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Evapotranspiration and water balance in a hot pepper (*Capsicum frutescens* L.) field during a dry season in the tropics

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Abstract. Evapotranspiration and water balance in a hot pepper (*Capsicum frutescens* L.) field during the 2nd dry season were analyzed in this study. Actual evapotranspiration (ET) was estimated by Bowen Ratio Energy Budget (BREB) method, potential evaporation (EP) was calculated by Penman method, and irrigation volume of water was measured manually. Meteorological instruments were installed in the experimental field during hot pepper cultivation. Leaf area index increased during the growing stages where the highest LAI of 1.65 in the generative stage. The daily average of ET was 1.94 and EP was 6.71 mm resulting in low Kc. The Kc values were significantly different between stage to stage under T-test analysis ($\alpha = 0.05$). Moreover, Kc in every stage could be related to soil water content (SWC) in logarithmic function. Totally, ET during hot pepper cultivation was 179.19 mm, while rainfall was 180.0 mm and irrigation water was 27.42 mm. However, there was a water shortages during vegetative and generative stages. This study suggested that consumptive water of hot pepper was complimented by soil and groundwater under the condition of water shortages in the vegetative and generative stages during the 2nd dry season.

1. Introduction

Chili is one of the strategic commodities in Indonesia besides rice, corn, soybean, beef, and sugar cane. There are two types of chili commonly cultivated in Indonesia, namely chili pepper (*Capsicum annum)* and hot pepper (*Capsicum frutescens* L.). Hot pepper is the most important low elevation vegetable in terms of production area and value but has the major production constraints such as seed material quality, high production costs, fluctuating market prices, and farmers' lack of knowledge [1].

Nationally, the production of hot pepper in 2015 was 869,954 tons produced from various provinces in Indonesia. However, the hot pepper productivity has decreased in some province in 2016, such as 10.89% in West Java; 6.94% in Aceh; 10.36% in North Sumatera; 4.77% in South Sulawesi; 23.38% in Central Sulawesi; and 12.42% in Lampung [2]. The decreasing of chili production may due to the limiation in amount of water supply [3] where traditionally, farmers in Indonesia cultivated hot pepper during the dry season as complementally crop to rice especially in the 2nd dry season on September to the middle of December. In this season, rainfall was limmited and surface irrigation water was stopped.

Irrigation should be available [4] to overcome the decreasing of production during dry season caused by drought conditions. Therefore, information about the amount of hot pepper water consume is required. Understanding the consumptive water use and water balance is critical to evaluate water stress. Therefore, the aims of this study were to estimate the water consume of hot pepper and to analyze the water balance on hot pepper cultivation. The output of this study is necessary due to the planning of irrigation, improving irrigation practices, and assisting in irrigation scheduling [5, 6, 7].

2. Method

2.1. Study site

This study was conducted in the experimental field, which is administratively located in Tanabangka village, Bajeng Barat district, Gowa Regency, South Sulawesi, Indonesia. There are two seasons in this area; one is the rainy season from December to April, and the other is the dry season from May to November. The total annual rainfall varies from 2,467 mm to 3,294 mm [8]. The study field was under Renggang Water User Association (P3A Renggang) coordination. The total agriculture area of Renggang was 74.40 ha. Land use during the 2nd dry season 2013 were used for 38.8 ha (51.54%) of green beans, 4.91 ha (6.60%) of rice, 0.96 ha (1.29%) of maize, 3.55 ha (4.77%) of vegetable, 0.20 ha (0.27%) of soy bean, 0.11 ha (0.15%) of hot pepper, and 26.39 ha (35.47%) fallow. Hot pepper (*Capsicum frutescens* L.) var. Baskhara F1 was cultivated in the field during the 2nd dry season from September 11th to December 11th, 2013. The crops was transplanted in the field after 37 days seedling and the growing stage was divided in three; vegetative stage (September 11 – October 2), generative stage (October 3 to November 22), and harvesting stage (November 23 – December 11). The area of hot pepper field was 40.8 m x 27.37 m. Each plot of 20 m x 0.7 m was separated by 0.40 m space and the planting density was 50 cm x 50 cm. The study field was surrounding by green beans field, fallow, and corn.

2.2. Data

Meteorological instruments were installed in the field on September 7 before hot pepper transplanted. Rainfall data were collected by automatic rain gauge (ECRN-100, Decagon). The station for the microclimate observation consisted of CNR-4 (Kipp and Zonen, Netherland) for net radiation at 2.0 m height; psychrometers HMP-45A (Vaisala Inc. Helsinki, Finland) for air temperature and relative humidity observation at 0.5 m and 2.0 m for both, respectively; anemometers 014A (Met One, USA) for wind speed observation; heat plate PHF-03 (PREDE) for soil heat observation; and thermocouple for soil temperature observation at soil surface (at 0 cm). All of the instruments were connected to the CR23X logger (Campbell). Soil moisture at 5 cm soil depth was observed by 5TE (Decagon) sensor. Automatic rain gauge and 5TE sensors were connected to the EM5b logger. All of the microclimate data were recorded every 10 minutes and were averaged in every one hour. The plant height, number of leaf and leaf area index (LAI) of hot pepper were measured weekly. There was no surface irrigation water in the 2nd dry season. Therefore, the irrigated water was pumped up from a well. The farmer pumped ground water, collected it in a big tank and irrigated to every hot pepper plant manually like a manual drip irrigation method. In this study, we measured manually the volume of pumping water by volumetric method in each event of irrigation and daily groundwater level was measured by scale [9].

2.3. Data analysis

2.3.1. Evapotranspiration. The actual evapotranspiration as the consumptive water use was estimated by using Bowen Ratio Energy Budget method [10, 11, 12]:

$$ET = [(Rn - G)/(1 + Bo)]/(2499 - 2512\ T)$$

where ET is actual evapotranspiration (mm/d), Rn is net radiation (W m^{-2}), G is soil heat flux (W m^{-2}), Bo is bowen ratio, T is air temperature (^{o}C). Bowen ratio was calculated by equation:

$$Bo = \gamma\ (\Delta T/\Delta e)$$

where γ is pscychrometer constant, ΔT (^{o}C) and Δe (kPa) are differences in air temperature and vapor

pressure between two height above the crop canopy.
EP was estimated by Penman method [13].

2.3.2. Crop coefficient (Kc). Crop coefficient (Kc) was calculated as the ratio of actual evapotranspiration to potential evaporation (EP). The differences of Kc in every stage of hot pepper growth was analysed by parametric statistical analysis. On the other hand, the relationship of soil water content (SWC) and Kc was analysed by logarithmic function.

2.3.3. Water balance. The water balance was analysed by using the simple equation:

$$R + I = ET + P + \Delta S$$

where R is rainfall, I is irrigation practiced, ET is actual evapotranspiration, P is percolation, and ΔS is changes of store water within the soil layer.

3. Result and Discussion

3.1. Microclimate Condition

The event of irrigation, daily rainfall and the daytime of microclimate conditions in the hot pepper field are shown in figure 1. During the 2nd dry season, irrigation event was done eight times with the total of irrigation was 27.42 mm while the total rainfall was 180.0 mm.

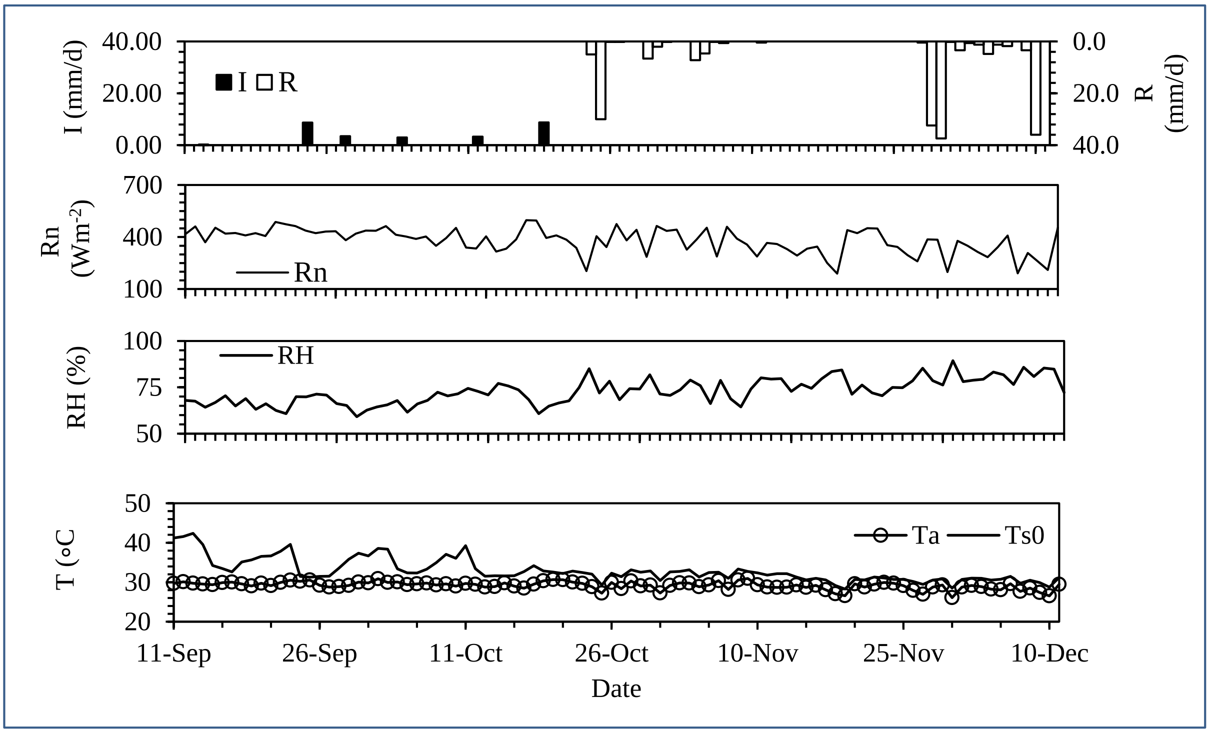

Figure 1. Variation of volume of irrigation (I), daily rainfall (R), and day time average of microclimate condition (net radiation; Rn, relative humidity; RH, air temperature; Ta, and, soil temperature at 0 cm depth; Ts0) in hot pepper field, 2013.

The daytime average of net radiation was 379.21 Wm^{-2} and the average relative humidity was 72.49%. Relative humidity increased from 65.79% (vegetative stage) to 72.23% (harvesting stage). Soil temperature at 0 cm depth was higher than air temperature during the hot pepper cultivation.

3.2. Groundwater Level

Groundwater level fluctuation during the dry season are shown in figure 2. The groundwater level was 69.0 cm from the soil surface in July and gradually increased until it reached to the peak; 170.0 cm from the surface on October 22.

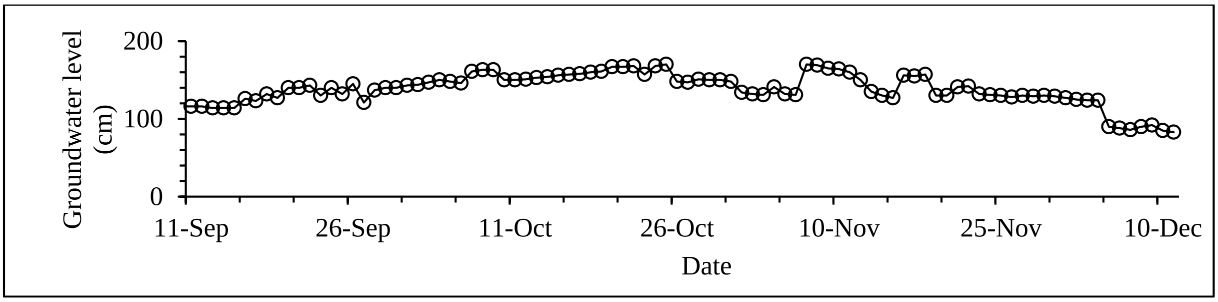

Figure 2. Groundwater level fluctuation during the dry season, 2013.

3.3. Plant Height, Number of Leaf and Leaf Area Index (LAI)

The variation of plant height, number of leaf and LAI during the generative stage in the experimental field are shown in figure 3. These values increased due to the plant growth. The highest plant height was 44.9 cm, the number of leaf was 135.5 and LAI was 1.65.

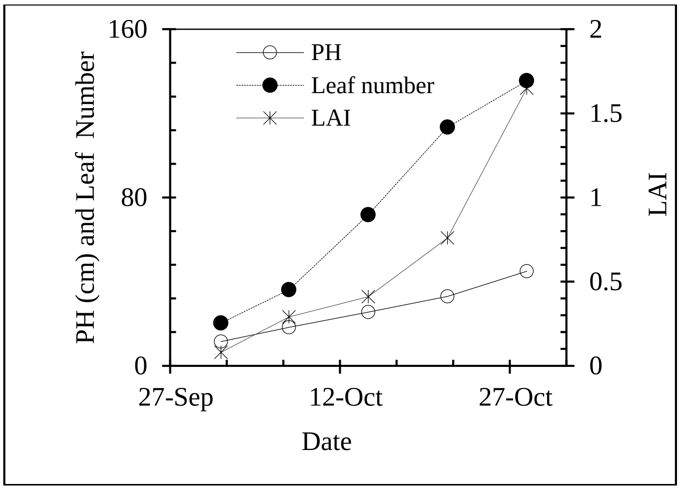

Figure 3. Variation of plant height (PH), number of leaf, and LAI of hot pepper during the generative stage.

3.4. Crop Coefficient (Kc)

The daily consumptive water use and crop coefficient (Kc) of hot pepper are shown in figure 4. Based on estimation, ET was lower than EP where the daily average of ET and EP were 1.94 mm and 6.71 mm, respectively. The result of ET in this study was simmilar to the study that conducted by Qiu [14]. We assumed the lower ET caused by the low plant density and resulting in the low Kc [15]. The crop coefficient of hot pepper increased from the vegetative stage to the harvesting stage where the average of Kc was 0.25 and 0.33, respectively. Statistically, Kc in each stage was significantly different between stage to stage as shown in figure 5. This study also founded Kc could be related to soil water content at 5cm depth (SWC5) by a logarithmic function where the R^2 for vegetative, generative, and harvesting stages were 0.86, 0.81, and 0.85 respectively (figure 4). This relationship on every stage of hot pepper growth was expressed by Kc = a *ln*(SWC5) + b as shown in table 1.

3.5. Water Balance of Hot Pepper Field
Water balance in the hot pepper cultivation in the 2nd dry season is shown in table 2. Totally, the amount of water supply by rainfall and irrigation was higher than evapotranspiration. However, the water supply during vegetative and generative stages was less than evapotranspiration. This water balance suggest that the consumptive water of hot pepper could be supplemented by soil and ground water, which accounted for 70.78% in vegetative stage and 28.02% in generative stage.

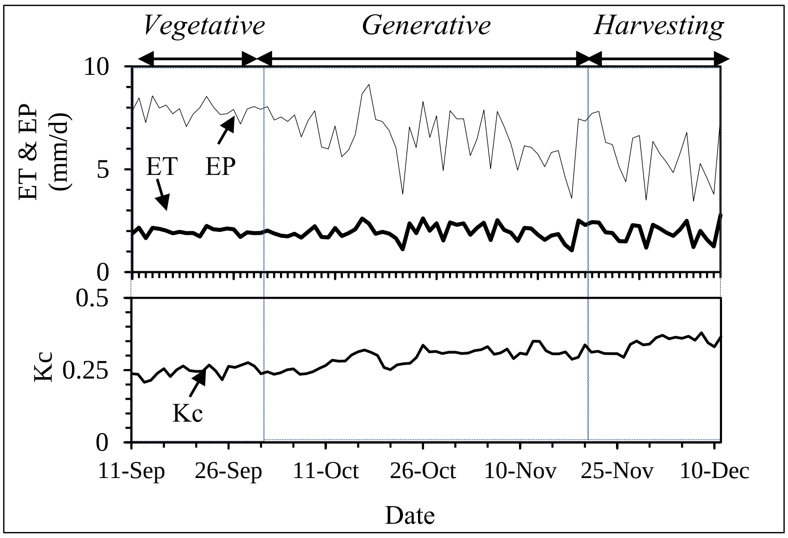

Figure 4. Daily variations of ET, EP and Kc of hot pepper crops during the 2nd dry season.

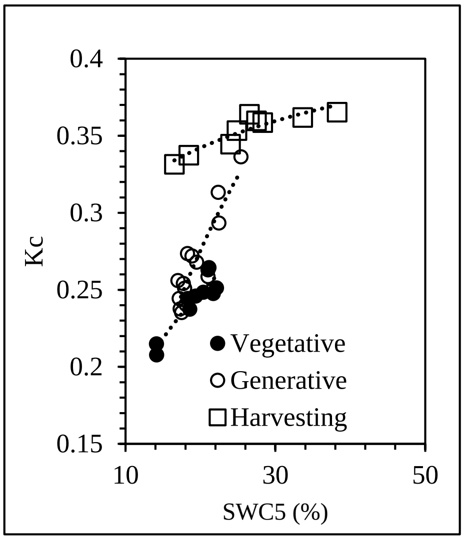

Figure 5. The relationship of SWC5 (%) and Kc of Hot Pepper in every stages.

Table 1. Parameters of logarithmic function for the relation of SWC5 and Kc in the hot pepper field.

Crop stages	a	b
Vegetative	0.1038	- 0.0626
Generative	0.216	- 0.3714
Harvesting	0.0429	0.2137

Table 2. Water balance in the hot pepper field during the 2nd dry season, 2013.

Plant stages	Days (Date, 2013)	Water supply (mm)		Evapotranspiration		P+ΔS
		Rainfall	Irrigation	(mm)	(mm/d)	(mm)
Vegetative	22 (11Sept-2 Oct)	0.00	12.39	42.41	1.93	-30.02
Generative	51 (3 Oct - 22 Nov)	57.20	15.03	100.35	1.97	-28.12
Harvesting	19 (23 Nov - 11 Dec)	122.80	0.00	36.43	1.92	86.37
Total	92 (11 Sept - 11 Dec)	180.00	27.42	179.19		28.23

4. Conclusion
Evapotranspiration and water balance in the hot pepper field were analyze in this study. Daily evapotranspiration was highest in generative stage and was lower than potensial evaporation throughout the growing season, which resulted to the low crop coefficient (Kc). This study also showed that Kc was different between the growing stage to stage, changing from 0.25 to 0.33. We

also found that the Kc in each growing stage could be individually related to soil water content (SWC) with a logarithmic function. Water balance analysis showed that the hot pepper could grow even under the water shortage during vegetative and generative stages. It was suggested that the consumptive water of hot pepper could be supplemented by soil and ground water, which accounted for 70.78% in vegetative stage and 28.02% in generative stage.

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