REWAS tools were used to simulate sugarcane production under various conditions and calculate real water savings from each scenario. The results showed that good farm management in irrigation methods were able to increase crop yields. Without good management practice, irrigation did not show higher water productivity than rainfed agriculture. By changing the irrigation method from furrow irrigation to drip irrigation, it was only able to achieve real water savings up to 8% compared to the apparent water savings which is 30%. The above results do not intend to prevent drip irrigation application and good farm management use, instead to emphasize the importance of proper calculations on real water savings at the basin level in terms of water scarcity. Future study is required to acquire a better knowledge of real water savings in sugarcane through field experiments.

Keywords— irrigation, real water savings, sugarcane, water productivity, water scarcity

I. INTRODUCTION

Malang Regency is located in the southern part of East Java Province, Indonesia (E112°17' - 112°57' and S 7°44' - 8°26'). It is one of the sugar-producing regions of the country. Sugarcane harvested area on Malang Regency in 2019 is estimated to be about 39.686 hectares [1]. Due to its climatic condition, sugarcane farmers are facing water scarcity for several years. Therefore, farmers are required to be more adaptable and adjust their present field management.

Putra, et al. [2] proposed many methods for raising agricultural yields while lowering crop water needs. The effective irrigation method is one of the key possibilities that farmers may use as an adaptive way to respond to this occurrence. Another strategy is to return sugarcane solid wastes to the field as an organic mulch and nutrition source.

Various studies have shown that the techniques and methods used (including irrigation) to increase productivity and overcome the water crisis can significantly save water use in sugarcane. For instance, Olivier and Singels [3] studied the largest reduction in water use of sugarcane by irrigation requirement was 32%. Relation of this agricultural water management in terms of production and water use can be simulated by AquaCrop. It is a model commonly used to simulate and analyze the water balance, crop yields, and water productivity of crops under certain managements [4, 5]. It may also be used to calculate the water footprint of certain crops [6].

However, FAO assesses that the current water savings concept only considers apparent water savings, namely the decrease in the amount of water due to particular water management compared to the previous method [7]. By this concept, "losses water" is recognized to inconsumable and non-recoverable for the downstream part. Since, the water users at the downstream part can use that "losses water", then the concept should no longer be accepted. Therefore, the real water savings concept was introduced as a new definition in water savings calculation which considers non-beneficial consumption as well as non-recoverable return flow as the true "losses water" which cannot be considered for water resources in the downstream area.

This study aimed to simulate several water savings methods, i.e. combination of different fertilizer rate, mulching, soil bunds, and weed control and their effects to sugarcane productivity as well as the water real saving based on FAO method. The AquaCrop model was used to simulate and analyze the water balance, crop yields, and water productivity of crops. The modelling results will be useful in determining which field management practices will positively contribute to water balance, crop yields as well as the real water savings.

II. METHODS

A. Geographical characteristic of Malang Regency

The daily climatic data used in this simulation were provided by the Malang Climatological Station. Daily climate data from 2005 to 2014 were used for this simulation due to a lack of data availability and completeness in recent years. The monthly climatic data distribution over a ten-year average is depicted in Figure 1.

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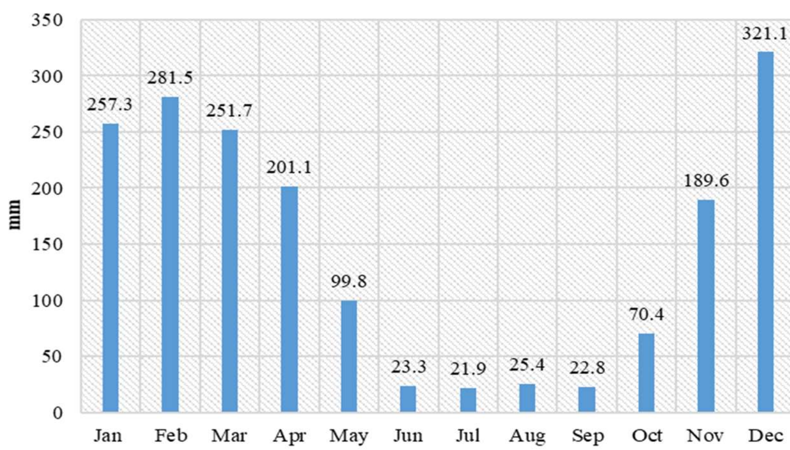

FIGURE 1. DISTRIBUTION OF MONTHLY CLIMATE DATA OF MALANG REGENCY

Crop parameters are primarily drawn from AquaCrop default data, which is based on FAO-56 stages [8]. According to Kapur, et al. [9], the reference harvest index (HI_0) was changed from default values and set at 74%. Based on current sugarcane production techniques in Malang Regency, a planting schedule was also established at the start of the dry season in April.

TABLE 1. SOIL CHARACTERISTICS OF SUGARCANE PLANTATION IN MALANG REGENCY

Soil parameter		Unit	Value
pH			6.7 (neutral)
Cation Exchange Capacity		me.100g^{-1}	11.54
Soil texture	Clay fraction	%	4.50
	Silt fraction		3.10
	Sand fraction		92.40
Soil moisture	pF 0 (saturated)	g.g^{-1}	0.41
	pF 2.5 (field capacity)		0.35
	pF 4 (wilting point)		0.05

A prior study was conducted in Malang to investigate the soil properties of sugarcane crops [10]. The soils of Malang Regency are described as sandy soils in general. The soil chemical and physical properties used in this simulation are summarised in Table 1.

B. Field Management Scenarios

Three alternative irrigation methods were simulated and compared in this study, i.e. rainfed, furrow irrigation, and drip irrigation. Rainfed irrigation was used in this study to evaluate its impact on water balance and agricultural production to surface irrigation. Furrow irrigation was employed since it is a conventional and more common agricultural water supplying method in Indonesia [11], while drip irrigation was implemented as the most water efficient irrigation method [12]. Each irrigation method was simulated by three field management scenarios, i.e. conservative, moderate, and good. Those field management scenarios consisted of several agricultural water management techniques, i.e. fertilizer rate, mulching, soil bunds, and weed control. The description of each field management scenario was summarized in Table 2. Since the dry season had just begun in April, the initial soil water content for all scenarios was considered to be at field capacity. Crop water requirements and irrigation schedule for each irrigation method were calculated using CropWAT 8.0.

TABLE 2. FIELD MANAGEMENT PRACTICES OF THREE SCENARIOS

Simulation	Conservative	Moderate	Good
Fertilizers	60%	80%	100%
Mulching	None	About Half, Organic Mulches	Significant, Organic Mulches
Soil bunds	None	0.25	0.25
Weed control	Fairly Poor	Moderate	Very Good

C. AquaCrop Model

The AquaCrop model considered mainly four variables, i.e. climate, crop, field management, and soil. In this study, climate variables consist of evapotranspiration, and temperature, crop variables consist of growth cycle and harvest index, field management variables consist of fertilizer rate, mulches, soil bunds, weeds, and irrigation techniques, and soil variables consist of soil type and groundwater condition. These particular input variables were then simulated simultaneously to determine the crop development (also called green canopy cover), crop transpiration, above-ground biomass, and finally crop yield [13].

Crop yield (Y) was computed by the following equation [13]:

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

where f_{HI} is a factor that considers the stressors that are used to adjust the Harvest Index from HI_0, which has a value of 74%. Because the biomass created in this simulation was dry, the water content of sugarcane biomass was used to adjust the dry yield to wet yield. The average water content of sugarcane biomass in this scenario is 57.5% [14].

Water productivity (WP) was calculated by the following equation [13]:

$$WP = \frac{Y}{ET_a}$$

where B denotes the quantity of biomass produced from above ground, and Tr denotes the amount of crop water transpiration. Alternatively, we may determine water productivity by dividing yield over actual evapotranspiration

D. Water Savings

According to Kaune, et al. [7], water savings can be divided into two concepts, i.e. apparent water savings and real water savings. Apparent water savings term was determined by decreased water amount by particular change relative to the total water inflow of previous stage. In real water savings, water use for agriculture is divided into four categories, i.e. beneficial consumption, non-beneficial consumption, recoverable return flows, and non-recoverable return flows. Hence, real water savings term was defined as sum of non-beneficial consumption and non-recoverable return flows relative to total water inflow of previous stage. Schematization of the real water savings concept is shown in Figure 2.

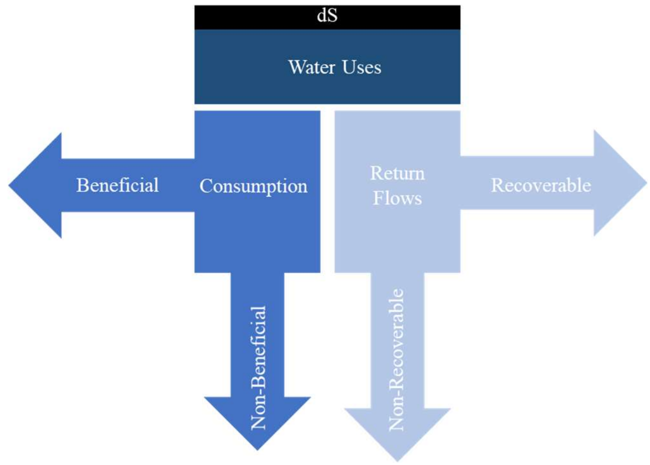

FIGURE 2. SCHEMATIZATION OF REAL WATER SAVINGS [7]

Apparent water saving (AWS) was calculated for each irrigation method at each scheme (rainfed was not included), by the following equation:

$$AWS_i = \frac{I_{ref} - I_i}{I_{ref}} \; x \; 100\%$$

where AWS_i is the apparent water saving of a certain irrigation method at a particular scheme, I_{ref} is the inflow reference (in this case is furrow irrigation in conservative method), and I_i is the inflow of certain irrigation method at particular scheme. On the other hand, Real Water Saving (RWS) was calculated by consider the amount of non-beneficial consumptions and non-recoverable return flows over the inflow and effective rainfall, which defined as below:

$$RWS_i = \frac{(NBC_{ref} - NBC_i) + (NRF_{ref} - NRF_i)}{(R+I)_{ref}} \; x \; 100\%$$

where RWS_i is the real water saving of a certain irrigation method at a particular scheme, NBC_{ref} is the non-beneficial consumption reference (in this case is furrow irrigation in conservative method), NBC_i is the non-beneficial consumption of certain irrigation method at particular scheme, NRF_{ref} is the non-recoverable return flow reference (in this case is furrow irrigation in conservative method), NRF_i is the non-recoverable return flow of certain irrigation method at particular scheme, R_{ref} is the effective rainfall reference, and I_{ref} is the inflow reference.

III. RESULTS AND DISCUSSION

A. Crop Yield

The influence of different management scenarios on crop yield is undeniable. However, in this study, there are no notable differences in sugarcane yields between both irrigation methods and rainfed unless good management practices are applied (Figure 3). Irrigation methods did not show significant impacts to yields, since the difference was only small (<1%) by applying both furrow and drip irrigation in all methods. The difference can only reach up to 17% if the shifting is from rainfed to drip irrigation. It also notified that by changing the management scenarios from conservative method to moderate method and to good method in drip irrigation, it can generally increase the sugarcane yield by 48% and 125%, respectively.

As can be seen from the results, the AquaCrop model simulated a wide range of sugarcane yields. The results' dependability, on the other hand, should be compared to the other studies. It is useful for convincing people that the AquaCrop model correlates well with field observations. Hence, this model may be used to a wide range of field projects. In the preceding five years, Indonesian sugarcane harvests averaged 65-75 tons per acre [1]. These values were lower than the maximum yield ever reported in Indonesia, which was 110 tons per hectare in the 1960s, according to Putra, et al. [15]. These values are also lower than the AquaCrop model simulated results since there are various ecological factors that might inhibit plant development and decrease crop production.

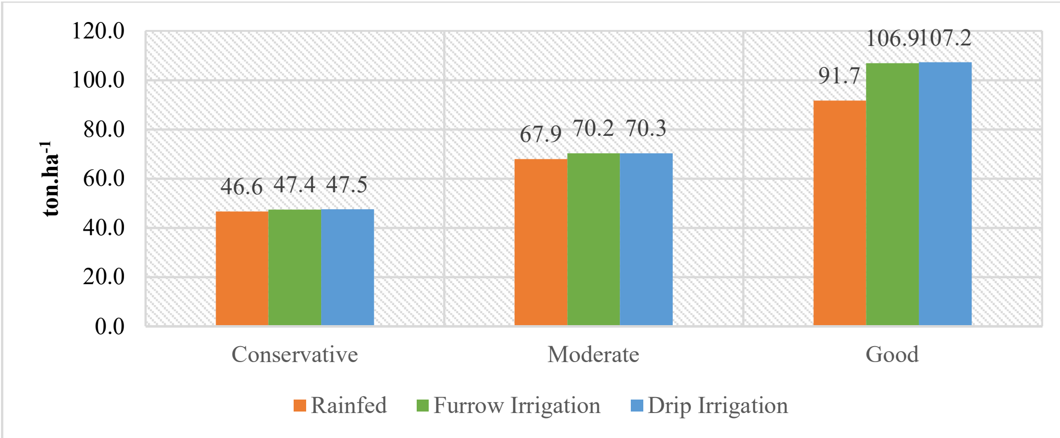

FIGURE 3. CROP YIELDS OF DIFFERENT FIELD MANAGEMENT SCENARIOS AND IRRIGATION METHODS

B. Water Productivity

The water productivity was also increasing by changing to better field management. Water productivity for rainfed in conservative, moderate, and good management were 2.52, 3.84, and 5.28 kg.m^{-3}, respectively. Water productivity for furrow irrigation in conservative, moderate, and good management were 2.37, 3.44, and 5.29 kg.m^{-3}, respectively. Water productivity for drip irrigation in conservative, moderate, and good management were 2.30, 3.46, and 5.30 kg.m^{-3}, respectively. Good management resulted in larger water productivity values since it obtained higher yield while using less water compared to poor managements which resulted in lower yields. On the other side, it may be claimed that agricultural yields and water productivity can be improved by improving farm management techniques, such as fertilizer rate, mulching, soil bunds, and weed control. However, there was no significant effect of irrigation methods to water productivity.

Rabnawaz, et al. [16] also measured water productivity in the field on a sugarcane plantation. They observed that sugarcane production and irrigation water application had a linear relationship. The water productivity values were found to range between 2.22 and 3.50 kg.m-3. The simulated model's greater results values are most likely attributable to the differences in both approaches. Furthermore, the simulated water productivity levels did not differ considerably from earlier observations.

C. Real Water Savings vs Apparent Water Savings

Since the rainfed agriculture did not require irrigation, then the comparison of both real water savings as well as apparent water savings was only conducted for furrow irrigation and drip irrigation in the three different field management scenarios. In this case, conservative method of furrow irrigation was also set as the reference. Therefore, by changing the irrigation methods, the apparent water savings percentage was 30%. However, the percentage of real water savings for both irrigation methods were somewhat lower. The real water savings of moderate and good methods for furrow irrigation were only 4% and 6%, respectively. The drip irrigation showed slightly larger real water savings for the conservative, moderate, and good methods relative to conservative methods of furrow irrigation, i.e. 2%, 6%, and 8%, respectively. Indeed, these lower values due to the beneficial water consumption and recoverable return water flows were considered as the reusable water for the downstream part.

IV. CONCLUSION

Several methods have been introduced to manage sugarcane field adapted to the water scarcity. Those methods resulted positive impacts in terms of water balance, crop yields, and water productivity. Those parameters can also be conducted by simulation using AquaCrop model. However, regarding to the water shortage, the concept of water savings was not longer accurate to determine only by the decreased water amount due to more efficient water use. This study showed that irrigation methods as well as field management which apparently decreased water savings to 30% were only lowering water use up to 8% in broader consideration (level basin area). Future researches are strongly needed to obtain clearly understanding on real water savings in sugarcane by conducting the field experiment.

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